Ecological Integrity Tables for Utah Animals of Conservation Concern

by

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Introduction

History of Ecological Integrity Tables

In 2005 the Utah Division of Wildlife Resources (UDWR) produced the "Utah Comprehensive Wildlife Conservation Strategy" (Sutter et al. 2005), now known as the Utah Wildlife Action Plan (or WAP, 2005), which prioritized animal taxa (vertebrates and mollusks) of conservation concern in Utah. Animal taxa were arranged in 3 "tiers". Tier I comprised taxa having federal conservation status (mostly U. S. Fish and Wildlife Service, but also U. S. Forest Service; i.e., federally listed, candidate, and conservation agreement taxa). Tier II contained taxa of state conservation concern, the Utah state sensitive species list (UDWR). Tier III listed taxa of possible or uncertain state conservation concern.

Over the 4-year period 2005–2008 UDWR, in collaboration with The Nature Conservancy (TNC), prepared Ecological Integrity Tables (EITs or "tables") for 104 of the 106 animal taxa in Tiers I and II of the WAP (2005). The 2 taxa that were omitted were the whooping crane (*Grus americana*) and the brown bear (*Ursus arctos*), neither of which currently occurs in Utah. Also, a partial redundancy exists as a result of the fact that the full species, the Deseret mountainsnail (*Oreohelix peripherica*), is included in Tier II of the WAP and 1 of its nominal subspecies (recently found to be taxonomically invalid), the "Ogden Rocky mountainsnail" (*Oreohelix peripherica wasatchensis*), is in Tier I of the WAP; thus, 2 EITs are included here despite our misgivings concerning this duplication. Additionally, the WAP (2005) included the leatherside chub (*Gila copei*); this taxon has since been partitioned into 2 full species now called the northern leatherside chub (*Lepidomeda copei*) and the southern leatherside chub (*Lepidomeda aliciae*), and EITs for each of these resultant taxa have been produced. Finally, 2 additional taxa, the Great Plains toad (*Bufo cognatus*) and the mountain plover (*Charadrius montanus*), were added to Tier II in 2007, and tables for these 2 taxa were created, bringing the total number of EITs compiled here to 107.

Concept of Ecological Integrity Tables

The Ecological Integrity Table format and its elements were developed by The Nature Conservancy as a module used for site-level conservation planning known as Conservation Action Planning (CAP), Ecological Integrity Tables being a component of TNC's Excel-based CAP workbook used in such planning. An Ecological Integrity Table is a tabular means of storing and displaying information on the biological and ecological functioning or viability of a taxon—in this case, an animal taxon (species or subspecies) in Tier I or Tier II of the WAP. Various departures from original TNC rules for the preparation of Ecological Integrity Tables have been made, but these departures have in all cases involved greater inclusiveness and thus have not reduced the usefulness of the tables to TNC or for the CAP process; the tables can, as needed, still be trimmed to sparer form.

Form and function of Ecological Integrity Tables

Ecological Integrity Tables, as presented here, comprise 5 columns, 1 of which is divided into 4 sub-columns:

(1) **Key Ecological Attribute** is a *conceptual* factor (or factors), such as abundance, habitat, reproduction, food, hibernation, predation, competition, hybridization, disease, or parasitism, that is critically important for the taxon's long-term persistence. This column, too, is used in TNC's Excel-based CAP workbook. (For some others it may serve little purpose other than providing the theoretical context for the Indicator that follows it.)

(2) **Indicator** is a *real* factor (a part of the conceptual factor or Key Ecological Attribute of the previous column) that is measured (e.g., vegetation height, water temperature), counted (e.g., number of stems >30 cm dbh per hectare), categorized (e.g., soil texture), identified (e.g., species of predators), or otherwise assessed (e.g., law enforcement). This column and the next column are the main part of the table, the part that would be applied by any user of the table.

(3) **Indicator Rating** is subdivided into 4 columns, **Poor** (red), **Fair** (yellow), **Good** (green), and **Very Good** (green). Generally the threshold that defines ecological "integrity" (suitability) of an Indicator for the long-term persistence of the taxon (its viability) is the boundary between the Fair and Good categories. Good and Very Good ratings are desirable or even of vital importance. Fair ratings are marginal. Poor ratings are undesirable and may not provide long-term sustainability for the taxon.

(4) **Basis for Indicator Rating** typically is 1 or more literature sources that support the Indicator Rating. All references to literature can be found in the Literature Cited.

(5) **Comments** are brief explanatory notes pertaining to the Indicator or the Indicator Rating. Users of the tables are strongly encouraged to read the Comments. The Comments column was not part of the original EIT format developed by TNC (for its Excel-based CAP workbook); it is a modification that has been added by UDWR.

There are 2 other important parts of the tables:

(1) **Footnotes** provide additional information. Some are general and are provided as background concerning the taxon. Others are specific and pertain to certain Indicators or Indicator Ratings. Still others discuss problems concerning the Basis for Indicator Ratings, such as errors or inconsistencies found in literature sources. Users of the tables are strongly advised to read the footnotes. Footnotes were not part of the original EIT format developed by TNC; they are a modification that has been added by

UDWR. Asterisk footnotes have been added to indicate the most important Indicators, thus facilitating the reduction of the tables to 5 or fewer rows or Indicators by TNC or others who wish to truncate the tables for their own purposes.

(2) **Literature Cited** provides the full citations for the references (Basis for Indicator Ratings), as mentioned above. Literature Cited was not part of the original EIT format developed by TNC; it is a modification that has been added by UDWR.

The original format of the EIT template includes an additional initial (i.e., far left) column, Category, which contains 1 of 3 possibilities—size, condition, or landscape context. For brevity and to enable printing of the EITs on standard, 8½ X 11-inch paper, the Category column has not been included in the versions of the EITs presented here. However, the tables exist and are available on request as Excel spreadsheets that contain the Category column as well as expanded, 3-column versions of the Key Ecological Attribute column (discussed above). The Category column and the 3-column versions of the Key Ecological Attribute column are used in TNC's Excel-based CAP workbook as organizing or sorting tools.

Uses of Ecological Integrity Tables

The potential applications of the EITs compiled here are diverse and may be different for different users.

Among uses for the tables is the CAP process, Ecological Integrity Tables being, as previously mentioned, part of TNC's Excel-based CAP workbook used in site planning. The tables are used at the local scale in a CAP process (1) to identify the current and desired *status* of taxa within a defined site and (2) to identify the most relevant and urgent *threats* to taxa within the site—both of which lead to (3) identifying the most effective *actions* for conserving the taxa within the site and *assessing* the effectiveness of such actions over time.

Ecological Integrity Tables also may be used at broader scales in planning for sensitive species conservation (1) to provide baseline estimates of regional or rangewide status of taxa and (2) to provide estimates of trends of taxa at broader scales by means of repeated application of indicators over time.

Initial measures of Indicators (i.e., application of the Indicator Ratings to current conditions at a site or sites) can provide a baseline measure of ecological "integrity" or viability of the taxon. Subsequent measures of the same Indicators (i.e., application of the Indicator Ratings to new, possibly changed, conditions at a site or sites) can provide an indication of trends in the Indicators and of the overall ecological "integrity" or viability of the taxon at a particular locality or over larger landscapes.

In developing and implementing specific projects aimed at sensitive species conservation, Ecological Integrity Tables may also be used

- to develop guidelines for evaluating sensitive-species project proposals that are competing for limited funding,
- to guide or to refine the design of sensitive-species projects, or of objectives in project proposals, for which funding is sought,
- to expand the scope of sensitive-species projects to include ancillary benefits to other co-occurring species with little or no added cost or effort,
- to avoid unintended adverse effects of actions in sensitive-species projects to other co-occurring species, and
- to achieve better management of sensitive species through awareness of potential adverse factors that are to be avoided.

Other intended uses involve quick assessment of sites when long-term, labor-intensive, and costly surveys, monitoring, and other studies are not feasible, including:

- estimation of the value (or priority) of a site that is known to be inhabited by a particular taxon for the conservation of that taxon (relative to other inhabited sites),
- estimation of the value of a site for potential conservation of a taxon when it is not known whether the taxon actually inhabits the site (i.e., to predict its presence or absence and the potential value of the site for its conservation), this use being especially important for taxa that are extremely difficult to detect,
- determination of whether there are actions that can be taken that will make a site more suitable for a taxon or actions that should be avoided in order to prevent a site from becoming unsuitable for the taxon, which additionally serves as a reference and overview of threats to the taxon in Utah,
- evaluation of the suitability of a site for potential translocation, introduction, or reintroduction of a taxon, and
- guidance of restoration projects intended to create or re-create suitable habitats and conditions meeting the life history requirements and ecological needs of a particular taxon.

We have sought, first, to make the tables applicable in Utah and, second, for those taxa that also occur elsewhere (as almost all of them do), to make the tables applicable as far as possible beyond the boundaries of Utah without diluting their usefulness in Utah. Limitations on the geographical or seasonal (e.g., breeding season) applicability of the tables are mentioned in the table footnotes.

Constraints and limitations of the tables

We have striven to make the EITs presented here as accurate and as defensible as possible. However, we have been constrained in this endeavor by a variety of factors, and we offer the following warnings and disclosures:

- The tables are not meant to represent exhaustive reviews of the taxa, the ecology of the taxa, or the literature pertaining to the taxa. Instead, they are intended to be succinct, emphasizing the critical aspects of a taxon's ecology, such as limiting factors. For some of the taxa treated here, exceedingly little information concerning their ecologies has been reported (e.g., the southern tightcoil, *Ogaridiscus subrupicola*). For other taxa so much ecological information is available that it was impossible to review all of it within the limited time that could be allotted to a single taxon (e.g., the ferruginous hawk, *Buteo regalis*).

- Some taxa have multiple ecologies in different parts of their geographic ranges or in different local settings (e.g., the cutthroat trout, *Oncorhynchus clarkii*; the desert night lizard, *Xantusia vigilis*; the bald eagle, *Haliaeetus leucocephalus*; the Mexican spotted owl, *Strix occidentalis lucida*).

- In some cases in which the ecology of a taxon varies geographically, little is known of the ecology of the taxon in Utah or even in western North America, but much ecological information is available concerning the taxon elsewhere, such as in eastern North America (e.g., the grasshopper sparrow, *Ammodramus savannarum*; the bobolink, *Dolichonyx oryzivorus*). In such cases we have been judicious in the use of ecological information from faraway places, having cautiously evaluated its applicability in Utah.

- Some sources provided ecological information that was bivariate or multivariate. Adapting such data to the univariate form of the EITs was problematic, as explained in the Comments column of the affected tables or in footnotes.

- Many sources used "breakdowns" or divisions of data that differed from those in the EITs; that is, they separated data ranges either into fewer or into more categories than the EITs allowed. The format of the EITs accommodates 4 rating categories for each Indicator, but original sources may have divided data into 3, 5, 6, or some other number of categories. This problem was particularly troublesome when the original source used more than 4 categories.

- Within a table, indicators may be correlated, and thus some redundancy may exist within a table. For example, frost-free days and minimum winter temperatures are strongly correlated with each other, and they also are correlated with both elevation and latitude.

- Some taxa are extreme ecological generalists (e.g., the spotted bat, *Euderma maculatum*); they occur in almost all habitats, and their limiting factors may not be ecological. The EITs in such cases serve at least as reminders that the taxa are ecological generalists with few ecological limitations.

- For correct understanding and proper application of the tables, it is critically important that users read the Comments column *and the footnotes*, if any. The importance of this is demonstrated by the fact that many of the questions raised by reviewers of the tables had already been answered in the Comments fields or, even more commonly, in the footnotes.

Legal considerations

Under the cooperative agreement between TNC and UDWR, the *contents* of the tables are in the public domain and may be freely shared, but both the blank table template (its *form*) and the instructions for the tables (not provided here), were developed and are owned by TNC except for the modifications made by UDWR (i.e., the last column, Comments; footnotes; and Literature Cited), are solely the property of TNC. Thus it is prohibited for UDWR or others to claim as their own property or to attempt to sell the Ecological Integrity Table blank template and its instructions, which are TNC property.

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Table of Contents

bivalve mollusks

western pearlshell (*Margaritifera falcata*) 12
California floater (*Anodonta californiensis*) 23

gastropod mollusks

desert springsnail (*Pyrgulopsis deserta*) 29
carinate Glenwood pyrg (*Pyrgulopsis inopinata*) 32
Hamlin Valley pyrg (*Pyrgulopsis hamlinensis*) 36
longitudinal gland pyrg (*Pyrgulopsis anguina*) 39
Ninemile pyrg (*Pyrgulopsis nonaria*) 43
Otter Creek pyrg (*Pyrgulopsis fusca*) 46
southern Bonneville pyrg (*Pyrgulopsis transversa*) 49
Bear Lake springsnail (*Pyrgulopsis pilsbyana*) 53
northwest Bonneville pyrg (*Pyrgulopsis variegata*) 57
bifid duct pyrg (*Pyrgulopsis peculiaris*) 61
sub-globose Snake pyrg (*Pyrgulopsis saxatilis*) 65
Black Canyon pyrg (*Pyrgulopsis plicata*) 68
smooth Glenwood pyrg (*Pyrgulopsis chamberlini*) 72
desert valvata (*Valvata utahensis*) 77
fat-whorled pondsnail (*Stagnicola bonnevillensis*) 80
cloaked physa (*Physa megalochlamys*) 83
Utah physa (*Physella utahensis*) 85
wet-rock physa (*Physella zionis*) 87
Yavapai mountainsnail (*Oreohelix yavapai*) 91
Brian Head mountainsnail (*Oreohelix parawanensis*) 93
Eureka mountainsnail (*Oreohelix eurekensis*) 95
lyrate mountainsnail (*Oreohelix haydeni*) 99
Deseret mountainsnail (*Oreohelix peripherica*) 102
“Ogden Rocky mountainsnail” (*Oreohelix peripherica wasatchensis*) 107

Kanab ambersnail (*Oxyloma kanabense*) 109
southern tightcoil (*Ogaridiscus subrupicola*) 116

ray-finned fishes

Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) 118
Bonneville cutthroat trout (*Oncorhynchus clarkii utah*) 126
Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) 133
Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*) 143
Bonneville whitefish (*Prosopium spilonotus*) 150
Bear Lake whitefish (*Prosopium abyssicola*) 154
Bonneville cisco (*Prosopium gemmifer*) 158
Colorado pikeminnow (*Ptychocheilus lucius*) 164
bonytail (*Gila elegans*) 177
humpback chub (*Gila cypha*) 182
Virgin chub (*Gila seminuda*) 190
roundtail chub (*Gila robusta*) 196
least chub (*Iotichthys phlegethontis*) 207
Virgin spinedace (*Lepidomeda mollispinis*) 210
southern leatherside chub (*Lepidomeda aliciae*) 215
northern leatherside chub (*Lepidomeda copei*) 222
woundfin (*Plagopterus argentissimus*) 228
desert sucker (*Catostomus clarkii*) 235
bluehead sucker (*Catostomus discobolus*) 242
flannelmouth sucker (*Catostomus latipinnis*) 248
June sucker (*Chasmistes liorus*) 255
razorback sucker (*Xyrauchen texanus*) 261
Bear Lake sculpin (*Cottus extensus*) 267

amphibians

western toad (*Bufo boreas*) 272
Arizona toad (*Bufo microscaphus*) 281

Great Plains toad (*Bufo cognatus*) 285
Columbia spotted frog (*Rana luteiventris*) 288
relict leopard frog (*Rana onca*) 297

reptiles

desert tortoise (*Gopherus agassizii*) 303
western banded gecko (*Coleonyx variegatus*) 320
desert iguana (*Dipsosaurus dorsalis*) 323
common chuckwalla (*Sauromalus ater*) 328
zebra-tailed lizard (*Callisaurus draconoides*) 331
desert night lizard (*Xantusia vigilis*) 336
Gila monster (*Heloderma suspectum*) 339
western threadsnake (*Leptotyphlops humilis*) 347
smooth greensnake (*Opheodrys vernalis*) 350
cornsnake (*Elaphe guttata*) 354
Mojave rattlesnake (*Crotalus scutulatus*) 357
speckled rattlesnake (*Crotalus mitchellii*) 361
sidewinder (*Crotalus cerastes*) 364

birds

American white pelican (*Pelecanus erythrorhynchos*) 370
California condor (*Gymnogyps californianus*) 378
bald eagle (*Haliaeetus leucocephalus*) 391
ferruginous hawk (*Buteo regalis*) 397
northern goshawk (*Accipiter gentilis*) 400
greater sage-grouse (*Centrocercus urophasianus*) 406
Gunnison sage-grouse (*Centrocercus minimus*) 420
sharp-tailed grouse (*Tympanuchus phasianellus*) 427
mountain plover (*Charadrius montanus*) 439
long-billed curlew (*Numenius americanus*) 445
yellow-billed cuckoo (*Coccyzus americanus*) 459

Mexican spotted owl (*Strix occidentalis lucida*) 461
short-eared owl (*Asio flammeus*) 465
burrowing owl (*Speotyto cunicularia*) 471
black swift (*Cypseloides niger*) 479
Lewis' woodpecker (*Melanerpes lewis*) 485
American three-toed woodpecker (*Picoides dorsalis*) 493
southwestern willow flycatcher (*Empidonax traillii extimus*) 500
bobolink (*Dolichonyx oryzivorus*) 508
grasshopper sparrow (*Ammodramus savannarum*) 516

mammals

Preble's shrew (*Sorex preblei*) 522
fringed myotis (*Myotis thysanodes*) 525
western red bat (*Lasiurus blossevillii*) 528
Allen's big-eared bat (*Idionycteris phyllotis*) 531
spotted bat (*Euderma maculatum*) 534
Townsend's big-eared bat (*Corynorhinus townsendii*) 537
big free-tailed bat (*Nyctinomops macrotis*) 547
pygmy rabbit (*Brachylagus idahoensis*) 549
white-tailed prairie dog (*Cynomys leucurus*) 551
Utah prairie dog (*Cynomys parvidens*) 560
Gunnison's prairie dog (*Cynomys gunnisoni*) 572
silky pocket mouse (*Perognathus flavus*) 582
dark kangaroo mouse (*Microdipodops megalocephalus*) 585
Mexican vole (*Microtus mexicanus*) 590
gray wolf (*Canis lupus*) 593
kit fox (*Vulpes macrotis*) 603
black-footed ferret (*Mustela nigripes*) 613
Canada lynx (*Lynx canadensis*) 623

western pearlshell (*Margaritifera falcata*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population, reproduction	areal density within aggregations or mussel beds (no. of individuals/m^2)[3,*] "Mussel aggregations were defined as ≥10 individuals, separated from adjacent groups by >1 m of unoccupied substrate" (Howard and Cuffey 2003). see Comments and footnote 3	<2/m^2	2–10/m^2	11–50/m^2	>50/m^2	Howard and Cuffey (2003), Strayer et al. (2004), Stone et al. (2004), Nedeau et al. (no date)	The largest aggregation found by Howard and Cuffey (2003) in n. California contained ~1100 individuals in a 78-m^2 area, which implies ~14.1/m^2. However, Nedeau et al. (no date) stated: "In environments where host fish are abundant and human threats are minimal, western pearlshells can attain very high densities (>300/$yard^2$), often carpeting the stream bottom." Vannote and Minshall (1982) reported mean densities of living populations in the Snake River, Idaho, in 3 habitats as 5.4, 8.3, and 192/m^2, but buried, dead population densities were higher (220 and 455/m^2).
population, reproduction	linear density (no. of individuals/50 m of stream channel) ($D_L^{(50)}$)[3,*]	<5/ 50 m	5–10/ 50 m	11–20/ 50 m	>20/ 50 m	Howard and Cuffey (2003, Fig. 2D)	The highest linear density of this species found by Howard and Cuffey (2003, Fig. 2D) in n. California was 23 individuals per 50 m of stream channel. In ½ mi of the Truckee River of extreme ne. California, Murphy (1942) estimated that there were 20,000 *M. falcata* >40 mm in length; this would be 1,243 per 50 m of stream.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population, reproduction	aggregation size (no. of individuals in a mussel bed)[3,*]	<10	10–99	100–199	≥200	Howard and Cuffey (2003, Fig. 3B)	Howard and Cuffey (2003), in n. California, reported: "The largest aggregation of *M. falcata* consisted of ~1100 individuals in a 78-m^2 area . . . ." The mean aggregation size was 112. "Mussel aggregations were defined as ≥10 individuals, separated from adjacent groups by >1 m of unoccupied substrate" (Howard and Cuffey 2003). In the Truckee River of extreme ne. California, "one bed was found containing 10,000 mussels [*M. falcata*]" (Murphy 1942).
reproduction, recruitment	population structure (age distribution within aggregations)[1,4,*]	all individuals of 1 age (or size) category (if all are large and old, recruitment apparently is not occurring; if all are small and young, future reproduction may be delayed until they reach maturity)	age distribution very highly skewed, almost all individuals of 1 age (or size) category	age distribution skewed or even highly skewed, but some individuals of all ages (or sizes)	individuals of all ages (or sizes)	Vannote and Minshall (1982), Strayer et al. (2004)[1,4]	Living populations of *M. falcata* in 3 habitats in the Salmon River, Idaho, found by Vannote and Minshall (1982, Table 1, Fig. 1) had modal age ranges of 25–40, 30–40, and 60–100 y. "In [the] rare but highly stable habitats *M. falcata* attains maximal density, old age, and a population structure that is highly skewed towards large individuals . . . . These few, uniquely structured populations may be critical in providing long-term recruitment for re-establishing populations in main channel and tributary areas vulnerable to periodic scour."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body*	other (e.g., ponds, lakes, reservoirs)	irrigation ditches	streams	rivers	Nedeau et al. (no date) and other sources	Although Clarke (1981) asserted that *M. falcata* "[o]ccurs in running streams wider than 4 m", *M. falcata* "can inhabit headwater streams less than a few feet wide, but are more common in larger rivers. This species can even be found in some irrigation ditches in Oregon" (Nedeau et al. no date).
habitat	stream features[2] **N.B.**: Ratings are uncertain and apparently vary with location—see Comments. The importance of this indicator is questionable.[2]	riffles	runs	—	pools	Howard and Cuffey (2003)	In the Salmon River of Idaho, Vannote and Minshall (1982) "found *M. falcata* . . . to be widely distributed . . .; however, contiguous beds generally were restricted to cobble and boulder 'ramp-like' runs connecting deep pools to riffles or rapids. . . . *M. falcata* were absent from deep pools, except within gravel-filled fractures on bedrock ledges, and from riffles."
habitat, thermal biology, life cycle (host compatibility) and recruitment	water temperature[4,*]	hot	warm	cool	cold	various sources including Roscoe and Redelings (1964), Nedeau et al. (no date)	". . . [H]ost compatibility may depend on temperature: Glochidia that transform successfully on a particular fish species within a certain temperature range may be rejected at temperatures outside this range . . ." (Strayer et al. 2004, citing another source that studied another species of North American unionacean mussel). See also footnote 4.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water quality and clarity*	foul, turbid	—	—	clean, clear	various sources including Nedeau et al. (no date)	
habitat	substrate[2] **N.B.**: Except for the "poor" rating, ratings are uncertain and apparently vary with location—see Comments and footnote 5. The importance of this indicator (except for "poor") is questionable.[2]	silt; mud, clay	gravel-cobble-sand; sand; boulder-cobble crevice	cobble interstices; bedrock crevices	sedge root mats	Howard and Cuffey (2003, Table 1)	"Sedge mats constituted only 1.6% of all habitats [substrates], but contained 38% of the mussels in the study area" (Howard and Cuffey 2003). "Substrates were classified as bedrock, boulder (>250 mm), cobble (60–250 mm), gravel (2–60 mm), sand (<2 mm), or sedge root mats (*Carex nudata*)" (Howard and Cuffey 2003). Nedeau et al. (no date), however, stated of *M. falcata*: "Sand, gravel, and cobble are preferred substrates, especially in stable areas of the streambed. Large boulders help create these stable environments by anchoring the substrate and creating a refuge from strong currents on their downstream side."[5]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	mean summer water velocity (in inhabited reaches of stream)[2] **N.B.**: Ratings are uncertain and apparently vary with location—see Comments. The importance of this indicator is questionable.[2]	>1.1 m/s	0.2–1.1 m/s	0.1–0.2 m/s	<0.1 m/s	Howard and Cuffey (2003, Fig. 4B), Stone et al. (2004, Fig. 3c)	The "ratings" are based on findings in streams in n. California. In sw. Washington, Stone et al. (2004, Fig. 3c) considered flows greater than ~0.4 m/s to be unsuitable and ~0.3 m/s to be preferred. However, in the Salmon River, Idaho, Vannote and Minshall (1982) found *M. falcata* mainly in "'ramp-like' runs connecting deep pools to riffles or rapids. As water flows over the ramp it becomes progressively shallower and swifter, averaging about 1 $m \cdot s^{-1}$ at base flow and 3–4 $m \cdot s^{-1}$ over extant mussel beds at bankfull discharge."
habitat (substrate stability)	stream features that create stability of substrates (i.e., flow refuges)[2,*]	—	—	—	large boulders, banks or stream margins	Vannote and Minshall (1982), Howard and Cuffey (2003), Nedeau et al. (no date)	"Large boulders help create . . . stable environments by anchoring the substrate and creating a refuge from strong currents on their downstream side. Banks are often favorable habitats because the current is slack and the substrates are more stable" (Nedeau et al. [no date]). (Probably what Nedeau et al. [no date] meant by "banks" was stream margins or shorelines.) Their comments appear to be references to the works of Vannote and Minshall (1982) and Howard and Cuffey (2003).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
recruitment, life cycle (hosts for parasitic immature life stage)	fish species[2,6,*]	other	certain other native fishes (i.e., speckled dace, Lahontan redside, Tahoe sucker) and non-native salmonid fishes (i.e., brook trout)[3]	some non-native salmonid fishes (e.g., rainbow trout, brown trout)[3]	some native salmonid fishes (e.g., cutthroat trout, Chinook salmon, Coho salmon, sockeye salmon)	Murphy (1942), also Clarke (1981), Nedeau et al. (no date)[6]	Murphy (1942) experimentally infected the 4 fishes rated as "fair" with glochidia of *M. falcata*, but these were poor hosts: "On these four only a few of the glochidia from their original heavy infection completed metamorphosis." He considered these 4 species to be "possible as hosts, but not well suited." On 2 other fish species (mottled sculpin and mountain whitefish, which is a native salmonid). Murphy (1942) could not induce infection by glochidia of *M. falcata*. See footnote 6.
competition	introduced aquatic mollusks (e.g., Asian clam, zebra or quagga mussels, and especially the New Zealand mudsnail—see Comments)	abundant	fairly common	scarce	none	Bogan (1993, p 605) and sources cited therein	The introduced New Zealand mudsnail, *Potamopyrgus antipodarum*, is now established in much of the geographic range of *M. falcata* and thrives in the aquatic habitats required by *M. falcata*. Being parthenogenetic, *P. antipodarum* can quickly dominate the aquatic ecosystems that it inhabits, in some places covering all submerged surfaces and eliminating all other aquatic macroinvertebrates, apparently through competition.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
thermal requirements, availability of (vs. barriers to) fish hosts (especially migratory fish spp.), suitable flow regimes that do not result in unnatural siltation (burying mussels) or scouring (exposing mussels)[4]	alterations of flow regimes (e.g., dams, diversions for irrigation, power generation, and municipal and industrial water supplies, flood control, channelization, channel reconstruction, road building)*	occurring (past, present, or future)	—	—	none	Vannote and Minshall (1982), Strayer et al. (2004)[4], Nedeau et al. (no date)	"Road building or indiscriminant clearing of large boulders from canyon roads along the [Salmon] river can jeopardize the local high-density mussel populations by creating new depositional zones in proximity to existing beds. Flood control measures and channel reconstruction after major flood disturbances frequently involve channel enlargement and removal of block-boulders (e.g., segments of Big Thompson Creek, Colorado; Teton River, Idaho); this activity alters current patterns, turbulence, and sediment storage and thus dramatically affects ecological relationships" (Vannote and Minshall 1982).
nutrient enrichment (eutrophication), siltation, chemical pollution[4]	agricultural, municipal, and mining effluents*	present, entering inhabited streams	—	—	none	Nedeau et al. (no date)	See Comment below and footnote 4.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
siltation (from erosion) and sedimentation	timber harvest, mining, and other activities that increase sediment loads*	occurring (past, present, or future)	—	—	none	Nedeau et al. (no date)	"Scientists in Idaho found that when these mussels were covered with a substantial amount of fine sediment, they were unable to move to the surface and perished" (Nedeau et al. no date). This appears to be a reference to the work of Vannote and Minshall (1982), who found large beds of dead *M. falcata* that had been killed by being buried under sand and gravel.
direct destruction of mussels and their habitat	in-stream gravel mining*	occurring (past, present, or future)	—	—	none	Strayer et al. (2004)	

[1]This species occurs in Pacific drainages from s. Alaska to California and New Mexico, in interior basins of w. North America, and east of the continental divide in the headwaters of the Missouri River in Montana; its habitat is sometimes characterized as "trout streams" (i.e., cold, clear, clean, swift, well-oxygenated, and with coarse substrates), often in mountainous country. "The mussels [*M. falcata*] become sexually mature at nine to twelve years . . . . Average life spans are sixty to seventy years, with some capable of living over one hundred years, making it one of the longest-lived animal species on Earth" (Nedeau et al. no date). "With a maximum lifespan exceeding one hundred years, they have experienced the effects of water management in the West more than any species; some individuals that are alive today were in the same spot years before the Grand Coulee Dam was built!" (Nedeau et al. no date). Strayer et al. (2004) warned: ". . . [S]ome events (e.g., severe pollution) kill all mussels instantaneously, but many populations are now threatened by chronic stresses with slower effects. It is particularly difficult to assess the long-term dynamics of long-lived animals like unionaceans, whose populations may persist for a long time under conditions of negative population growth. Many populations today probably have negative growth rates and are destined ultimately to disappear unless environmental conditions change. Such populations represent a large 'extinction debt' . . . that will become apparent over the coming decades as these long-lived animals die."

[2]Various authors have found that, though unionacean mussels typically are very patchy in their occurrence, such patchiness is not related to such habitat characteristics as water depth, current speed, or substrate particle size. For example, Haag and Warren (1998) found that "[p]atterns of mussel community variation were correlated with patterns of fish community variation but not with habitat." Strayer (1999) observed that "[t]he considerable within-reach patchiness of unionid mussels in rivers has not been explicable by simple habitat features such as water depth, current speed, or sediment grain size" and "hypothesized that mussels are found chiefly in stable areas of the river bed where hydraulic stresses during floods are low." He "used movement of marked rocks to locate flow refuges during floods in 2 small rivers . . ." and found that "mussel beds were spatially coincident with flow refuges, but not with other measured features of the habitat (water depth, current speed, sediment grain size) in both study sites." Similarly, Howard and Cuffey (2003) found that distribution of *M. falcata* in n.

California streams coincided with parts of the streams that had low hydraulic stresses: "In all flow regimes (summer, winter, 5-y flood, and the largest floods on record), we found mussels in areas of lower boundary shear stresses and lower velocities. Our study suggests that . . . mussels appear to be distributed in a manner that protects them from the highest flow-induced stresses." These and other studies[4,5] suggest that (1) availability of suitable native fish hosts and (2) flow refuges are the most important ecological factors for unionid mussels. Although habitat features such as substrates, water velocities, and stream features (e.g., pools, runs, riffles) have been included in this table, results concerning such habitat variables from various studies of *M. falcata* are discordant and perhaps are not ecologically meaningful. (Even other habitat variables including water depth and shading of stream by overhanging vegetation [Roscoe and Redelings 1964] or canyon walls have been reported, but the importance of these is even more questionable, and they are not included in the table. Stream shading, for example, could be locally related to thermal environment or to concealment form predators. Further, species of the genus *Margaritifera*, including *M. falcata*, traditionally have been considered "calciphobes", disfavored by water hardness [i.e., dissolved calcium carbonate]; however, recent studies have questioned this generalization and presented data that contradicts it.)

[3]Aggregation size (number of individuals in a mussel bed) and density are critically important. If there are few mussels (low aggregation size) or they are dispersed (low density), then sperm may not reach females and reproduction does not occur. "Mussels are broadcast spawners, releasing large numbers of sperm into a water column that often is well mixed. There have been no studies of sperm dispersal in nature, but recent studies suggest that sperm dispersal may be inadequate, even in fairly dense populations. Two studies . . . found the proportion of gravid females in a population to be positively correlated with population density. [One of these] estimated that successful reproduction required population densities as high as 10 mussels per square meter, far greater than local densities in most populations. . . . These observations suggest that mussel populations in nature may often be too sparse to provide adequate sperm to breeding females, a result that would have great consequences for the ecology and conservation of these animals. Thus, mussel populations might consist of large areas of low density, which contribute little or nothing to the viability of the population, along with a few high-density nuclei that drive population growth and the genetic structure of the population. In such populations, the high-density nuclei would be the prime subjects of . . . conservation efforts" (Strayer et al. 2004, citing other sources).

[4]The long life spans of mussels (e.g., >100 y in *M. falcata*) ". . . suggests several questions about their demography and conservation. Is their distribution and abundance controlled chiefly by day-to-day conditions or by rare events that occur every few generations (i.e., at > 100-year intervals)? . . . If pearly mussels are sexually competent for decades, does their recruitment occur during most years or only rarely and under just the right combination of conditions? We have very little information on demography of mussel populations, but in at least one well-studied population [of a different species], successful recruitment occurred only once every 5 to 10 years . . . . Human actions have stopped recruitment in many mussel beds. For example, low temperatures downstream of hypolimnetic-release reservoirs have prevented mussel reproduction at some sites for decades . . . . The beds that exist on these sites today are remnants from the time before the dams were built. Likewise, residual contaminants [e.g., pollutants from mining, agriculture, or industry buried in substrates] or changes in host fish communities may prevent recruitment in mussel beds. Thus, mussel beds may be relicts of a time when conditions really were suitable for mussels, not indicators of currently favorable conditions. When researching the environmental requirements of populations or assessing populations for conservation status, it is important to distinguish such relict beds from 'live' mussel beds that support sustainable recruitment. . . . [R]esidual contamination from past episodes of pollution may have left a toxic legacy in streams and rivers. . . . Ironically, the bulk of the toxicity literature is based on water-only exposures, even though studies have shown that sediment-associated contaminants probably contributed to the decline of mussels in many large rivers . . . . [N]egative density dependence can cause sparse populations to continue to decline even after the original cause of decline is removed. The most likely cause of negative density dependence in mussels is low reproductive success in sparse populations" (Strayer et al. 2004).

[5]In the Salmon River of Idaho, Vannote and Minshall (1982) "found *M. falcata* . . . to be widely distributed throughout the canyon reach; however, contiguous beds generally were restricted to cobble and boulder 'ramp-like' runs connecting deep pools to riffles or rapids." The population densities that they found were $5.4/m^2$ in "sand and gravel bars", $8.3/m^2$ in "cobble/boulder-shielded runs", and $192/m^2$ in "large, block-boulder-controlled reaches". In a stream in sw. Washington, Stone et

al. (2004) found that *M. falcata* "preferred substrates where boulders increased bed roughness, allowing small gravel and sand to create a stable, heterogeneous substrate." In their habitat suitability index (2004, Fig. 4c), large gravel, cobble, and bedrock were not avoided, and fines, small gravel, and boulders were preferred.

[6]"In some locations where western pearlshells are still abundant, native cutthroat trout are being replaced by nonnative rainbow, brown, and brook trout. The long-term effects of extirpating the primary host fish on a native mussel, albeit with a species that may also serve as a host, is unknown. Native fish hosts—that mussels have coevolved with—might be better hosts than nonnative species because they are better adapted to local environmental conditions and their populations may be more stable in the long-term. Also, the mussel may have evolved specializations for unique traits of the native host fish such as habitat use, behavior, and immune responses to parasitism" (Nedeau et al. no date). Strayer et al. (2004, citing another source), had earlier written: "There may be local adaptation between mussels and hosts, resulting in higher compatibility of glochidia with fish populations from the mussel's native basin than with fish of the same species from distant drainages . . . ."

*Most important indicators.

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California floater (*Anodonta californiensis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body	temporary waters (e.g., ditches); stagnant waters; very high-gradient streams	impound-ments, reservoirs, perennial streams	lakes, ponds	large rivers, river lakes, spring complexes	various authors (e.g., Taylor 1961)	
habitat (adult)	substrate*	coarse (gravel, rock)	fine but not soft (e.g., stiff mud)	at least somewhat fine and soft	fine and soft (silt, mud, sand, fine gravel)	various authors (e.g., Frest and Johannes 1992)	
habitat (adult and larval)	shifting of substrate (e.g., from floods, road and bridge construction)	great (unstable)	medium (moderately unstable)	slight (moderately stable)	none (stable)	Frest and Johannes (1992), Burke (1995)	Adult floaters, such as this species, are much more sedentary than other mussels, being almost sessile. Thus their movements are limited, and they are unable to reposition themselves when buried by shifting sediments and suffocate. Scouring or shifting of riffle areas that either removes or covers rock or gravel would destroy larvae.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (larval)	substrate*	fine (mud, sand, silt)	somewhat fine (sand)	very coarse (rocky)	coarse (loose gravel)	D'Eliscu (1972)—see comments; Burke (1995)	D'Eliscu (1972) concluded: "The morphology, physiology and difficulty of collection of the juvenile stage [of *Anodonta californiensis*] seem to indicate occupation of an entirely different habitat from that of the adult." He noted: "The juveniles of some species [of freshwater mussels, including this one] possess byssal glands and inhabit loose gravel, while the adults live in deep mud or sand . . . ."
microhabitat (adult)	position in channel (*if river or stream*)	thalweg of river; rapids; riffles	—	—	beds of fine substrates below rapids; sand bars at margins where tributaries enter rivers; pockets of fine substrates at the base of boulders; quiet pools with fine substrates	Frest and Johannes (1992)	
microhabitat (larval)	position in channel (*if river or stream*)	quiet, soft-bottomed pools	—	—	riffle areas immediately upstream from soft-bottomed, quiet pools	Burke (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
microhabitat	position in lakes and reservoirs	—	—	—	shallows of upper reaches; mouths of tributaries	Burke (1995)	
habitat	water temperature	hot or cold	warm	cool	cool	Frest and Johannes (1992)	Preferred temperature ranges (quantitative) have not been reported.
habitat	oxygenation of water	very low	low	medium	high (e.g., below rapids)	Frest and Johannes (1992)	Quantitative dissolved oxygen ranges have not been reported.
habitat	water depth fluctuations	great (e.g., as in artificial reservoirs)	—	some natural, seasonal fluctuations	none	Frest and Johannes (1992), Burke (1995)	
habitat	elevation	high	medium	medium	low		Although upper elevational limit is not known, known occurrences in Utah are below 6,500 ft elevation.
habitat	sediment loads (e.g., of rivers)	high	medium	medium	low	Frest and Johannes (1992)	
habitat	water withdrawal (diversions, groundwater pumping)	existing	—	—	none	Taylor (1961), Burke (1995)	
habitat	impoundment of lotic habitats	existing nearby	—	—	none existing or planned	Taylor (1961), Frest and Johannes (1992), Burke (1995)	Impoundments cause unfavorable or unsuitable changes in water temperatures, dissolved oxygen levels, and other water characteristics.
flooding	grazing or logging (resulting in increased flooding)	existing	—	—	none	Taylor (1981), Burke (1995)	Flooding buries floaters in silt, suffocating them, and alters habitat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
toxicants	pollution or contamination (e.g., heavy metals, pesticides, fertilizers, oil)	present	—	—	none	Taylor (1961), Frest and Johannes (1992), Burke (1995)	
larval hosts	barriers to fish movements	present	—	—	none	Burke (1995)	Barrier to fish movements could prevent host fish from reaching suitable habitats for adult floaters, where fish become parasitized, and for larval floaters (where larvae leave the hosts).
competition, parasites, disease	introduced bivalves	present in drainage	—	—	none	Burke (1995)	Pauley and Becker (1968) reported infection and histopathology of *Anodonta californiensis* by the parasite *Aspidogaster conchicola*, which parasitizes many other species of bivalves, including other mussels. The Asian clam, *Corbicula* sp., may be an important competitor.
predation	introduced turtles or sport fishes	abundant	many	few	none		Many turtles and some sport fishes are predators of mollusks, including bivalves.

[1]Identification of floaters (genus *Anodonta*) to species is uncertain in large areas of interior western North America (e.g., the Great Basin and Utah) (see Oliver and Bosworth 1999, Mock et al. 2004), and the contents of this table only uncertainly apply to this species.

[2]Like other unionoids (freshwater mussels), this species requires a fish host in order to complete its life cycle. Thus, the presence of certain species of fish(es) is necessary in order for a population of the floater to be maintained. It is unfortunate that the fish host(s) of this species is(/are) not known with certainty, for such information would be of critical importance and could be one of the most important factors that could be included in this table. Bequaert and Miller (1973) believed that the disappearance of "the proper [but unknown] (specific) host fish" "explains why *A. californiensis* is now near extinction in Arizona, while perhaps only a century ago it may have been widespread in the State." Some freshwater mussels are quite host-specific, obligately requiring a single host species, while others are less so, facultatively using several, in some cases even many, host species. Anthropogenic moving of the host fishes (e.g., through stocking, bait bucket introductions) also results in the transporting of the mussels that parasitize them. Clarke (1993) argued that the speckled dace or the Utah chub may the host of

larval *Anodonta* in Utah, but Mock et al. (2004) reasoned that the host could be the common mosquitofish, which is a nonnative, introduced species in Utah. If the host range of *Anodonta* sp. in Utah is broad, it is possible that all 3 of these, and perhaps even other, fishes are suitable hosts. D'Eliscu (1972) successfully used mosquitofish as artificial hosts in laboratory experiments with *Anodonta californiensis*, and the early work of Lefevre and Curtis (1908) showed that floaters, as a group, are not so narrowly host-specific as other mussels, parasitizing a wide variety of freshwater fishes of various families and even different orders. Presumably a species of native fish, naturally co-occurring with the floater, would provide the most suitable host, rather than nonnative, introduced fish species, even if the latter were acceptable hosts.

[2]It should be noted that certain features of the microhabitats of adults and larvae of this species are very different—in fact, nearly opposites. Larvae are believed to require gravelly or rocky substrates in fast flowing areas such as riffles, whereas adults are known to require mud, silt, or fine sand substrates in quiet areas such as pools (below rapids or riffles or adjoining inflows of tributaries).

*Most important indicators.

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desert springsnail (*Pyrgulopsis deserta*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 10 springs, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		All known populations inhabit springs in the Virgin River drainage (Hershler and Landye 1988, Hershler 1994), but characteristics of these springs have not been reported.[1]
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, “boxing” of spring, etc.
habitat (degradation)	recreation-al use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail, distinction of the 2 species requiring very close examination.
habitat (hybridization)	introduced species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping.	Identification of *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		Several of the inhabited springs are within or near towns (e.g., St. George, Middleton, Littlefield; see Hershler and Landye 1988).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	One locality is stated as "70 m N of Interstate 15" (Hershler and Landye 1988), and others may also be near this or other highways.

[1]This species is known only from 10 springs in the Virgin River drainage, 7 in Washington County, Utah, and 3 in Mohave County, Arizona. One of the Utah localities was reported (Hershler and Landye 1988) as a "small spring"; otherwise, characteristics of the inhabited springs have not been reported.

*Most important indicators.

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carinate Glenwood pyrg (*Pyrgulopsis inopinata*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "scarce" at the type locality. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 3 springs, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc.
habitat (degradation)	recreation-al use (swimming, etc.)*	great	moderate	little (minimal)	none	Hershler (n.d.) reported recreational use and a high level of disturbance at 1 of the 2 springs in Glenwood.	Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis**	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping. Hershler (1998) commented that at 1 of the 2 known localities, this species "may be hybridizing with *P. kolobensis*, which occurs . . . in a spring only 3 km to the north." This species coexists with *P. chamberlini* in the 2 closely associated springs in Glenwood with no evidence of hybridization (Hershler 1998), but the 2 species may compete for resources.	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult. However, this species has a distinctive shell characteristic and should be distinguishable from most other species of *Pyrgulopsis* (e.g., *P. chamberlini*, with which it co-occurs) even by non-experts.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		2 of the 3 springs known to be inhabited by this species are within the town of Glenwood.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	State Hwy. 119 is immediately adjacent to 1 of the inhabited springs and presumably is very close to another inhabited spring as well.

[1]This species is known only from 3 springs in Sevier County, Utah: 2 at one locality and 1 at another locality. The spring at the type locality "flows out of a pipe and forms a shallow brook" (Hershler 1998). Hershler (n.d.) reported some habitat characteristics at 1 locality: a rheocrene, temperature 16 °C, conductivity 308 µmho/cm. The elevation at this locality is 5,580 ft.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

Hamlin Valley pyrg (*Pyrgulopsis hamlinensis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "abundant" at the sole locality of its occurrence. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 1 spring, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc.
habitat (degradation)	recreation-al use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d., 1998) reported that the inhabited spring is disturbed, being "slightly impacted by cattle".
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		Hershler (n.d.) mentioned that the inhabited spring is near a residence.
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only a single spring in Beaver County, Utah. Hershler (n.d.) reported that the inhabited spring is "a small, high-elevation rheocrene", at 7,160 ft, with "mostly rocky substrate", temperature 16 °C, and conductivity 209 µmho/cm.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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longitudinal gland pyrg (*Pyrgulopsis anguina*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "common" at 1 and "abundant" at the other known locality of its occurrence. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 2 springs, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc. Hershler (n.d.) reported for 1 of the 2 inhabited springs "issues out of box, flow mostly diverted to irrigation ditch".

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreation-al use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d., 1998) reported that livestock are present at both springs known to be inhabited and that disturbance is “moderate” at 1 and “high” at the other.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	Hershler (n.d.) reported that fish are present at 1 of the 2 inhabited springs.
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or “pyrg”), distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only 2 springs in Snake Valley on the Utah–Nevada border (1 in Utah, the other in Nevada). Hershler (n.d.) reported that the inhabited springs are rheocrenes, temperatures 16 and 17 °C, conductivities 392 and 450 µmho/cm, and elevations 5,400 and 5,540 ft. Hershler (1998) characterized one of these (the type locality) as "a shallow, 4 m wide rheocrene moderately disturbed by livestock."

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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Ninemile pyrg (*Pyrgulopsis nonaria*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "abundant" at 1 locality of its occurrence. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 2 springs, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc.
habitat (degradation)	recreation-al use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only 2 springs in Sanpete County, Utah. Hershler (n.d.) reported that 1 of the inhabited springs (the type locality) is a rheocrene, temperature 12 °C, conductivity 1,213 µmho/cm, and elevation 5,540 ft. Hershler (1998) similarly characterized this locality as "a shallow, broad, mineralized (1213 micromhos/cm) rheocrene emptying into Ninemile Reservoir."

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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Otter Creek pyrg (*Pyrgulopsis fusca*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "common" at 2 of the known localities. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 3 sites, is low relative to other kinds of organisms.)
habitat	spring(s) (and their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc.
habitat (degradation)	recreational use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d., 1998) reported that livestock are present at 2 of the inhabited sites and that disturbance is "slight" at these sites.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	Hershler (n.d.) reported that 1 of the inhabited sites is near a road.

[1]This species is known from only 3 springs in south-central Utah (1 in Piute County, 2 in Sevier County). Hershler (n.d.) reported that the inhabited springs are rheocrenes, temperatures 7, 12, and 13 °C, conductivities 190, 190, and 200 µmho/cm, and elevations 6,720, 7,060, and 7,250 ft. One of these "runs about 7 m; enters creek" (Hershler n.d.). Hershler (1998) characterized another of these (the type locality) as "a small brook (2 cm deep, 1 m wide), fed by numerous small springs, which enters Otter Creek."

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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southern Bonneville pyrg (*Pyrgulopsis transversa*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that at 2 of the 6 known localities this species is "common" and at 2 others it is "abundant". Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 6 springs, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc. Hershler (n.d.) reported that 1 of the inhabited springs has been dug out and another possibly so; 1 of these springs is "impounded below" and the other "enters reservoir".

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreational use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d.) reported that livestock are present at 3 of the springs known to be inhabited and that disturbance is “high” at 1 of these and “moderate” at the other 2.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or “pyrg”), distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only 6 springs in north-central Utah (4 in Tooele County and 1 each in Utah and Sanpete counties). Hershler (n.d.) reported habitat information for 5 of these: 4 are rheocrenes, 1 is a helocrene; temperatures 12, 12, 12, 13, and 16 °C; conductivities 360, 463, 500, 889, and 1,126 µmho/cm; and elevations 5,830 to 6,740 ft. Hershler (1998) characterized one of these (the type locality) as "a series of small, mineralized . . . springs" and "[t]he spring sampled is a small 'rheocrene' issuing out of a pipe."

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

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Bear Lake springsnail (*Pyrgulopsis pilsbyana*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that at 11 of the known extant localities for this species it was either "common" (7) or "abundant" (4). Springsnails often reach high densities in inhabited sites, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which currently is known from only 14 extant locations, is low relative to other kinds of organisms.)
habitat	water feature*	other	—	creeks (2), spring outflows (1), pond outflows (1)	springs (10) large, deep freshwater lake(s) (prehistoric)	see Comments	In parentheses are the numbers of Hershler's (1998) localities for each aquatic habitat type. However, the largest population (now extirpated) of this species prehistorically inhabited a large, deep freshwater lake (Bear Lake).
habitat	permanence of water*	none in summer or in drought years	much reduced in summer or in drought years	perennial, but some seasonal fluctuation	consistent, perennial		
habitat	flow alteration(s)[2]	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, impoundment, "boxing" of spring, etc.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreational use (swimming, etc.)[2]	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.
habitat	livestock*[,2]	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail, distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*[,2]	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]Extant occurrences of this species are known from 14 locations in se. Idaho (10), n.-c. Utah (3), and sw. Wyoming (1), although it also occurred prehistorically in Bear Lake on the Utah–Idaho border (Hershler 1998). The cause of extirpation of the Bear Lake population of this species, which almost certainly was by far its largest population, and the extirpation of other mollusks from this lake, is unknown.

[2]Hershler (n.d.) reported habitat information for the 12 of the 14 inhabited localities: 7 are rheocrenes, 1 or 2 are limnocrenes, 2 are streams, and 1 is seepage from a pond; elevations are 4,880–6,120 ft; temperatures ranged from 9–15 °C; conductivities (of 7 of the locations) were 330–1,350 µmho/cm. Hershler (n.d.) reported disturbance of these 12 inhabited sites as slight (6), moderate (5), and high (1). Disturbances noted by Hershler (n.d.) were diversions, livestock, recreation, impoundment, roads and highways, and an irrigation ditch.

*Most important indicators.

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Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

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northwest Bonneville pyrg (*Pyrgulopsis variegata*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that at 1 of the known localities this species is "scarce", at 4 it is "common", and at 3 it is "abundant". Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 12 springs, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc. Hershler (n.d.) reported diversion of 1 of the inhabited springs and a reservoir below another inhabited spring.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreational use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d.) reported that livestock are present at 4 of the springs known to be inhabited and that disturbance is “high” at 1 of these.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or “pyrg”), distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only 12 springs, 9 in extreme northwestern Utah and 3 in extreme northeastern Nevada (Hershler 1998). Hershler (n.d.) reported habitat information for at least 8 of these: elevations are 4,360–6,000 ft; 6 are rheocrenes, 2 are helocrenes; temperatures ranged 14–25 °C; conductivities ranged 211–936 µmho/cm.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

bifid duct pyrg (*Pyrgulopsis peculiaris*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that at 3 of the 7 known localities this species is "scarce", at 3 it is "common", and at 1 it is "abundant". Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 7 springs, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc. Hershler (n.d.) reported diversions of 2 of the inhabited springs.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreational use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites. Hershler (n.d.) reported recreational use of 4 of the 7 known inhabited springs.
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Hershler (n.d.) reported that livestock are present at 2 of the 7 springs known to be inhabited and that disturbance is "high" at 1 of these.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	Hershler (n.d.) reported that 1 of the 7 springs known to be inhabited by this species is "by [a] road" but did not specify whether this is a paved road.

[1]This species is known from only 7 springs: 5 in Millard County, Utah, and 2 in White Pine County, Nevada (Hershler 1998). Hershler (n.d.) reported habitat information for these: all 7 are rheocrenes; elevations range 5,520–7,470 ft; temperatures ranged 9–13 °C; and conductivities ranged 317–622 µmho/cm.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

sub-globose Snake pyrg (*Pyrgulopsis saxatilis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "common" at the only known locality. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 1 location, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of springs, etc.
habitat (degradation)	recreational use (swimming, etc.)	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites. Hershler (n.d.) reported recreational use of the only known inhabited complex of springs.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	
habitat (hybridization, competition)	introduced species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality	distance to paved roads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from only a single spring complex in Millard County, Utah, "a series of large, thermal (26.9 °C.) rheocrenes issuing from the side of a hill" (Hershler 1998). Unfortunately, thermal springs are favored sites for the release of exotic species such as tropical aquarium fishes and snails. Hershler (n.d.) reported the elevation as 5,080 ft and conductivity as 553 µmho/cm. Some of the indicators in this table are potential threats at the single known locality, and others are hypothetical and could apply at other sites if other springs inhabited by this species were found.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

Black Canyon pyrg (*Pyrgulopsis plicata*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that this species is "common" at the only known locality of its occurrence. Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 1 location, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)*	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of springs, etc.
habitat (degradation)	recreational use (swimming, etc.)[2]	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock*	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.
habitat (hybridization, competition)	introduced (or naturally coexisting) species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation or destruction of habitat	location with respect to urban areas*,[2]	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		
water quality	distance to paved roads*,[2]	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	

[1]This species is known from a single locality: a complex of springs in Garfield County, Utah. Hershler (1998) described the single locality of occurrence as "a large series of small rheocrenes emerging from a steep hillside and feeding a reservoir." Hershler (n.d.) reported habitat information for this locality: elevation 6,700 ft; temperature 16 °C; conductivity 236 µmho/cm.

[2]Hershler (n.d.) indicated that, at the only known locality, disturbance is "slight", and he did not observe fish, livestock, introduced mollusks, other species of springsnails, recreational use, diversions of flow, nearby roads, or human residences. Because the locality is on a steep hillside, some of these potential threats and disturbances (e.g., recreation, roads, buildings) seem unlikely to impact the site in the future. Thus, some of the "indicators" in this table probably would apply only at other inhabited sites if other populations of this species were discovered.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

smooth Glenwood pyrg (*Pyrgulopsis chamberlini*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	abundance	scarce (≤100)	fairly common (101–1,000)	common (1,001–10,000)	abundant (>10,000)		Hershler (n.d.) reported that at the only known locality this species is "abundant". Springsnails often reach high densities in inhabited springs, and the ratings should be understood in this context. Ratings are rough estimates and are not from the works of Hershler. (Despite local densities, the overall abundance of species such as this, which is known from only 2 closely associated springs at 1 locality, is low relative to other kinds of organisms.)
habitat	springs and spring runs (i.e., their outflows)*	no flow in summer or in drought years	flow much reduced in summer or in drought years	perennial, but some seasonal fluctuation in flow	consistent perennial flow		
habitat	flow alteration(s)*	highly altered	moderately altered	slightly altered	unaltered		Alterations include diversion of flow, "boxing" of spring, etc.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (degradation)	recreational use (swimming, etc.)*,[1]	great	moderate	little (minimal)	none		Recreation disturbs and degrades habitat, directly destroys snails, and could lead to introduction (via recreational equipment and toys) of other snails, diseases, and parasites. Hershler (1998) reported that the lower of the 2 inhabited springs is "highly impacted by recreational activities."
degradation or destruction of habitat	location with respect to urban areas*	within urban area	at edge of urban area	near urban area	far from urban area (remote, isolated)		The only known populations of this species are in 2 closely associated springs within a town (Glenwood).[1]
habitat	livestock	present with access to inhabited spring head, pools, and outflow	present but partially excluded (e.g., from spring head but not from pools or outflows)	present in surrounding landscape but excluded from inhabited springs and pools	absent or completely excluded from springs and spring pools and all surroundings	If livestock are present and are not excluded from springs, trampling results in snail mortality, and trampling and defecation degrade water quality.	Although the 2 associated springs known to be inhabited by this species are within the town of Glenwood and it thus is unlikely that livestock will become a problem there, if other, rural population(s) of this species were discovered, livestock could be an important threat to it (them).
habitat (predators)	molluscivorous fishes	present	—	—	absent	Molluscivorous fishes, if present, would likely be introduced and could eliminate population.	Hershler (n.d.) did not note the presence of fishes in the 2 associated springs that are know to be inhabited by this species, but if other population(s) of this species were discovered, fishes could be a serious threat to it (them).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (competitors)	introduced mollusks*	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	The parthenogenetic New Zealand mudsnail (*Potamopyrgus antipodarum*) is potentially the greatest molluscan threat. Moreover, it is related to and resembles the native springsnail (or "pyrg"), distinction of the 2 species requiring very close examination.
water quality	distance to paved roads*,[1]	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way; highway construction and maintenance.	State Hwy. 119 is immediately adjacent to 1 of the inhabited springs and presumably is very close to the other as well.[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (hybridization, competition)	introduced species of *Pyrgulopsis*	present	—	—	absent	Introduction of other species of *Pyrgulopsis* could result in a hybrid swarm and genetic swamping (and competition for resources).	Identification of most *Pyrgulopsis* to species is practically impossible (except by 1 world expert), making recognition of an introduced species very difficult. Another species of *Pyrgulopsis*, namely *P. inopinata*, does co-occur with *P. chamberlini* in both of the associated, inhabited springs in Glenwood, but there is no evidence of interbreeding (hybridization).[1] Whether there is competition between the 2 species is unknown. *P. inopinata*, unlike most species of *Pyrgulopsis*, has a distinctive shell characteristic that should allow it to be distinguished from *P. chamberlini*, even by non-experts.

[1]This species is known only from 2 closely associated springs in the town of Glenwood, Sevier County, Utah, of which Hershler (1998) wrote: "At Glenwood, two springs are found in a small drainage. An upper spring flows alongside HWY 119, while in a deeply entrenched area below, a second, more mineralized rheocrene emerges amongst a thicket of downed trees. The type locality is the lower spring, which was highly impacted by recreational activities. Note that this species also occurs in the upper spring and that *P. inopinata* [the carinate Glenwood pyrg]. . . also is present in both springs." Hershler (n.d.) reported habitat information for this locality: rheocrene, elevation 5,580 ft, temperature 16 °C, conductivity 308 µmho/cm.

*Most important indicators.

Literature Cited

Hershler, R. (no date [ca. 1992]). Field survey and preliminary taxonomy of Great Basin springsnails. Final report for Cooperative Agreement P 852-A1-0035 between U. S. D. I. Bureau of Land management and the Smithsonian Institution. 11 pp + 2 appendices.

Hershler, R. 1998. A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part I. Genus *Pyrgulopsis*. *The Veliger* 41: 1–132.

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gvo

desert valvata (*Valvata utahensis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	average density (individuals/m^2)	<25	25–50	50–100	>100	USFWS (1995), Frest and Johannes (1992)	Frest and Johannes (1992) found average densities of ~24/m^2 in 2 declining colonies.
population	no. of individuals (in a local population or colony)	<50,000	50,000–500,000	500,000–5,000,000	>5,000,000	USFWS (1995), Frest and Johannes (1992)	Frest and Johannes (1992) found that 2 declining colonies on a TNC preserve each consisted of ≤6,000 individuals. The species was extremely abundant historically in Utah Lake and prehistorically in Bear Lake.
habitat	type of water body*	areas with strong currents, rapids; hot springs	rivers	shallow shorelines of rivers, pools adjacent to rapids, perennial flowing water associated with large spring complexes	large, natural lakes	various authors and USFWS (1995)	
habitat	substrate (particle size)*	gravel, pebble, rock, boulder	mixed fine and coarse	mixed fine and coarse	mud, silt, sand	USFWS (1995)	
habitat (food)	submerged aquatic plants	none	other aquatic vegetation	other aquatic vegetation	beds of *Chara* (muskgrass)	USFWS (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	dissolved oxygen[2]	low	medium	medium	high	USFWS (1995)	This indicator is questionable validity and importance since the largest known (though extirpated) population was in Utah Lake, which is not highly oxygenated.
habitat	water temperature[2]	hot	warm	cool	cold	USFWS (1995)	This indicator is of questionable validity and importance since the largest known (though extirpated) population was in Utah Lake, which is relatively warm.
habitat	water pollution in watershed	unnatural nutrient and sediment loads; contamin-ants; runoff from dairies, feedlots, agriculture; effluent from fish hatcheries, municipal sewage treatment facilities	—	—	none	USFWS (1995)	
habitat	alterations of natural hydrology (hydro-electric development, load-following[3], impoundment, water withdrawal and diversions)	existing or planned	none existing or planned	none existing or planned	none existing or planned	USFWS (1995)	Practices that either flood or dewater the habitat of the species, even temporarily, can be devastating to the snail, as can practices that change water velocity, temperature, or dissolved oxygen.

[1]This species was formerly much more widespread in occurrence—historically and even more so prehistorically. It is extant only in the Snake River and associated spring complexes in Idaho, but its known historical (e.g., Utah Lake) and prehistoric (e.g., Bear Lake) occurrences show that conditions suitable for the species are much broader than would be supposed if only the remnant population of the Snake River system were considered. The narrow range of conditions observed in the remnant Snake River population may in fact be marginal or suboptimal for the species, for it was historically most abundant in Utah Lake, a shallow, turbid, slightly alkaline, relatively warm lake, and apparently was similarly abundant prehistorically in Bear Lake, a deep, clear, fresh, cool lake. It may be unrealistic to attempt to define its habitat much beyond *aquatic situations that are not excessively saline (e.g., the Great Salt Lake) or hot (e.g., hot springs)*.

[2]The recovery plan for 5 federally listed snail species of the Snake River (USFWS 1995) considered this assemblage to be a cold-water biota and recommended the cold-water biota standard: "dissolved oxygen concentrations exceeding 6 milligrams/liter (mg/l) at all times, water temperatures of 22°C (71.6°F) or less with maximum daily averages of no greater than 19°C (66.2°F), specific ammonia concentrations, and specific requirements for salmonid [fish] spawning." Although the cold-water standard may be of critical importance to some or all of the other 4 species, it is unlikely, in view of the historical occurrence of this species in Utah Lake (its largest known population), that the cold-water standard is required or even preferred by the species or that it requires or prefers conditions suitable for salmonids (e.g., trout).

[3]Load-following is the practice of artificially lowering or raising river water levels to meet short-term needs of hydroelectric operations.

*Most important indicators.

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Frest, T. J., and E. J. Johannes. 1992. Distribution and ecology of the endemic and relict mollusc fauna of Idaho TNC's Thousand Springs Preserve. Report prepared for The Nature Conservancy of Idaho. Deixis Consultants, Seattle, Washington. iii + 291 pp.

U. S. Fish and Wildlife Service. 1995. Snake River aquatic species recovery plan. Snake River Basin Office, Ecological Services, U. S. Fish and Wildlife Service, Boise, Idaho. vi + 92 pp.

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gvo

fat-whorled pondsnail (*Stagnicola bonnevillensis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population size	no. of individuals	≤10,000	10,001–50,000	50,001–100,000	>100,000	Clarke (1991) considered total (global) population, which he estimated to be ≥3,100,000, to be "vigorous and healthy." The smallest local population was estimated by Clarke to be ~100,000; the largest, >1,000,000.	Clarke often grossly overestimates mollusk populations.
water quality	trichloroethylene (TCE) contamination*	present	—	—	absent		Toxicology has not been established for mollusks.
water quality	perchlorate contamination*	present	—	—	absent		Toxicology has not been established for mollusks.
habitat (predators)	molluscivorous fishes*	present	—	—	absent	Introduction of molluscivorous fishes could eliminate populations (Clarke 1991).	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (competitors)	introduced mollusks	present	—	—	absent	Any mollusks other than those naturally occurring could out-compete the native species or be sources of diseases and parasites.	
habitat (hybridization)	introduced species of *Stagnicola**	present	—	—	absent	Introduction of other species of *Stagnicola* could result in a hybrid swarm and genetic swamping.	
habitat	livestock*	present with access to all inhabited pools and surroundings	present but excluded from some inhabited pools	present in surrounding landscape but excluded from all inhabited pools	absent (excluded from all pools and all surroundings)	If livestock are present and are not excluded from pools, trampling results in snail mortality, and trampling and defecation degrade water quality, substrates, and food sources.	
water quality	distance to paved roads, railroads*	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and brake linings; potential threat from spills from tanker trucks.	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality	distance to up-gradient sources of ground-water contamination*	<1 km	1–5 km	5–10 km	>10 km	Discussion with USFWS toxicologist.	Up-gradient sources of groundwater contamination (TCE and perchlorate) exist near known populations of this species.
water quality	distance to petroleum pipelines*	<3 km	3–5 km	5–10 km	>10 km	Discussion with USFWS toxicologist.	2 petroleum-product pipelines traverse known habitat of this species, and both have sprung leaks in recent years (USFWS 2003).

[1]Details of aquatic habitat features for this species are deemed unimportant and uninformative. Although known extant populations assigned to this species inhabit shallow, clear, spring-fed pools, the species is known prehistorically to have inhabited a deep, turbid lake (Pleistocene Lake Bonneville) with strong wave action. It is assumed here that many, varied freshwater habitats in the Bonneville Basin are suitable for the species.

*Most important indicators.

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gvo

cloaked physa (*Physa megalochlamys*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body*	other (e.g., rivers, streams, springs)	drainage ditches, borrow-pit ponds, roadside swales	large perennial lakes	extensive marshes and ponds (fluctuating or drying seasonally, or perennial)	Taylor (1988)	
habitat	aquatic vegetation	absent	—	—	present	Taylor (1988)	Taylor (1988) reported cattail (*Typha*) and bulrush (*Scirpus*) at 2 inhabited sites and waterlily (*Nuphar*), *Utricularia* (bladderwort), *Myriophyllum* (water-milfoil), and "arrowweed" (i.e., arrowleaf, *Sagittaria*) at another (the type locality). Although presence of aquatic vegetation seems to be ecologically important to *P. megalochlamys*, the particular taxa of the aquatic plants that are present do not.
habitat	substrate	—	—	—	fine mud	Taylor (1988)	Taylor (1988) mentioned the substrate of only the type locality (a large pond in Wyoming). **N.B.**: The importance of this indicator is uncertain.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physical "structures" in water	—	—	—	dead wood, stones, submergent and emergent vegetation	Taylor (1988)	**N.B.**: The importance of this indicator is uncertain.
loss of habitat	dewatering[2]	occurring	—	—	none	Oliver and Bosworth (1999)	See footnote 2.
habitat degradation, mortality	disturbance (e.g., trampling by cattle)[2]	occurring	—	—	none	Oliver and Bosworth (1999)	See footnote 2.

[1]This species, named and described by Taylor (1988), occurs at scattered localities in interior w. North America. It is known in Utah from a single locality (in Snake Valley, nw. Millard County) and is presumed to be rare in this state. Taylor (1988) did not report the habitat at the Utah locality, and he commented concerning this species that "the habitat range is poorly known."

[2]Oliver and Bosworth (1999) considered dewatering and degradation of aquatic habitats to be potential threats to this species at the single known Utah locality, which is in an arid region "where human demands on water resources are great."

*Most important indicator.

Literature Cited

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gvo

Utah physa (*Physella utahensis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of individuals	<100	100–1,000	1,001–10,000	>10,000		Clarke (1991) estimated very large numbers of this species at several sites in n. Utah, but his estimates often appear to be excessively large.
habitat	water feature	other (e.g., roadside ditches)	—	—	freshwater lakes, spring-fed pools, springs	Oliver and Bosworth (1999)	Although this species formerly was abundant in a large, shallow freshwater lake (Utah Lake, the type locality), it has been extirpated from that water body since mid-20th century. More recent records are from springs and spring-fed pools.
predation	introduced fishes*	occurring (past, present, or future)	—	—	none	Oliver and Bosworth (1999)	
loss of habitat	dewatering (e.g., diversions, draining) and other hydrologic alterations*	occurring (past, present, or future)	—	—	none	Oliver and Bosworth (1999)	

[1]This species occurs only in n. Utah, w.-c. Colorado, and sw. Wyoming. Few extant occurrences are known.

*Most important indicators.

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wet-rock physa (*Physella zionis*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography*	—	—	horizontal surfaces of large flat rocks at the base of walls of narrow canyons	vertical sandstone walls of narrow canyons	Pilsbry (1926), Gregg (1940), Whipple (1988)	The narrowness and depth of the wet canyons that are inhabited by this species probably are of critical importance in maintaining a suitable range of environmental conditions and reducing environmental extremes of moisture, humidity, evaporation, and temperature.
habitat, avoidance of desiccation	hydrology[2,*]	—	—	—	seeps, springs, and their outflows	Pilsbry (1926), Ng and Barnes (1986), Whipple (1988)	*P. zionis* requires perennially wet rock, typically canyon walls kept wet by seeps.[2] Within seeps, Ng and Barnes (1986) found that these snails were statistically significantly associated with the shallowest water (0–1 mm deep) and the lowest flow.
habitat, food	"plant" association*	—	—	—	algae (on rock surfaces), hanging gardens (e.g., maidenhair ferns, cardinal flowers, columbines)	Pilsbry (1926), Whipple (1988)	Although other authors have noted the association of *P. zionis* with algae, Ng and Barnes (1986) did not find the presence of algae to be statistically significant.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	average no. of individuals (all sizes & ages) per 0.1 m^2 in July	<1/ 0.1 m^2	1–5/ 0.1 m^2	6–10/ 0.1 m^2	>10/ 0.1 m^2	Whipple (1988)	Whipple (1988) obtained density data for 3 inhabited sites in July; these ranged from ~9 to ~13/ 0.1 m^2. She presented density data for all months at 2 sites: Highest densities occurred during October (24 and 40/ 0.1 m^2). Lowest densities were during December and January (2/ 0.1 m^2) or January and February (1–2/ 0.1 m^2). Ng and Barnes (1986) also presented density data, but theirs were not so systematically collected as Whipple's and did not include all months; they also offered estimates of some populations. Clarke (1991) also "estimated" populations, but his estimates appear to be mere guesses and are of very questionable accuracy.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, destruction of habitat	natural threats (e.g., freezing, floods, falling debris such as rock, drought)	frequent, intense, extensive	somewhat frequent, intense, or extensive	infrequent and of limited extent and intensity	none	Whipple (1988)	Since this species presumably has experienced natural threats throughout its existence, it is doubtful that such factors represent serious threats to its continued survival. However, local populations certainly could be eliminated by natural catastrophic events. Ng and Barnes (1986) demonstrated experimentally that this species has great ability to remain attached to substrates in flowing water and is not easily washed away.
mortality	collecting, other human disturbance	uncontrolled and believed to occur	legally limited, but adequacy of enforcement uncertain	very limited, by permit only, and with adequate enforcement	none	Chamberlin and Jones (1929), Whipple (1988)	"Mr. [A. M.] Woodbury reported that [the steep cliffs near the type locality and upstream] had been stripped of snails by collectors on previous occasions . . ." (Chamberlin and Jones 1929). Since the entire known range of this species is within what is now a national park, such over-collecting presumably no longer takes place. Whipple (1988) "observed snail mortality due to . . . human disturbance . . . ."
loss or degradation of suitable habitat	dewatering of drainage (e. of Virgin R. or s. of Orderville Canyon)	existing or planned	—	—	none	Clarke (1991)	Desiccation is a known cause of mortality in this species (Whipple 1988).
destruction of habitat	construct-ion of new walkways*	planned	—	—	none	Clarke (1991)	

[1]This species occurs only in 2 connected canyons, Zion Canyon and Orderville Canyon, along the North Fork of the Virgin River in Zion National Park, Washington County, Utah, a linear reach of ~3.1 mi. Ng and Barnes (1986) commented that "there are no large populations" and that this species ". . .probably has never existed in large numbers, and, in comparison to other snails, it may be considered rare."

[2]*P. zionis* is classified as an aquatic species because it belongs to a family of otherwise obligately aquatic gastropods. However, it is the exception within this family (Physidae). Unlike its truly aquatic relatives, it inhabits wet terrestrial situations, specifically wet canyon walls covered with algae and hanging gardens.

*Most important indicators.

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Yavapai mountainsnail (*Oreohelix yavapai*[1])
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography	flats	—	—	mountains, canyons	Ferriss (1920), Pilsbry (1939)	
habitat	substrate (texture)	fine (loam, sand, clay)	mixed (few rocks)	mixed (somewhat rocky)	coarse (rocky, e.g., talus, rock slides)	Ferriss (1920), Pilsbry (1939)	
habitat	slope	none	slight	moderate	moderate to steep	Ferriss (1920), Pilsbry (1939)	
habitat	elevation	<3,000 ft or >11,000 ft	—	—	3,000–11,000 ft	Pilsbry (1939) and other sources	
habitat (degradation)	livestock (grazing)	present in large numbers	present in moderate numbers	present in small numbers	absent	Clarke (1993), Clarke and Hovingh (1994)	Alteration of habitat and trampling of snails by livestock is potentially a threat in some places (e.g., sheep on Navajo Mountain).
habitat (degradation)	fire	prescribed burns planned or implemented	no fire control	some fire control	fire control plan exists	Clarke (1993), Clarke and Hovingh (1994)	
habitat (degradation)	timber harvest	occurring or planned in immediate vicinity of colony	occurring or planned in general vicinity of colony	possible in the future in the general area	none		Where this species occurs in association with harvestable timber, disturbance and alteration of habitat as well as direct destruction of the colony are threats.

[1]It is questionable whether this species, as currently recognized, is actually a single species rather than a complex of several species. Recently Metcalf and Smartt (1997) elevated one of the named subspecies of this species to full specific status (and synonymized 2 other of the nominal subspecies with it). It is quite possible that other races of the species also deserve specific status and that yet others deserve no taxonomic status, even as subspecies. The overall range of this species extends from central Arizona (and, as formerly arranged, New Mexico) to northern Wyoming and southern Montana, but most of this large area is uninhabited by the species, which occurs only in a few small, isolated populations—many of them separated from the others by hundreds of miles—within this

region. Their geographic distributions and the fact that there are differences in size and in shell morphology between the various subspecies suggest that several species may have been combined in an artificial, composite "species." Despite the patchy and discontinuous distribution of this species, in some places (e.g., the Grand Canyon and Navajo Mountain) multiple of its putative subspecies occur together or in very close proximity (Ferriss 1920, Pilsbry 1939, Spamer and Bogan 1993), which further suggests existing taxonomic misunderstanding. The taxonomic situation is made even more complex by "fossil" material assigned to this species and the fact that "fossils" of several of the named subspecies that are believed to be extinct can be found with its living subspecies.

[2]Habitats and other aspects of the ecology of the Yavapai mountainsnail differ so greatly among its various subspecies and populations that it is difficult to find ecological factors shared by them, and this greatly limits the usefulness of this table. For example, some populations assigned to this species occur in very hot, dry, vegetationally sparse places at low elevations (e.g., within the Grand Canyon) while others inhabit cool, moist, forested areas at high elevations (e.g., just below timberline in mountains). Since its geographical distribution is discontinuous and highly fragmented, this species cannot be expected to occur in all places where conditions appear to be suitable for it—even where conditions match those where thriving colonies are known.

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Brian Head mountainsnail (*Oreohelix parawanensis*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	inhabited area (area of inhabited patches or colonies)*	<1 ha	1–2 ha	2–3 ha	>3 ha	Oliver and Bosworth (2002)	Oliver and Bosworth (2002) found ≤2.3 ha to be inhabited within ~11 ha overall area.
population	no. of inhabited patches (i.e., colonies or subpopulations)*	≤3	4–6	7–9	≥10	Oliver and Bosworth (2002)	Oliver and Bosworth (2002) found shells in 7 colonies but live individuals in only 4 of these, and 3 colonies may be extinct.
habitat (food, microhabitat)	currants (*Ribes* spp.)*	absent	present but scarce and sparse	present in small scattered clumps	abundantly present in large, dense, thriving (i.e., tall) clumps	Oliver and Bosworth (2002)	Oliver and Bosworth (2002) noted close association with *Ribes*, which may be the main food source and provide critical microhabitat.
habitat (substrate chemistry [calcium source])	exposed limestone*	none	some, mixed with sandstone	some, mixed with basalt	much (with or without basalt)	Oliver and Bosworth (2002)	Mountainsnails (*Oreohelix*) are strongly calciphilic (Oliver and Bosworth 2002, and sources cited therein).
habitat (degradation)	livestock	occasionally present in large numbers or always present	rarely present in small numbers	only stray individuals ever present	absent	Oliver and Bosworth (2002)	Oliver and Bosworth (2002) noted some evidence of livestock where snails occur and large numbers of livestock <10 km away.
habitat (degradation)	distance to ski runs, lifts, bldgs., roads	<0.5 km	0.5–1 km	1–1.5 km	≥1.5 km	Oliver and Bosworth (2002)	Oliver and Bosworth (2002) discussed potential impacts or threats form human activities and developments.

[1]This species is strictly endemic, so far as is known, to a very small area near the summit of Brian Head Peak, Iron County, Utah (see Oliver and Bosworth 2002).

*Most important indicators.

Literature Cited

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gvo

Eureka mountainsnail (*Oreohelix eurekensis*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of live individuals/ha	<1/ha	1–12/ha	13–25/ha	>25/ha	see Comments	Oliver and Bosworth (2000) found 3 live individuals in an area of ~0.03 ha, which implies a density of ~100/ha (i.e., if the colony had been 33X as large).
habitat	shrub (e.g., sagebrush, currants) and/or tree (e.g., aspen) cover	absent	—	—	present	Henderson and Daniels (1916), Roscoe and Grosscup (1964), Clarke (1993), Clarke and Hovingh (1994), Oliver and Bosworth (2000)	
habitat, calcium for shell formation	exposed rock see Comments	—	sandstone	—	limestone	Henderson and Daniels (1916), Clarke (1993), Clarke and Hovingh (1994), Oliver and Bosworth (2000), Roscoe and Grosscup (1964)	Members of the genus *Oreohelix* typically are strongly calciphilic (Henderson and Daniels 1916), and most reports of this species have mentioned exposed limestone. However, Roscoe and Grosscup (1964) stated that they found it in an area where the only exposed rock was sandstone.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography*	—	—	—	slopes	Henderson and Daniels (1916), Roscoe and Grosscup (1964), Clarke (1993), Clarke and Hovingh (1994), Oliver and Bosworth (2000)	
habitat	elevation* see Comments	<7,200 ft or >8,700 ft	—	—	7,200–8,700 ft	Roscoe and Grosscup (1964), Clarke (1993), Clarke and Hovingh (1994), Oliver and Bosworth (2000)	The few reported elevations range from 7,218 ft (Clarke 1993, Clarke and Hovingh 1994) to 8,678 ft (Oliver and Bosworth 2000). Whether these extremes approach the elevational limits of *O. eurekensis* is unknown.
mortality, habitat degradation and destruction	timber harvest	occurring (past, present, or future)	—	—	none	Oliver and Bosworth (2000)	
mortality, habitat degradation and destruction	livestock grazing*	occurring (past, present, or future)	—	—	none	Oliver and Bosworth (2000)	
mortality, habitat degradation and destruction	mining*	occurring (past, present, or future)	—	—	none	Clarke (1993), Oliver and Bosworth (1999)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, habitat degradation and destruction	"scientific" collecting[2,*]	occurring	—	—	none	Oliver (personal observations)	After the rediscovery of the type locality of *O. e. uinta* was reported by Oliver and Bosworth (2000), attempts by others to collect this taxon resulted in appalling devastation of the limited inhabited area (~0.03 ha) that involved human trampling of the slope and its sparse vegetation and turning and complete displacement of most rocks and boulders, many of them having been allowed to tumble down the inhabited slope. These inappropriate collecting activities have resulted in serious degradation and destruction of both microhabitat and macrohabitat of the snails at this locality. (See also footnote 2.)

[1]*O. eurekensis* apparently occurs only in Utah. It has been reported from a few locations scattered across the northern part of the state, its distribution being patchy and discontinuous. This taxon was originally named as a race of *Oreohelix hemphilli*, the Whitepine mountainsnail, of e. Nevada, and later was elevated to specific status. The population in the Deep Creek Mountains of extreme w.-c. Utah was assigned to *O. eurekensis* by Roscoe (1954) but to *O. hemphilli* by Ports (2004). Ports (2004) also reported *O. hemphilli* from other ranges in w. Utah, and he suggested that *O. eurekensis* and *O. hemphilli* may be synonyms. Thus, whether *O. eurekensis* should be considered a full species, a race of *O. hemphilli*, or taxonomically invalid (i.e., merely a junior synonym of *O. hemphilli*) is uncertain.

[2]Henderson and Daniels (1917) reported that they collected "about 600" *O. eurekensis*, "mostly alive", at the type locality in 1916. Clarke's (1993) field sheets indicate that he and co-workers found only 3 live *O. eurekensis* at this locality in 1992. It is possible that the excessive collecting by Henderson and Daniels (1917) may have reduced the population so greatly that it has not been able to recover.

*Most important indicators.

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gvo

lyrate mountainsnail (*Oreohelix haydeni*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of live individuals per hectare see Comments	<1/ha	1–12/ha	13–25/ha	>25/ha	"Ratings" are estimates based on field experience with various species of *Oreohelix* (Oliver, personal observations).	Only live snails should be counted; empty (dead) shells of *Oreohelix* can last for many years (centuries or millennia) and often are abundant, even in extirpated colonies. Clarke (1993) estimated a 60-acre (24.3-ha) colony to contain 1 million individuals (41,152/ha) despite the fact that only 10 live individuals were found (0.41/ha), and he estimated a 100-acre (40.5-ha) colony to contain 1 million to 10 million individuals (24,691–246,913/ha) though only 6 live individuals were found (0.15/ha). He did not explain how he arrived at his estimates, which appear to be grossly exaggerated (Oliver and Bosworth 1999).
habitat, calcium carbonate (for shell formation)	limestone*	no calcareous sol or exposed limestone	calcareous soil present, exposed limestone absent	some exposed limestone	abundant limestone talus	Henderson and Daniels (1916, 1917), Oliver (personal observations)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	shrub cover (e.g., mountain mahogany, balsam root, bitterbrush, maple, sagebrush, chokecherry, serviceberry, oak)*	absent	—	—	present	Henderson and Daniels (1916, 1917), Pilsbry (1939), Oliver (personal observations)	
habitat degradation (destruction of shrub cover, loss of duff or vegetative debris, erosion)	clearing of woody shrubs and trees*	occurring (past, present, or future)	—	—	none	Henderson and Daniels (1917)	
habitat degradation and destruction, mortality (burial in lime dust)	quarrying of lime for cement	occurring in vicinity	—	—	none in vicinity	Henderson and Daniels (1917), Clarke (1993)	
habitat degradation (destruction of shrub cover, loss of duff or vegetative debris, erosion)	livestock grazing*	intensive	moderate	slight	none	Henderson and Daniels (1917), Clarke (1993)	Henderson and Daniels (1917) considered a colony near Logan, Utah to be “likely near extinction” from the effects of overgrazing and subsequent erosion.
habitat degradation (destruction of shrub cover, loss of duff or vegetative debris, erosion)	burning	occurring	—	—	none	Henderson and Daniels (1917)	

[1]This species occurs mainly in n.-c. Utah, but out-lying populations assigned to it also occur in w. Colorado (where it has not been found alive since 1918), se. and w. Idaho, and w. Montana. Its taxonomic status is uncertain, and several taxonomic questions pertaining to it remain unanswered. Several authors have mentioned (or at least implied) the possibility that it may be an ecophenomorph of *Oreohelix strigosa*. It is also possible that it may be a complex of several unrecognized species.

*Most important indicators.

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Deseret mountainsnail (*Oreohelix peripherica*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of live individuals in colony	≤100	101–500	501–1,000	>1,000	see Comments	Clarke (1991) estimated the population of living individuals of the nominal race *O. p. weberiana* to be ~20,000 but found only 2 live individuals, and Clarke (1993) estimated the population of live individuals of the nominal race *O. p. wasatchensis*[1] to be between 10,000 and 100,000. However, Clarke often grossly overestimates mollusk populations.
population	density (live individuals per square yard) in colony	<0.3/yard^2	0.3–1/yard^2	1–3/yard^2	>3/yard^2	see Comments	It is important that only living individuals be counted in determinations of population and density. "Ratings" are based on Clarke's estimate of density within the colony of the nominal race *O. p. wasatchensis*[1], where he found ~7 live individuals/yard^2 in the densest part of the colony and ~0.7/yard^2 in other parts of the colony.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	extent of colony	<0.05 acre	0.05–0.1 acre	0.1–1 acre	>1 acre	see Comments	Clarke (1991) estimated the extent of the colony of the nominal race *O. p. weberiana* to be ~600 X ~400 ft (~5.51 acres). Clarke (1993) estimated the colony of the nominal race *O. p. wasatchensis*[1] to be ≤10 acres, with the greatest concentration within an area of ~20 X ~80 ft (~0.04 acres). Clarke's estimates were, in at least the first case (Clarke 1991), influenced by the areal extent of dead shells; dead shells do not necessarily indicate either the presence or the extent of a living population. It should be noted that there are other species of mountainsnails (*Oreohelix*) that occur in much smaller colonies than those estimated by Clarke.
habitat	topography*	other (e.g., lowland flats, high mountains)	—	—	foothills and lower mountain slopes	various sources including Henderson and Daniels (1916, 1917), Clarke (1991, 1993)	
habitat, calcium carbonate (for shell formation)	limestone* see Comments	no calcareous soil or exposed limestone	calcareous soil present, exposed limestone absent	some exposed limestone	abundant exposed limestone	Henderson and Daniels (1916, 1917)	The nominal race *O. p. wasatchensis*[1] is associated with quartzite boulders (Pilsbry 1939, Clarke 1993, Meadows 2002).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	plant association (vegetative cover)*	little or no vegetative cover, open	grass	perennial forbs (e.g., balsam root), shrubs (e.g., bitterbrush, sagebrush)	trees (e.g., maple, oak, possibly juniper)	Henderson and Daniels (1916, 1917), Pilsbry (1939), Clarke (1991, 1993), Meadows (2002)	
habitat, protective cover, perhaps food	duff (e.g., leaf litter)*	none	very little	moderate amounts	abundant, well-developed	Henderson and Daniels (1917), Clarke (1993), Meadows (2002)	
habitat	elevation*	<4, 400 ft or >5,800 ft	—	—	4,400–5,800 ft	UNHP database (2008)	The known elevational range of this species is remarkably narrow, 4,460–5,760 ft (1,359–1,756 m) (Utah Natural Heritage Program database, 2008).
habitat fragmentation (vs. integrity)	roads, trails	many	some	few	none	Meadows (2002)	Meadows (2002) reported that within habitat occupied by the nominal race *O. p. wasatchensis*[1] there are 2 USFS trails, 2 public utility roads, and numerous trails used by mountain-bikers, hikers, and joggers, and he showed that pathways are barriers to movement by this snail and fragment its habitat, potentially producing subpopulations with greater risk of extinction.
habitat (loss and disturbance)	residential encroachment	adjacent	nearby	none	none	Clarke (1993)	Clarke (1993), discussing the nominal race *O. p. wasatchensis*[1], noted that fires are frequent in forests near residential areas. This may be true of other disturbances as well.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation (erosion), habitat fragmentation (trails), mortality (trampling)	presence of livestock (e.g., sheep), over-grazing see Comments	many	moderate numbers	few	none	Henderson and Daniels (1917, p 62), Clarke (1991)	Henderson and Daniels (1917) commented, concerning 1 site where they found this species: "[It] has been considerably denuded by overgrazing, and erosion has washed the soil and dead leaves from beneath the shrubs and *Balsamorrhiza* that formerly afforded shelter for the snails. Bleached shells almost whitened the ground down the slopes from clumps of bushes where now there is no snail cover at all. It is difficult to see how the shrubbery can long continue to exist." Clarke (1991) mentioned grazing and the presence of sheep trails within a colony of the nominal race *O. p. weberiana*. (See "indicator" 2 rows above.)
habitat degradation (destruction of shrub cover, loss of duff or vegetative debris, erosion)	fire (e.g., burning)	occurring	—	—	none	Henderson and Daniels (1916, p 335)	

[1]This species occurs in n.-c. Utah. Recent molecular genetics work by Weaver et al. (2007) raises questions concerning morphology-based taxonomy of this nominal species, its nominal race *O. p. wasatchensis*, and some other nominal taxa of large mountainsnails. They found that 2 very distinct clades exist within what has been called *O. p. wasatchensis*, and they intimated that 1 of these clades may represent a new, unnamed species.

*Most important indicators.

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"Ogden Rocky mountainsnail"[1] (*Oreohelix peripherica wasatchensis*[2])
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of individuals	≤100	101–1,000	1,001–10,000	>10,000	Clarke (1993) estimated the single known (= entire global) population of live individuals to be between 10,000 and 100,000.	Clarke often grossly overestimates mollusk populations.
population	density	«0.7 (live)/yard^2	~0.7 (live)/yard^2	~0.7–7 (live)/yard^2	>7 (live)/yard^2	Clarke (1993)	It is important that only living individuals be counted in determinations of population and density.
habitat	substrate or ground cover	limestone only	limestone and quartz	quartzite boulders	well-developed leaf litter	Clarke (1993)	
habitat	plant association	little or no vegetative cover, open, treeless	sagebrush and other shrubs	oak clumps	big-tooth maple groves	Clarke (1993), Meadows (2002)	
habitat (integrity)	roads, trails	many	some	few	none	Meadows (2002) showed that pathways are barriers to movement by this snail and fragment its habitat, potentially producing subpopulations with greater risk of extinction.	Meadows (2002) reported that within occupied habitat there are 2 USFS trails, 2 public utility roads, and numerous trails used by mountain-bikers, hikers, and joggers.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (loss and disturbance)	residential encroachment	adjacent	nearby	none	none	Clarke (1993)	Clarke (1993) noted that fires are frequent in forests near residential areas. This may be true of other disturbances as well.

[1]Although in most animal groups subspecies are not given unique common names, those subspecies with special federal regulatory status are assigned common names by the U. S. Fish and Wildlife Service. However, the common name invented for this putative taxon by the U. S. Fish and Wildlife Service is nonsensical, implying that it is a race of *Oreohelix strigosa*, the Rocky mountainsnail. The putative taxon *wasatchensis* is instead a subspecies of *Oreohelix peripherica*, the Deseret mountainsnail, and could correctly be called the Ogden race of the Deseret mountainsnail (however, see footnote 2).

[2]Recent (2004) work at Brigham Young University by Keith Crandall and co-workers (in press), using molecular genetic techniques, has shown that *Oreohelix peripherica wasatchensis* is not a valid taxon, even at the subspecific level. U. S. Fish and Wildlife Service rules require that invalid taxa be removed from candidate status for possible listing as endangered or threatened. When this has been done, the Utah Division of Wildlife Resources similarly will remove this nominal taxon from the Utah Sensitive Species List.

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Kanab ambersnail (*Oxyloma kanabense*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	inhabited area	<10 m^2	10–100 m^2	100–1,000 m^2	>1,000 m^2 (i.e., >0.1 ha)		Estimates of some inhabited (and potentially inhabited) areas have included 7 m^2, 840 m^2, and 2 ha (see England 1995). Potential habitat at an inhabited site in the Grand Canyon has varied in the range of ~195–367 m^2 (Sorensen and Kubly 1997).
population	density (in June)	<10/m^2	10–20/m^2	20–30/m^2	>30/m^2	Stevens et al. (1997)	Seasonal variation in densities is very great. Sampling in March, June, August, and September, Stevens et al. (1997) found lowest densities in June and highest in September, the latter densities being 5–17X greater than June densities.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	estimated no. of individuals	<100	100–1,000	1,001–10,000	>10,000	various sources (e.g., England 1995, Clarke and Lunceford 1991, Clarke and Hovingh 1994, Stevens et al. 1997)	Clarke and Lunceford (1991) estimated the Three Lakes population as 100,000 in 1990. Other populations have been estimated to contain 300 and 16,000 individuals (England 1995). One population increased from an estimated 18,476 individuals on 30 March to 104,004 on 17 September of the same year (>5X increase), and another increased from 617 to 17,370 (>18X) during the same period (Stevens et al. 1997), which shows the dynamic nature of the population biology of this species, the extreme effect that timing of population estimates can have, and potential problems with comparisons of population estimates from different sources and times.
habitat	perennial surface water from springs or seeps*	wet areas associated with seeps	wet areas associated with small springs	wet areas associated with large springs, spring runs, and pools	spring-fed wetlands (marshes, wet meadows) at the base of sandstone or limestone cliffs	England (1995), Clarke and Lunceford (1991), Spamer and Bogan (1993), Clarke and Hovingh (1994)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	proximity to river or permanent stream	<1 m or >300 m	1–5 m or 200–300 m	5–10 or 100–200 m	10–100 m		All known populations are in wet situations (see above indicator) near perennial streams or rivers; however, siltation from flooding has caused the loss of "a significant portion" of 1 population and scouring may have reduced or eliminated others (England 1995). Thus it appears that a permanent watercourse is typically associated with proper habitat, but that the watercourse itself can be a threat during floods.
habitat and food	plant association*	other	horsetails, wetland grasses, violets, plantains, willows, alders, poison ivy, maidenhair ferns, helleborine orchids, columbines, shooting-stars	sedges (*Carex*), rushes (*Juncus*), water smartweed (*Polygonum amphibium*)	cattails (*Typha*), monkey-flowers (*Mimulus*), watercress (*Nasturtium officinale*)	England (1995), Clarke and Lunceford (1991), Spamer and Bogan (1993), Clarke and Hovingh (1994), Stevens et al. (1997), Sorensen and Kubly (1997)	Many of the plants listed in the "fair" rating are not actually utilized, even as substrates, by the snails but are merely associated with suitable habitats.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
parasitism	trematode (*Leucochloridium cyanocittae*) infestation (see Comments)	high	medium	low	none	Stevens et al. (1997)	A population in the Grand Canyon was found in August to be heavily infested (possibly >27%) with this parasite, which requires ambersnails as the intermediate hosts (Stevens et al. 1997). The trematode is transmitted by passerine birds, which are the definitive hosts. Stevens et al. (1998) concluded that the parasite is persistent in this ambersnail population, with infestation varying from <1% to 9.5%. However, **whether the parasite represents a threat to the snails is questionable**.
mortality (from trampling), habitat degradation (from overgrazing, defecation, trampling)	livestock	present in large numbers	present in small numbers	present in small numbers and only during winter	absent	England (1995), Clarke and Lunceford (1991)	
mortality (from trampling), habitat degradation	recreation-al use (e.g., trampling, etc., by "river runners")	high	moderate	low	none	England (1995), Spamer and Bogan (1993), Sorensen and Kubly (1997)	Outdoor recreation has the potential to impact certain populations (e.g., those in the Grand Canyon).
habitat loss	dewatering (e.g., draining of wetlands, diversions of flow, water withdrawal)*	occurring or planned	—	—	none	England (1995), Clarke and Lunceford (1991), Clarke and Hovingh (1994)	Dewatering apparently has extirpated 1 Utah population (see England 1995).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (from being washed away or buried), habitat loss	flooding and scouring (e.g., natural and from water releases from reservoirs)	severe or frequent	periodical	rare	rare or none	England (1995), Stevens and Meretsky (1997), Sorensen and Kubly (1997)	Releases from Glen Canyon Dam resulting in downstream flows ≥25,000 cfs potentially negatively impact ambersnail populations in the Grand Canyon (England 1995). However, although Stevens and Meretsky (1997) found that all ambersnails below the 45,000 cfs flood level in a population in the Grand Canyon were lost during an experimental flood, a year later the population in this area had returned to near its former size (Stevens et al. 1998).
alteration of flow regime	impoundment	existing or planned	—	—	none		The management of Lake Powell and Glen Canyon Dam is believed, by some, negatively to impact populations along the Colorado River (England 1995). It is possible that other, unknown populations were destroyed (inundated) by the creation of this very large reservoir. It is rumored that there are plans for a large, additional reservoir on Kanab Creek.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat destruction and degradation	commercial development, construction, and destruction of various kinds (e.g., road and bridge construction)	existing or planned	—	—	none		Clarke and Lunceford (1991) reported that 1 colony was devastated by bulldozing.

[1]Taxonomy of this organism is unstable and uncertain (typical of the family, Succineidae, to which it belongs and which is in great need of revision). Traditionally it has been considered as a very widely disjunct subspecies of the Niobrara ambersnail, *Oxyloma haydeni*, of Nebraska and elsewhere on the Great Plains (also recently reported in Canada). More recently it has been treated as a full species (though with inconsistent spelling, *kanabensis* and *kanabense*). However, results of recent genetic and morphological studies are both difficult to interpret and difficult to reconcile with each other, and the taxon is variously regarded as (1) a subspecies, *Oxyloma haydeni kanabense* (the traditional arrangement), (2) a species, *Oxyloma kanabense* (the very tentative current view held, seemingly, by the many malacologists), or (3) a complex of several species (i.e., *Oxyloma kanabense* and perhaps several unnamed species). Not only has the taxon *kanabense* been regarded as allied to Nebraska snails, but it has also been identified from various locations along the Colorado River in Arizona (from the vicinity of Page to the Grand Canyon) and recently from the province of Alberta. Any one of the suggested taxonomic possibilities, regardless of their perceived likelihood, could be correct. However, it does not appear likely that understanding that will resolve these systematic and taxonomic uncertainties will soon be achieved. Based on limited molecular genetic work, ambersnails of Vasey's Paradise in the Grand Canyon appear to be very distinct from other ambersnails, and it would not be surprising if these snails were eventually accorded specific status; however, they are currently (2005) treated as Kanab ambersnails by malacologists and resource management agencies. This table utilizes information from southern Utah and northern Arizona, including Vasey's Paradise, and may be considered applicable to members of the genus *Oxyloma* in these areas, but no taxonomic opinion should be inferred.

*Most important indicators.

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southern tightcoil (*Ogaridiscus subrupicola*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physical, geological feature	—	—	rockslides	caves	Chamberlin and Jones (1929), Pilsbry (1946), Smith (1957)	See footnote 1.
mortality, habitat destruction or degradation	archeological or other human disturbance (e.g., vandalism, recreation, scientific collecting)*	repeated, intensive	has occurred, but minimal	none	none	Oliver (personal observations, 2003)	See footnote 1.

[1]This species shows a relictual distribution. Pilsbry (1946) had only 3 localities for *Ogaridiscus subrupicola subrupicola*, 1 each in Utah, Idaho, and Oregon, and only 1 locality for *Ogaridiscus subrupicola spelaeum*, in California. Seemingly nothing of the ecology of these populations has been reported. The Utah locality, which is the type locality of the species, was visited by biologists from the Utah Division of Wildlife Resources in 2003. Only a few empty shells of this species were found, and the species is now presumed to be extirpated from the type locality and from Utah, probably the result of repeated human disturbance of the cave (especially by archeologists, who repeatedly have excavated, moved, and sifted very large amounts of substrates in and from the cave and have overturned and displaced all rocks on its floor). The Utah locality is an ancient sea cave (formed by wave action) between the Stansbury and Provo terraces of Pleistocene Lake Bonneville and ~380 ft above the average level of the current Great Salt Lake. (Characteristics of this cave are: ~4,580 ft elevation, ~100 m long, ~1–3.4 m wide, ~1–12 m high, limestone and shale.) The type locality of the subspecies *O. s. spelaeum* also is a cave. Additionally, Smith (1957) reported *O. s. spelaeum* from 3 other caves and from "a shaded rockslide" on the bank of a stream. Baker (1930) referred to *O. subrupicola* (and 2 species that he considered to be its close relatives) as "more or less subterranean in habits", although by this he apparently did not necessarily mean cavernicolous. Whether caves are the preferred habitat of this species is unknown, as are the ecological tolerances and requirements of this species. The Utah locality is surrounded by dry grassland; some of the other localities may be within forests, but this has not been reported and is merely speculative. The scant information that has been reported concerning *O. subrupicola* suggests that cool, moist, shaded or dark (including totally dark), rocky situations are preferred or required.

*Most important indicator.

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Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of sexually mature adults (≥15 cm)	≤50/mi	51–150/mi	151–400/mi	>400/mi	Hirsch et al. (2005)	
effective population (avoidance of genetic drift, etc.)	no. of adults (≥15 cm)	≤50	51–500	501–2,000	>2,000	Hirsch et al. (2005), Rieman et al. (1993)	
temporal stability (ability to withstand stochastic events, e.g., fire, drought, flooding)	inhabited stream length (or connected suitable habitat)	<6 mi	6–19 mi	20–49 mi	≥ 50 mi	Hirsch et al. (2005)	
genetic purity (absence of introgressed genes from hybridization with introduced species)	tested (electrophoresis or DNA) % CRCT[2] genetic material in focal pop.	<80% (i.e., >20% introgression)	80–89% (i.e., 11–20% introgression)	90–99% (i.e., 1–10% introgression)	>99% (i.e., <1% introgression)	Hirsch et al. (2005)	
habitat (juvenile and adult)	watershed area	«9 mi^2	<9 mi^2	≥9 mi^2	»9 mi^2	Hirsch et al. (2005)	
adult, juvenile, and fry habitat (growth and survival)	average maximum water temperature during the warmest period of the year*	<4 °C or >20 °C	4–6.5 °C or 19–20 °C	6.5–12 °C or 14– 19 °C	12–14 °C	Hickman and Raleigh (1982)	Hirsch et al. (2005) considered a mean daily range of 8–16 °C to be an "optimal desired reference condition". In lacustrine habitats, use temperature strata nearest optimum (13 °C) in dissolved oxygen zones >3 mg/L (Hickman and Raleigh 1982).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat (embryo survival and development)	average maximum water temperature during embryo development	<3.5 °C or >16 °C	3.5–4.5 °C or 14.5–16 °C	4.5–7 °C or 12–14.5 °C	7–12 °C	Hickman and Raleigh (1982)	Hirsch et al. (2005) considered a mean daily range of 8–13 °C during spawning and incubation to be an "optimal desired reference condition".
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature ≤15 °C)	<4.3 mg/L	4.3–5.1 mg/L	5.1–7 mg/L	>7 mg/L	Hickman and Raleigh (1982)	
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature >15 °C)	<6.3 mg/L	6.3–7.2 mg/L	7.2–9 mg/L	>9 mg/L	Hickman and Raleigh (1982)	
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for ≤5 m stream width)	<15 cm	15–20 cm	20–30 cm	≥30 cm	Hickman and Raleigh (1982)	for ≤5 m stream width

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for >5 m stream width)	<26 cm	26–32.5 cm	32.5–45 cm	≥45 cm	Hickman and Raleigh (1982)	for >5 m stream width
spawning habitat (embryo survival)	average water velocity over spawning areas during embryo development	<20 cm/s or >75 cm/s	20–25 cm/s or 67.5–75 cm/s	25–30 cm/s or 60–67.5 cm/s	30–60 cm/s	Hickman and Raleigh (1982)	
habitat (useable cover for adults)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period*	<6%	6–12%	12–25%	>25%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas. Hirsch et al. (2005) considered 35–60% pools/total area to be an "optimal desired reference condition" (see indicator 5 rows below).
habitat (useable cover for juveniles)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period	<3%	3–7%	7–15%	>15%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas. Hirsch et al. (2005) considered 35–60% pools/total area to be an "optimal desired reference condition" (see indicator 4 rows below).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat	average substrate particle size (diameter) in spawning areas	<0.3 cm or >8 cm	0.3–0.75 cm or 7.5–8 cm	0.75–1.5 cm or 6–7.5 cm	1.5–6 cm	Hickman and Raleigh (1982)	Sample all potential spawning areas. Size of spawning-area gravel is correlated with or determines water exchange rates, proper redd construction, and fry survival.
winter habitat and escape cover for fry and small juveniles	% of substrate particles that are 10–40 cm diameter	<5%	5–7.5%	7.5–10%	≥10%	Hickman and Raleigh (1982)	
food production (aquatic insects)	dominant (≥50%) substrate type in riffle-run areas*	rubble and gravel «25%; almost entirely fines, bedrock, or large boulders	rubble and gravel ≤25%; fines, bedrock or large boulders predominate	rubble, gravel, boulders, and fines present in approx. equal amounts, or predominant-ly gravel; aquatic vegetation may or may not be present	mainly rubble or small boulders, or aquatic vegetation in areas with springs; less gravel, large boulders, or bedrock	Hickman and Raleigh (1982)	
habitat	pools as % of stream (relative to riffle-runs) during late summer low flow*	<7.5%	7.5–17.5% or 87.5–100%	17.5–40% or 60–87.5%	40–60%	Hickman and Raleigh (1982)	Hirsch et al. (2005) considered 35–60% pool habitat to be an "optimal desired reference condition".
organic input to aquatic habitat (nutrients)	stream-bank vegetation, using index ∑ = 2(%shrubs) + 1.5(%grasses) + 1(%trees) + 0(%bare ground)	<45%	45–100%	100–140%	>140%	Hickman and Raleigh (1982)	Indicator is for streams ≤50 m wide. Shrubs provide best input, followed by grasses and forbs, then trees (as shown in formula for index).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
erosion control	average % rooted vegetation and stable rocky ground cover along stream-bank during summer*	<32.5%	32.5–50%	50–75%	75–100%	Hickman and Raleigh (1982)	Hirsch et al. (2005) considered stream-bank stability >90% "of potential based on inherent capability associated with natural riparian communities" to be an "optimal desired reference condition".
water chemistry (CRCT survival)	annual maximum and minimum pH	<5.75 or >9	5.75–6 or 8.75–9	6–6.5 or 8–8.75	6.5–8	Hickman and Raleigh (1982)	For lacustrine situations, measure pH in zone of best combination of dissolved oxygen and temperature.
flow regime	average daily base flow (during late summer low flow)/ average annual daily flow*	<25%	25–37.5%	37.5–50%	>50%	Hickman and Raleigh (1982), Hirsch et al. (2005)	Flows affect quantity and quality of pools, in-stream cover, and water quality.
stream habitat, cover	pool abundance and quality during late growing season low flow period (see pool classification[3])*	almost entirely 3rd class pools («10% of stream habitat is 1st class pools and «50% is 2nd class pools)[3]	<10% of stream habitat is 1st class pools and <50% is 2nd class pools[3]	10–30% of stream habitat is 1st class pools or ≥50% is 2nd class pools[3]	≥30% of stream habitat is 1st class pools[3]	Hickman and Raleigh (1982)	See footnote 3 for descriptions of pool classes. Hirsch et al. (2005) considered 35–60% pools/total area to be an "optimal desired reference condition".
riffle-run habitat (food sources)	% fines (<3 mm) in riffle-run areas during average summer flows	>40%	30–40%	10–30%	<10%	Hickman and Raleigh (1982)	
spawning habitat (embryos and fry survival)	% fines (<3 mm) in substrate of spawning areas during average summer flows	>20%	15–20%	5–15%	<5%	Hickman and Raleigh (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
optimal water temperatures and photosynthetic rates	stream area shaded between 1000 and 1400 hrs (see comments)	<15% or >97.5%	15–30% or 90–97.5%	30–50% or 75–90%	50–75%	Hickman and Raleigh (1982), Hirsch et al. (2005)	not applicable for streams >50 m wide or for cold streams (<18 °C)
habitat, suitable conditions (e.g., temperature)	elevation	<6,000 ft (or <5,500 ft on north-facing slopes)	—	—	≥6,000 ft (or ≥5,500 ft on north-facing slopes)	Hirsch et al.(2005)	Maximum elevation was not specified by Hirsch et al. (2005) but may be ~11,000 ft (or use indicators for water temperatures).
disease risk	presence of significant disease or pathogens in stream or watershed	pathogens present in stream segment with focal pop. (whether or not focal pop. has tested positive)	pathogens known in same stream or drainage ≤10 km away, no barriers exist between infected pop. and focal pop., but pathogens not yet found in same stream segment as focal pop.	pathogens known in same stream or drainage but >10 km away or ≤10 km where existing barriers exist but may be at risk of failure; stocking requires fish health screening and pathogen-free clearance	pathogens absent or unknown, no stocking occurs, barrier provides complete blockage to upstream movement of fish from other pops.	Hirsch et al. (2005) and other sources	"The diseases of concern are those that cause severe and significant impacts to population health and include but are not limited to whirling disease, furunculosis, infectious pancreatic necrosis virus, etc." (Hirsch et al. 2005).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization risk	introduced hybridizing taxa (other cutthroat trout sspp. or rainbow trout)	sympatric with CRCT in same stream segment	in same stream or drainage ≤10 km (6 mi) from CRCT pop. and no barriers exist	in same stream or drainage >10 km (6 mi) from CRCT pop., but not in same stream segment as CRCT, or ≤10 km (6 mi) from CRCT pop. and barriers exist but may be at risk of failure	barrier(s) provide complete blockage to upstream fish movement and introduced taxa cannot reach CRCT pop.	Hirsch et al. (2005) and other sources	
competition and predation	introduced fish taxa including other trout taxa (e.g., brown trout, brook trout, lake trout, rainbow trout) and sport fish taxa	present, abundant	present in moderate numbers	present but very rare	absent	Hirsch et al. (2005)	
disturbance, degradation	livestock	present in large numbers	present in moderate numbers	present in low numbers	absent	various sources (e.g., Hirsch et al. 2005)	

[1]Various populations of the Colorado River subspecies of the cutthroat trout are (1) resident (residing in 1 stream or a network of smaller streams for entire life), (2) fluvial (residing primarily in a larger stream or river but migrating to streams to spawn), and (3) adfluvial (residing primarily in a lake environment but migrating to riverine environments to spawn) (Hirsch et al. 2005). This table is mainly for riverine (i.e., resident and fluvial) populations. Although lacustrine (i.e., adfluvial) populations are known, most of this table is not applicable to such populations. **N.B.: To be viable and reproducing, lacustrine populations *must* have access to suitable streams for spawning.** "Populations" in isolated lakes that are artificially maintained by routine stocking are not naturally sustainable and viable but are non-reproducing captives and are not addressed in this table.

[2]CRCT = Colorado River cutthroat trout.

[3] 1st class pools: large, deep, with large low-velocity areas, >30% of bottom obscured due to depth, surface turbulence, or presence of logs, debris, boulders, or overhanging banks or vegetation; or, depth ≥1.5 m in streams ≤5 m wide or ≥2 m in streams >5 m wide. 2nd class pools: moderate size and depth, with moderately large low-velocity areas, 5–30% of bottom obscured; these are typically large eddies behind boulders or moderately deep low-velocity areas beneath overhanging banks or vegetation. 3rd class pools: small and/or shallow, little low-velocity area, cover absent or only shade, surface turbulence, or very limited structure (e.g., debris, boulders, bank, or vegetation); these are typically wide, shallow areas of stream or small eddies behind boulders; nearly entire bottom is visible.

*Most important indicators.

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Bonneville cutthroat trout (*Oncorhynchus clarkii utah*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of sexually mature adults (≥15 cm)	≤50/mi	51–150/mi	151–400/mi	>400/mi	May and Albeke (2005)	
population	no. of adults (≥15 cm)	≤50	51–500	501–2,000	>2,000	May and Albeke (2005), Rieman et al. (1993)	
temporal stability	inhabited stream length (or connected suitable habitat)	<6 mi	6–19 mi	20–49 mi	≥ 50 mi	May and Albeke (2005)	
genetic purity (absence of introgressed genes from hybridization with introduced species)	tested (electrophoresis or DNA) % BVCT[2] genetic material in focal pop.	<80%	80–89%	90–99%	>99%	May and Albeke (2005)	
habitat (juvenile and adult)	watershed area	«9 mi^2	<9 mi^2	≥9 mi^2	»9 mi^2	May and Albeke (2005)	
adult, juvenile, and fry habitat (growth and survival)	average maximum water temperature during the warmest period of the year	<4 °C or >20 °C	4–6.5 °C or 19–20 °C	6.5–12 °C or 14– 19 °C	12–14 °C	Hickman and Raleigh (1982)	May and Albeke (2005) considered 8–16 °C to be a high quality reference condition. In lacustrine habitats, use temperature strata nearest optimum (13 °C) in dissolved oxygen zones >3 mg/L (Hickman and Raleigh 1982).
spawning habitat (embryo survival and development)	average maximum water temperature during embryo development	<3.5 °C or >16 °C	3.5–4.5 °C or 14.5–16 °C	4.5–7 °C or 12–14.5 °C	7–12 °C	Hickman and Raleigh (1982)	May and Albeke (2005) considered 8–13 °C to be a high quality reference condition.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature ≤15 °C)	<4.3 mg/L	4.3–5.1 mg/L	5.1–7 mg/L	>7 mg/L	Hickman and Raleigh (1982)	
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature >15 °C)	<6.3 mg/L	6.3–7.2 mg/L	7.2–9 mg/L	>9 mg/L	Hickman and Raleigh (1982)	
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for ≤5 m stream width)	<15 cm	15–20 cm	20–30 cm	≥30 cm	Hickman and Raleigh (1982)	for ≤5 m stream width
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for >5 m stream width)	<26 cm	26–32.5 cm	32.5–45 cm	≥45 cm	Hickman and Raleigh (1982)	for >5 m stream width

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat (embryo survival)	average water velocity over spawning areas during embryo development	<20 or >75 cm/s	20–25 or 67.5–75 cm/s	25–30 or 60–67.5 cm/s	30–60 cm/s	Hickman and Raleigh (1982)	
habitat (useable cover for adults)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period	<6%	6–12%	12–25%	>25%	Hickman and Raleigh (1982), May and Albeke (2005)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas. May and Albeke (2005) considered 35–60% pools/total area to be a high quality reference condition.
habitat (useable cover for juveniles)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period	<3%	3–7%	7–15%	>15%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas. May and Albeke (2005) considered 35–60% pools/total area to be a high quality reference condition.
spawning habitat	average substrate particle size (diameter) in spawning areas	<0.3 cm or >8 cm	0.3–0.75 cm or 7.5–8 cm	0.75–1.5 cm or 6–7.5 cm	1.5–6 cm	Hickman and Raleigh (1982)	Sample all potential spawning areas. Size of spawning-area gravel is correlated with or determines water exchange rates, proper redd construction, and fry survival.
winter habitat and escape cover for fry and small juveniles	% of substrate particles that are 10–40 cm diameter	<5%	5–7.5%	7.5–10%	≥10%	Hickman and Raleigh (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food production (aquatic insects)	dominant (≥50%) substrate type in riffle-run areas	rubble and gravel «25%; almost entirely fines, bedrock, or large boulders	rubble and gravel ≤25%; fines, bedrock or large boulders predominate	rubble, gravel, boulders, and fines present in approx. equal amounts, or predominant-ly gravel; aquatic vegetation may or may not be present	mainly rubble or small boulders, or aquatic vegetation in areas with springs; less gravel, large boulders, or bedrock	Hickman and Raleigh (1982)	
habitat	pools as % of stream (relative to riffle-runs) during late summer low flow	<7.5%	7.5–17.5% or 87.5–100%	17.5–40% or 60–87.5%	40–60%	Hickman and Raleigh (1982)	
organic input to aquatic habitat (nutrients)	stream-bank vegetation, using index ∑ = 2(%shrubs) + 1.5(%grasses) + 1(%trees) + 0(%bare ground)	<45%	45–100%	100–140%	>140%	Hickman and Raleigh (1982)	Indicator is for streams ≤50 m. Shrubs provide best input, followed by grasses, then trees (as shown in formula for index).
erosion control	average % rooted vegetation and stable rocky ground cover along stream-bank during summer	<32.5%	32.5–50%	50–75%	75–100%	Hickman and Raleigh (1982)	May and Albeke (2005) considered stream-bank stability >90% "of potential based on inherent capability associated with natural riparian communities" to be a high quality reference condition.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water chemistry (BVCT survival)	annual maximum and minimum pH	<5.75 or >9	5.75–6 or 8.75–9	6–6.5 or 8–8.75	6.5–8	Hickman and Raleigh (1982)	For lacustrine situations, measure pH in zone of best combination of dissolved oxygen and temperature.
flow regime	average daily base flow (during late summer low flow)/ average annual daily flow	<25%	25–37.5%	37.5–50%	>50%	Hickman and Raleigh (1982), May and Albeke (2005)	Flows affect quantity and quality of pools, in-stream cover, and water quality.
stream habitat	pool abundance and quality during late growing season low flow period (see pool classification[3])	almost entirely 3rd class pools («10% of stream habitat is 1st class pools and «50% is 2nd class pools)[3]	<10% of stream habitat is 1st class pools and <50% is 2nd class pools[3]	10–30% of stream habitat is 1st class pools or ≥50% is 2nd class pools[3]	≥30% of stream habitat is 1st class pools[3]	Hickman and Raleigh (1982)	See footnote 3 for descriptions of pool classes. May and Albeke (2005) considered 35–60% pools/total area to be a high quality reference condition.
riffle-run habitat (food sources)	% fines (<3 mm) in riffle-run areas during average summer flows	>40%	30–40%	10–30%	<10%	Hickman and Raleigh (1982)	
spawning habitat (embryos and fry survival)	% fines (<3 mm) in substrate of spawning areas during average summer flows	>20%	15–20%	5–15%	<5%	Hickman and Raleigh (1982)	
optimal water temperatures and photosynthetic rates	stream area shaded between 1000 and 1400 hrs (see comments)	<15% or >97.5%	15–30% or 90–97.5%	30–50% or 75–90%	50–75%	Hickman and Raleigh (1982), May and Albeke (2005)	not applicable for streams >50 m wide or for cold streams (<18 °C)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
disease risk	presence of significant disease or pathogens in stream or watershed	pathogens present in stream segment with focal pop. (whether or not focal pop. has tested positive)	pathogens known in same stream or drainage ≤10 km away, no barriers exist between infected pop. and focal pop., but pathogens not yet found in same stream segment as focal pop.	pathogens known in same stream or drainage but >10 km away or ≤10 km where existing barriers exist but may be at risk of failure; stocking requires fish health screening and pathogen-free clearance	pathogens absent or unknown, no stocking occurs, barrier provides complete blockage to upstream movement of fish from other pops.	May and Albeke (2005)	
hybridization risk	introduced hybridizing taxa (other cutthroat trout sspp. or rainbow trout)	sympatric with BVCT in same stream segment	in same stream or drainage ≤10 km (6 mi) from BVCT pop. and no barriers exist	in same stream or drainage >10 km (6 mi) from BVCT pop., but not in same stream segment as BVCT, or ≤10 km (6 mi) from BVCT pop. and barriers exist but may be at risk of failure	barrier(s) provide complete blockage to upstream fish movement and introduced taxa cannot reach BVCT pop.	May and Albeke (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
competition and predation	introduced fish taxa including other trout taxa (e.g., brown trout, brook trout, lake trout, rainbow trout) and sport fish taxa	present, abundant	present in moderate numbers	present but very rare	absent	May and Albeke (2005)	
disturbance, degradation	livestock	present in large numbers	present in moderate numbers	present in low numbers	absent	various sources (e.g., May and Albeke 2005)	

[1]This table is mainly for riverine populations. Although a few lacustrine populations are known, most of this table is not applicable to such populations. **N.B.**: To be viable, reproducing populations, lacustrine populations *must* have access to suitable streams for spawning.

[2]Bonneville cutthroat trout = BVCT in this table.

[3]1st class pools: large, deep, with large low-velocity areas, >30% of bottom obscured due to depth, surface turbulence, or presence of logs, debris, boulders, or overhanging banks or vegetation; or, depth ≥1.5 m in streams ≤5 m wide or ≥2 m in streams >5 m wide. 2nd class pools: moderate size and depth, with moderately large low-velocity areas, 5–30% of bottom obscured; these are typically large eddies behind boulders or moderately deep low-velocity areas beneath overhanging banks or vegetation. 3rd class pools: small and/or shallow, little low-velocity area, cover absent or only shade, surface turbulence, or very limited structure (e.g., debris, boulders, bank, or vegetation); these are typically wide, shallow areas of stream or small eddies behind boulders; nearly entire bottom is visible.

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Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of sexually mature adults (≥15 cm)	≤50/mi	51–150/mi	151–400/mi	>400/mi		This indicator is based on guidelines developed for 2 other races of *O. clarkii*: *O. c. utah* and *O. c. pleuriticus*.
effective population (avoidance of genetic drift, etc.)	no. of adults (≥15 cm)	≤50	51–500	501–2,000	>2,000	Rieman et al. (1993)	
temporal stability (ability to withstand stochastic events, e.g., fire, drought, flooding)	inhabited stream length (or connected suitable habitat)	<6 mi	6–19 mi	20–49 mi	≥ 50 mi		This indicator is based on guidelines developed for 2 other races of *O. clarkii*: *O. c. utah* and *O. c. pleuriticus*.
genetic purity (absence of introgressed genes from hybridization with introduced species)	tested (electro-phoresis or DNA) % YCT[2] genetic material in focal pop.	<80% (i.e., >20% introgression)	80–89% (i.e., 11–20% introgression)	90–99% (i.e., 1–10% introgression)	>99% (i.e., <1% introgression)	UDWR (2000)	Use of both allozymes and nuclear DNA analyses (e.g., microsatellites, RAPDs, PINEs) is acceptable (UDWR 2000). See UDWR (2000) for introgression formula and genetic sample size formula.
habitat (juvenile and adult)	watershed area	«9 mi^2	<9 mi^2	≥9 mi^2	»9 mi^2		This indicator is based on guidelines developed for 2 other races of *O. clarkii*: *O. c. utah* and *O. c. pleuriticus*.
adult, juvenile, and fry habitat (growth and survival)	average maximum water temper-ature during the warmest period of the year*	<4 °C or >20 °C	4–6.5 °C or 19–20 °C	6.5–12 °C or 14– 19 °C	12–14 °C	Binns and Eiserman (1979), Hickman and Raleigh (1982)	In lacustrine habitats, use temperature strata nearest optimum (13 °C) in dissolved oxygen zones >3 mg/L (Hickman and Raleigh 1982).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat (embryo survival and development)	average maximum water temperature during embryo development	<3.5 °C or >16 °C	3.5–4.5 °C or 14.5–16 °C	4.5–7 °C or 12–14.5 °C	7–12 °C	Hickman and Raleigh (1982)	
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature ≤15 °C)	<4.3 mg/L	4.3–5.1 mg/L	5.1–7 mg/L	>7 mg/L	Hickman and Raleigh (1982)	
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature >15 °C)	<6.3 mg/L	6.3–7.2 mg/L	7.2–9 mg/L	>9 mg/L	Hickman and Raleigh (1982)	
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for ≤5 m stream width)	<15 cm	15–20 cm	20–30 cm	≥30 cm	Hickman and Raleigh (1982)	for ≤5 m stream width

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for >5 m stream width)	<26 cm	26–32.5 cm	32.5–45 cm	≥45 cm	Hickman and Raleigh (1982)	for >5 m stream width
spawning habitat (embryo survival)	average water velocity over spawning areas during embryo development	<20 cm/s or >75 cm/s	20–25 cm/s or 67.5–75 cm/s	25–30 cm/s or 60–67.5 cm/s	30–60 cm/s	Hickman and Raleigh (1982)	
habitat (useable cover for adults)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period*	<6%	6–12%	12–25%	>25%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas.
habitat (useable cover for juveniles)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period	<3%	3–7%	7–15%	>15%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas.
spawning habitat	average substrate particle size (diameter) in spawning areas	<0.3 cm or >8 cm	0.3–0.75 cm or 7.5–8 cm	0.75–1.5 cm or 6–7.5 cm	1.5–6 cm	Hickman and Raleigh (1982)	Sample all potential spawning areas. Size of spawning-area gravel is correlated with or determines water exchange rates, proper redd construction, and fry survival.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
winter habitat and escape cover for fry and small juveniles	% of substrate particles that are 10–40 cm diameter	<5%	5–7.5%	7.5–10%	≥10%	Hickman and Raleigh (1982)	
food production (aquatic insects)	dominant (≥50%) substrate type in riffle-run areas*	rubble and gravel «25%; almost entirely fines, bedrock, or large boulders	rubble and gravel ≤25%; fines, bedrock or large boulders predominate	rubble, gravel, boulders, and fines present in approx. equal amounts, or predominant-ly gravel; aquatic vegetation may or may not be present	mainly rubble or small boulders, or aquatic vegetation in areas with springs; less gravel, large boulders, or bedrock	Hickman and Raleigh (1982)	
habitat	pools as % of stream (relative to riffle-runs) during late summer low flow*	<7.5%	7.5–17.5% or 87.5–100%	17.5–40% or 60–87.5%	40–60%	Hickman and Raleigh (1982)	
organic input to aquatic habitat (nutrients)	stream-bank vegetation, using index ∑ = 2(%shrubs) + 1.5(%grasses) + 1(%trees) + 0(%bare ground)	<45%	45–100%	100–140%	>140%	Hickman and Raleigh (1982)	Indicator is for streams ≤50 m wide. Shrubs provide best input, followed by grasses and forbs, then trees (as shown in formula for index).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
erosion control	average % rooted vegetation and stable rocky ground cover along stream-bank during summer*	<32.5%	32.5–50%	50–75%	75–100%	Hickman and Raleigh (1982)	
water chemistry (YCT survival)	annual maximum and minimum pH	<5.75 or >9	5.75–6 or 8.75–9	6–6.5 or 8–8.75	6.5–8	Hickman and Raleigh (1982)	For lacustrine situations, measure pH in zone of best combination of dissolved oxygen and temperature.
water chemistry	nitrate nitrogen concentration	<0.01 or >2.0 mg/L	0.01–0.09 or 0.51–2.0 mg/L	0.10–0.14 or 0.26–0.50 mg/L	0.15–0.25 mg/L	Binns and Eiserman (1979)	
flow regime	average daily base flow (during late summer low flow)/ average annual daily flow*	<25%	25–37.5%	37.5–50%	>50%	Hickman and Raleigh (1982), Binns and Eiserman (1979)	Flows affect quantity and quality of pools, in-stream cover, and water quality.
stream habitat, cover	pool abundance and quality during late growing season low flow period (see pool classification[3])*	almost entirely 3rd class pools («10% of stream habitat is 1st class pools and «50% is 2nd class pools)[3]	<10% of stream habitat is 1st class pools and <50% is 2nd class pools[3]	10–30% of stream habitat is 1st class pools or ≥50% is 2nd class pools[3]	≥30% of stream habitat is 1st class pools[3]	Hickman and Raleigh (1982)	See footnote 3 for descriptions of pool classes.
riffle-run habitat (food sources)	% fines (<3 mm) in riffle-run areas during average summer flows	>40%	30–40%	10–30%	<10%	Hickman and Raleigh (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat (embryos and fry survival)	% fines (<3 mm) in substrate of spawning areas during average summer flows	>20%	15–20%	5–15%	<5%	Hickman and Raleigh (1982)	
optimal water temperatures and photosynthetic rates	stream area shaded between 1000 and 1400 hrs (see comments)	<15% or >97.5%	15–30% or 90–97.5%	30–50% or 75–90%	50–75%	Hickman and Raleigh (1982)	not applicable for streams >50 m wide or for cold streams (<18 °C)
disease risk	presence of significant disease or pathogens in stream or watershed	pathogens present in stream segment with focal pop. (whether or not focal pop. has tested positive)	pathogens known in same stream or drainage ≤10 km away, no barriers exist between infected pop. and focal pop., but pathogens not yet found in same stream segment as focal pop.	pathogens known in same stream or drainage but >10 km away or ≤10 km where existing barriers exist but may be at risk of failure; stocking requires fish health screening and pathogen-free clearance	pathogens absent or unknown, no stocking occurs, barrier provides complete blockage to upstream movement of fish from other pops.	various sources	Examples of diseases that are serious threats to population health include whirling disease, furunculosis, and infectious pancreatic necrosis virus.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization risk	introduced hybridizing taxa (other cutthroat trout sspp. or rainbow trout)	sympatric with YCT in same stream segment	in same stream or drainage ≤10 km (6 mi) from YCT pop. and no barriers exist	in same stream or drainage >10 km (6 mi) from YCT pop., but not in same stream segment as YCT, or ≤10 km (6 mi) from YCT pop. and barriers exist but may be at risk of failure	barrier(s) provide complete blockage to upstream fish movement and introduced taxa cannot reach YCT pop.	various sources including Varley and Gresswell (1988), Thurow et al. (1988), May (1996), Varley and Gresswell (1988)	"The [YCT] subspecies is estimated to exist in a genetically pure form in about 85% of the historic lake habitat but only in about 10% of the estimated original stream range" (Varley and Gresswell 1988).
competition and predation	introduced fish taxa including other trout taxa (e.g., brown trout, brook trout, lake trout, rainbow trout) and sport fish taxa	present, abundant	present in moderate numbers	present but very rare	absent	various sources including Thurow et al. (1988), May (1996)	Regulations that allow higher take of non-native trouts can benefit YCT (Thurow et al. 1988).
disturbance, degradation of habitat (stream bank sloughing, channel instability, erosion, sedimentation)	livestock	present in large numbers	present in moderate numbers	present in low numbers	absent	Thurow et al. (1988)	
stream sedimentation from erosion	agriculture (farming)	existing in vicinity	—	—	none in vicinity	Thurow et al. (1988)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation of habitat	eradication of riparian vegetation (e.g., herbicides or other agents)	existing or planned	—	—	none	Varley and Gresswell (1988), Thurow et al. (1988)	
migration, spawning, water quality, dewatering, habitat	construction of dams and reservoirs, failures of dams, water diversions	existing or planned	—	—	none	Varley and Gresswell (1988), Thurow et al. (1988)	"Of all possible enhancement activities, maintenance of adequate streamflow may be the most essential but the most difficult to attain" (Varley and Gresswell 1988).
sedimentation	mineral extraction	existing or planned	—	—	none	Thurow et al. (1988)	
reduced flows, blockage of passages, habitat degradation	hydro-electric energy development	existing or planned	—	—	none	Thurow et al. (1988)	
population decline	exploitation (angling)[4]	unlimited (inadequate regulations, enforcement, or compliance)	limited (partially adequate regulations, enforcement, and compliance)	very limited (adequate regulations and moderately good enforcement and compliance)	none (adequate regulations[4], enforcement, and compliance)	Varley and Gresswell (1988), Thurow et al. (1988), May (1986)	"Cutthroat trout may be more vulnerable to angling than any other trout or char. Consequently, exploitation can be a significant cause for the decline in populations accessible to anglers. . . . Angler exploitation and selective angling for large, old Yellowstone cutthroat trout has contributed to the decline of native cutthroat trout in the upper Snake River basin" (Thurow et al. 1988). See footnote 4.

[1]Various populations of the Yellowstone subspecies of the cutthroat trout are (1) resident (residing in 1 stream or a network of smaller streams for entire life), (2) fluvial (residing primarily in a larger stream or river but migrating to streams to spawn), and (3) adfluvial (residing primarily in a lake environment but migrating to riverine environments to spawn) (Varley and Gresswell 1988, Thurow et al. 1988). This table is mainly for riverine (i.e., resident and fluvial) populations. Although lacustrine (i.e., adfluvial) populations exist, most of this table is not applicable to such populations. **N.B.: To be viable and reproducing, lacustrine populations**

***must* have access to suitable streams for spawning.** "Populations" in isolated lakes that are artificially maintained by routine stocking are not naturally sustainable and viable but are non-reproducing captives and are not addressed in this table.

[2]YCT = Yellowstone cutthroat trout.

[3]1st class pools: large, deep, with large low-velocity areas, >30% of bottom obscured due to depth, surface turbulence, or presence of logs, debris, boulders, or overhanging banks or vegetation; or, depth ≥1.5 m in streams ≤5 m wide or ≥2 m in streams >5 m wide. 2nd class pools: moderate size and depth, with moderately large low-velocity areas, 5–30% of bottom obscured; these are typically large eddies behind boulders or moderately deep low-velocity areas beneath overhanging banks or vegetation. 3rd class pools: small and/or shallow, little low-velocity area, cover absent or only shade, surface turbulence, or very limited structure (e.g., debris, boulders, bank, or vegetation); these are typically wide, shallow areas of stream or small eddies behind boulders; nearly entire bottom is visible.

[4]"Yellowstone cutthroat trout have responded positively to catch-and-release-only (no kill) regulations in all cases. A two-fish, 330-mm maximum-size limit provided similar results on Yellowstone Lake . . ., but a rapid decline in landing rate and mean length were noted in Riddle Lake under the same regulation" (Varley and Gresswell 1988).

*Most important indicators.

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Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of adults (≥15 cm)	≤50	51–500	501–2,000	>2,000	Rieman et al. (1993) and other sources	
adult, juvenile, and fry habitat (growth and survival)	average maximum water temperature during the warmest period of the year*	<4 °C or >22 °C	4–6.5 °C or 20–22 °C	6.5–12 °C or 14– 20 °C	12–14 °C	Hickman and Raleigh (1982), Coffin and Cowan (1995)	In lacustrine habitats, use temperature strata nearest optimum (13 °C) in dissolved oxygen zones >3 mg/L (Hickman and Raleigh 1982).
spawning habitat (embryo survival and development)	average maximum water temperature during embryo development	<3.5 °C or >16 °C	3.5–4.5 °C or 14.5–16 °C	4.5–7 °C or 12–14.5 °C	7–12 °C	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature ≤15 °C)	<4.3 mg/L	4.3–5.1 mg/L	5.1–7 mg/L	>7 mg/L	Hickman and Raleigh (1982)	"For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l" (Hickman and Raleigh 1982).
habitat (adult, juvenile, fry, and especially embryo)	average minimum dissolved oxygen during late growing season low water period and during embryo development (at water temperature >15 °C)	<6.3 mg/L	6.3–7.2 mg/L	7.2–9 mg/L	>9 mg/L	Hickman and Raleigh (1982)	"For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l" (Hickman and Raleigh 1982).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for ≤5 m stream width)	<15 cm	15–20 cm	20–30 cm	≥30 cm	Hickman and Raleigh (1982)	for ≤5 m stream width
habitat (water depth allowing movement of adults and correlated with no. of pools and amount of in-stream cover)	average thalweg depth during late growing season low water period (for >5 m stream width)	<26 cm	26–32.5 cm	32.5–45 cm	≥45 cm	Hickman and Raleigh (1982)	for >5 m stream width
spawning habitat (embryo survival)	average water velocity over spawning areas during embryo development	<20 cm/s or >75 cm/s	20–25 cm/s or 67.5–75 cm/s	25–30 cm/s or 60–67.5 cm/s	30–60 cm/s	Hickman and Raleigh (1982)	
habitat (useable cover for adults)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period*	<6%	6–12%	12–25%	>25%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas.
habitat (useable cover for juveniles)	% of stream that is ≥15 cm deep and has ≤15 cm/s velocity during late growing season low water period	<3%	3–7%	7–15%	>15%	Hickman and Raleigh (1982)	Useable cover is associated with the depths and velocities indicated, which tend to exist in pool rather than riffle areas.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat	average substrate particle size (diameter) in spawning areas	<0.3 cm or >8 cm	0.3–0.75 cm or 7.5–8 cm	0.75–1.5 cm or 6–7.5 cm	1.5–6 cm	Hickman and Raleigh (1982)	Sample all potential spawning areas. Size of spawning-area gravel is correlated with or determines water exchange rates, proper redd construction, and fry survival.
winter habitat and escape cover for fry and small juveniles	% of substrate particles that are 10–40 cm diameter	<5%	5–7.5%	7.5–10%	≥10%	Hickman and Raleigh (1982)	
food production (aquatic insects)	dominant (≥50%) substrate type in riffle-run areas*	rubble and gravel «25%; almost entirely fines, bedrock, or large boulders	rubble and gravel ≤25%; fines, bedrock or large boulders predominate	rubble, gravel, boulders, and fines present in approx. equal amounts, or predominant-ly gravel; aquatic vegetation may or may not be present	mainly rubble or small boulders, or aquatic vegetation in areas with springs; less gravel, large boulders, or bedrock	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
habitat	pools as % of stream (relative to riffle-runs) during late summer low flow*	<7.5%	7.5–17.5% or 87.5–100%	17.5–40% or 60–87.5%	40–60%	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
organic input to aquatic habitat (nutrients)	stream-bank vegetation, using index ∑ = 2(%shrubs) + 1.5(%grasses) + 1(%trees) + 0(%bare ground)	<45%	45–100%	100–140%	>140%	Hickman and Raleigh (1982), Coffin and Cowan (1995)	Indicator is for streams ≤50 m. Shrubs provide best input, followed by grasses and forbs, then trees (as shown in formula for index).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
erosion control	average % rooted vegetation and stable rocky ground cover along stream-bank during summer*	<32.5%	32.5–50%	50–75%	75–100%	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
water chemistry (LCT[2] survival)	annual maximum and minimum pH	<5.75 or >9.5	5.75–6 or 9.25–9.5	6–6.5 or 8.5–9.25	6.5–8.5	Hickman and Raleigh (1982), Coffin and Cowan (1995)	For lacustrine situations, measure pH in zone of best combination of dissolved oxygen and temperature.
flow regime	average daily base flow (during late summer low flow)/ average annual daily flow*	<25%	25–37.5%	37.5–50%	>50%	Hickman and Raleigh (1982)	Flows affect quantity and quality of pools, in-stream cover, and water quality.
stream habitat	pool abundance and quality during late growing season low flow period (see pool classification[3])	almost entirely 3rd class pools («10% of stream habitat is 1st class pools and «50% is 2nd class pools)[3]	<10% of stream habitat is 1st class pools and <50% is 2nd class pools[3]	10–30% of stream habitat is 1st class pools or ≥50% is 2nd class pools[3]	≥30% of stream habitat is 1st class pools[3]	Hickman and Raleigh (1982)	See footnote 3 for descriptions of pool classes.
riffle-run habitat (food sources)	% fines (<3 mm) in riffle-run areas during average summer flows*	>40%	30–40%	10–30%	<10%	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
spawning habitat (embryos and fry survival)	% fines (<3 mm) in substrate of spawning areas during average summer flows	>20%	15–20%	5–15%	<5%	Hickman and Raleigh (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
optimal water temperatures and photosynthetic rates	stream area shaded between 1000 and 1400 hrs (see comments)	<15% or >97.5%	15–30% or 90–97.5%	30–50% or 75–90%	50–75%	Hickman and Raleigh (1982)	not applicable for streams >50 m wide or for cold streams (<18 °C)
spawning (lacustrine populations)	access to riverine tributaries with suitable stream discharges and water quality	absent	—	—	present	Hickman and Raleigh (1982), Coffin and Cowan (1995)	
disease risk	presence of significant disease or pathogens in stream or watershed	pathogens present in stream segment with focal pop. (whether or not focal pop. has tested positive)	pathogens known in same stream or drainage ≤10 km away, no barriers exist between infected pop. and focal pop., but pathogens not yet found in same stream segment as focal pop.	pathogens known in same stream or drainage but >10 km away or ≤10 km where existing barriers exist but may be at risk of failure; stocking requires fish health screening and pathogen-free clearance	pathogens absent or unknown, no stocking occurs, barrier provides complete blockage to upstream movement of fish from other pops.	various sources	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization risk	introduced hybridizing taxa (other cutthroat trout sspp. or rainbow trout)	sympatric with LCT[2] in same stream segment	in same stream or drainage ≤10 km (6 mi) from LCT[2] pop. and no barriers exist	in same stream or drainage >10 km (6 mi) from LCT[2] pop., but not in same stream segment as LCT, or ≤10 km (6 mi) from LCT pop. and barriers exist but may be at risk of failure	barrier(s) provide complete blockage to upstream fish movement and introduced taxa cannot reach LCT[2] pop.	various sources including Coffin and Cowan (1995)	
competition and predation	introduced fish taxa including other trout taxa (e.g., brown trout, brook trout, lake trout, rainbow trout) and sport fish taxa	present, abundant	present in moderate numbers	present but very rare	absent	Coffin and Cowan (1995) and other sources	
disturbance, degradation	livestock	present in large numbers	present in moderate numbers	present in low numbers	absent	various sources (e.g., Coffin and Cowan 1995)	

[1]The Lahontan subspecies of the cutthroat trout appears to have the broadest ecological tolerances of any of the cutthroat races. Under natural conditions (i.e., historically) it inhabited large terminal alkaline lakes, small oligotrophic alpine lakes, slow meandering low-gradient rivers, moderate-gradient montane rivers, and small headwater tributary streams. Among freshwater salmonids, it is able to tolerate remarkably high alkalinity, total dissolved solids, and salinity and remarkably high temperatures and daily temperature fluctuations. This table is mainly for riverine (fluvial) populations. Although many lacustrine populations are known, much of this table is not applicable to such populations. **N.B.: To be viable and reproducing, lacustrine populations *must* have access to suitable streams for spawning.** Coffin and Cowan (1995, p 38) commented that the habitat suitability index models of Hickman and Raleigh (1982) may not apply to many habitats occupied by this subspecies of the cutthroat trout; ironically, they then (Coffin and Cowan 1995, p 39–40) summarized the models of Hickman and Raleigh (1982), which they "offered as general guidance", and that summary was the most (and practically the only) specific and detailed ecological information contained in their

recovery plan. Coffin and Cowan (1995, p 38) considered the models of Hickman and Raleigh (1982) to define optimal conditions for the Lahontan cutthroat trout but noted that cutthroat trout of this subspecies are able to "thrive under less than optimal conditions" including "habitats inhospitable to brook trout" and "waters high in alkalinity and ion concentrations that are lethal to other species of fish". Thus, some of the ratings in this table derived from Hickman and Raleigh (1982) may represent somewhat higher quality conditions than this subspecies actually requires.

[2]LCT = Lahontan cutthroat trout.

[3]1st class pools: large, deep, with large low-velocity areas, >30% of bottom obscured due to depth, surface turbulence, or presence of logs, debris, boulders, or overhanging banks or vegetation; or, depth ≥1.5 m in streams ≤5 m wide or ≥2 m in streams >5 m wide. 2nd class pools: moderate size and depth, with moderately large low-velocity areas, 5–30% of bottom obscured; these are typically large eddies behind boulders or moderately deep low-velocity areas beneath overhanging banks or vegetation. 3rd class pools: small and/or shallow, little low-velocity area, cover absent or only shade, surface turbulence, or very limited structure (e.g., debris, boulders, bank, or vegetation); these are typically wide, shallow areas of stream or small eddies behind boulders; nearly entire bottom is visible.

*Most important indicators.

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Bonneville whitefish (*Prosopium spilonotus*)[1,2]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	type of water body*	other: shallow lakes, lotic waters (e.g., rivers, streams)	—	—	very deep lake(s)	various sources including Sigler and Sigler (1996)	The only inhabited water body is a very deep, cold, infertile (oligotrophic) lake.
habitat, life history, foraging, reproduction	variety of water depths*	unvaried, uniform, lacking shallows or medium depths (5–35 m)	—	—	varied, including shallows and medium depths (5–35 m)	various sources including White (1974)[2], Sigler and Sigler (1996), Tolentino and Thompson (2004), Kennedy (2005)	"Bonneville whitefish diet indicate [*sic*] that they are wide ranging and feed part of the time in shallow water, more so in winter than in summer. . . . Spawning takes place along shore and over rocky, shallow areas or sandy points . . . . Bonneville whitefish frequent the 40- to 100-ft (12.2- to 30.5-m) layer of water most of the time, but they may be much deeper. Adults are in shallow water more often than the young" (Sigler and Sigler 1996). Tolentino and Thompson (2004), pooling 3 ice-free sample periods, captured 96% of this species at depths of 5–35 m. Kennedy (2005) found that in spring and summer *P. spilonotus* inhabited mainly the shallower depths, 5–30 m.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning[3]	water depth*	<1 m or >14 m	—	—	1–14 m	White (1974)[2], Sigler and Sigler (1996)	
spawning[3]	substrate[4,*]	other (e.g., silt, marl, shells, vegetation)	sand (uncertain, see Comments)	—	rock rubble[4]	White (1974)[2], Sigler and Sigler (1996), Albrecht (2004)[4]	White (1974) and Sigler and Sigler (1996) considered sand to be a suitable spawning substrate. The work of Albrecht (2005) showed that rock was by far the preferred and the most suitable for spawning of the substrates that he considered; unfortunately Albrecht did not evaluate sand as a spawning substrate.
spawning habitat, recruitment (oviposition, survival of eggs, larvae, and juveniles)	surface elevation of Bear Lake[5,*] (water management)	<5,911 ft	5,915–5,911 ft	5,919–5,915 ft	5,923 (full pool)–5,919 ft	Albrecht (2004, Figures 10 and 11)[5]	The higher the water level in Bear Lake is, the greater the amount of rocky spawning habitat that is available.[5]
survival, reproduction	degradation of water quality (e.g., from fertilizers, pesticides)	occurring	—	—	none	Sigler and Sigler (1996)	"As with other Bear Lake coldwater fishes, the primary requisite for their [i.e., Bonneville whitefish's] continued welfare is maintenance of an optimum water quality" (Sigler and Sigler 1996).
predation	stocked piscivorous sport fishes (e.g., lake trout and cutthroat trout)[6]	abundant	fairly common	scarce	none	Kennedy (2005)[6]	The importance of this indicator is uncertain.[6]

[1]This species is strictly endemic to Bear Lake (Rich County, Utah, and Bear Lake County, Idaho), although it may have occurred in Pleistocene Lake Bonneville. There exists unresolved controversy as to whether *P. spilonotus* is a single species or 2 species.[2] Several studies have attempted to resolve this question, but their results have been conflicting or in some cases ambiguous. A name was proposed for the putative second species, "*Prosopium nannomaculatum*", but this name is not only invalid, being a *nomen nudum* and thus a violation of the International Code of Zoological Nomenclature, but is also both poorly formed (should have been "*nano-*" not "*nanno-*) and of incorrect gender (should have been "*-maculatus*" not "*-maculatum*"). The properly formed name, of correct gender, would have been "*nanomaculatus*", though this still would have been a *nomen nudum* and thus invalid.

[2]White (1974) asserted that *P. spilonotus* is actually 2 species, and he proposed the *nomen nudum* "*Prosopium nannomaculatum*" for 1 of them. He distinguished these 2 putative species both morphologically and ecologically. However, the validity of the 2nd species has not been unambiguously confirmed, and only 1 species is currently recognized by ichthyologists. His ecological data for the 2 putative species have therefore been combined here.

[3]Times and water temperatures for spawning of *P. spilonotus* reported by White (1974)[2] and by Sigler and Sigler (1996) do not agree. White (1974) reported spawning from late November to late December at temperatures ranging 2–5 °C (35.6–41 °C). However, Sigler and Sigler (1996) wrote: "Spawning takes place . . . from mid-February to early March . . . . Temperature preference for spawning appears to be 45°F (7.2°C)." (Interestingly, W. F. Sigler was on the committee that approved White's 1974 dissertation.) White's (1974) work was original, based on field data that he collected; Sigler and Sigler's (1996) is a secondary work, but they did not cite a source for their information on spawning of *P. spilonotus*. Since there is no overlap of either time (month) or temperature of spawning stated by these 2 sources, these data have not been incorporated in this table.

[4]Rocky substrates are rare and limited in Bear Lake, representing <1% of available bottom habitat (Albrecht 2004, p 30, citing another source), and they are required, for successful reproduction and recruitment, by all 4 (or 5) of the fish species that are endemic to Bear Lake. Albrecht (2004, p 29) suggested that "potential may exist for in-lake manipulative measures to be undertaken in order to preserve and enhance endemic fish populations by providing rock habitat . . . , particularly at low water lake elevations." He further commented (2004, p 35) that "attention should be directed to preserving and enhancing these important habitat types [i.e., rocky habitats] in Bear Lake . . . ." These management possibilities presumably include not only water management to ensure high lake levels[5] but also artificial addition of rocks or rocklike materials (e.g., scrap concrete) in at least some areas of Bear Lake where rocks are lacking (which is most of the lake).

[5]Bear Lake, although formerly natural, is now managed as a reservoir. Maintaining high water levels, at which there are more submerged rocky areas and thus more suitable rocky spawning habitat, is an important management action (Albrecht 2004, Figures 10 and 11).

[6]Although Sigler and Sigler (1996) considered predation to be insignificant as a factor limiting *P. spilonotus*, Kennedy (2005, p 33) wrote: ". . . [P]iscivorous native Bonneville cutthroat trout and non-native lake trout are stocked into the lake [Bear Lake] every year, which could directly reduce the population size of one or both whitefish species [*P. abyssicola* and *P. spilonotus*] or cause a change in habitat use. A shift in either fish's distribution [within the lake] from . . . these threats may cause overlapping distributions and increased risk of competition and hybridization. Conservation of these fishes depends on conserving the diverse habitat that allows them [to] have different distributions . . . ."

*Most important indicators.

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Bear Lake whitefish (*Prosopium abyssicola*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	type of water body*	other: shallow lakes, lotic waters (e.g., rivers, streams)	—	—	very deep lake(s)	various sources including McConnell et al. (1957), Sigler and Sigler (1996)	The only inhabited water body is a very deep, cold, infertile (oligotrophic) lake. See footnote 1.
habitat, spawning, foraging	water depths*	unvaried, uniform, lacking profundal areas (>150 ft deep)	—	—	50–208 ft (or perhaps deeper, Bear Lake being at least 208 ft deep)	McConnell et al. (1957), White (1974), Sigler and Sigler (1996), Tolentino and Thompson (2004), Kennedy (2005)	Writing of this species, McConnell et al. (1957) commented: " . . . [S]pawning occurs in water from 50 to 100 feet deep . . . . [Stomach contents] suggest a complete dependence on the soft marl bottom in deep water as a source of food." "Bear Lake whitefish are deep-water fish that live near the bottom, rarely frequenting inshore areas, either summer or winter . . ." (Sigler and Sigler (1996). Tolentino and Thompson (2004), pooling 3 ice-free sample periods, captured 92% of this species at depths of 40–60 m (131–197 ft). Kennedy (2005) found that this species in spring and summer inhabits mainly depths of 45–55 m (148–180 ft).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
foraging habitat	substrate*	other (e.g., boulders, sand)	—	—	marl	McConnell et al. (1957), Sigler and Sigler (1996), Tolentino and Thompson (2004)	See comment above.
spawning habitat, recruitment (oviposition, survival of eggs, larvae, and juveniles)	substrate[2,*]	marl, mollusk shells, vegetation	—	—	rock rubble[2]	Albrecht (2004)[2]	White (1974) believed that *P. abyssicola* spawns over silt and marl substrates at 15–28 m (50–90 ft), but the work of Albrecht (2004) showed that this belief was incorrect and instead that rocks are the preferred substrate and the one providing best survival of eggs.
spawning habitat, recruitment (oviposition, survival of eggs, larvae, and juveniles); profundal habitat (foraging, etc.)	surface elevation of Bear Lake[3,*] (water management)	<5,911 ft	5,915–5,911 ft	5,919–5,915 ft	5,923 (full pool)–5,919 ft	Albrecht (2004, Figures 10 and 11), Kennedy (2005)[3]	The higher the water level in Bear Lake is, the greater the amount of rocky spawning habitat and the greater the amount of profundal foraging habitat that is available.[3]
displacement of naturally occurring prey (food)	invasive nonnative benthic invertebrates (e.g., zebra and quagga mussels)	abundant	fairly common	scarce	none	Kennedy (2005)	"Boats from many areas throughout Utah and Idaho are launched daily onto Bear Lake throughout summer. This could lead to non-native benthic invertebrates becoming established thereby changing the prey base that these whitefish [*P. abyssicola*] rely on" (Kennedy 2005, p 33).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	stocked piscivorous sport fishes (e.g., lake trout and cutthroat trout)[4]	abundant	fairly common	scarce	none	Sigler and Sigler (1996), Kennedy (2005)[4]	
survival, reproduction	degradation of water quality (e.g., from fertilizers, pesticides)[5]	occurring	—	—	none	Sigler and Sigler (1996), Kennedy (2005)[5]	

[1]This species is strictly endemic to Bear Lake (on the Utah–Idaho border, Rich County, Utah, and Bear Lake County, Idaho), although it may have occurred in Pleistocene Lake Bonneville.

[2]Rocky substrates are rare and limited in Bear Lake, representing <1% of available bottom habitat (Albrecht 2004, p 30, citing another source), and they are required, for successful reproduction and recruitment, by all 4 (or 5) of the fish species that are endemic to Bear Lake. Albrecht (2004, p 29) suggested that "potential may exist for in-lake manipulative measures to be undertaken in order to preserve and enhance endemic fish populations by providing rock habitat . . . , particularly at low water lake elevations." He further commented (2004, p 35) that "attention should be directed to preserving and enhancing these important habitat types [i.e., rocky habitats] in Bear Lake . . . ." These management possibilities presumably include not only water management to ensure high lake levels[3] but also artificial addition of rocks or rocklike materials (e.g., scrap concrete) in at least some areas of Bear Lake where rocks are lacking (which is most of the lake).

[3]Bear Lake, although formerly natural, is now managed as a reservoir. Maintaining high water levels, at which there are more submerged rocky areas and thus more suitable rocky spawning habitat, is an important management action (Albrecht 2004, Figures 10 and 11). Kennedy (2005, p 29) found that in spring and summer *P. abyssicola* primarily inhabits depths of 45 to 55 m and pointed out that, when the lake is at full pool (282 km^2), the available area at the preferred depths is only 50 km^2. "At 5 m shallower than full pool, which can occur during drought conditions, . . . Bear Lake whitefish would occupy an area of only 30 km^2 in both seasons . . ." (Kennedy (2005, p 29).

[4]Commenting on limiting factors, Sigler and Sigler (1996) wrote: "Bear Lake whitefish appear to be affected only by predation and senility." Their predators include lake trout (nonnative and stocked) and cutthroat trout (native but stocked to increase abundance); Bear Lake whitefish are rarely taken by anglers. Kennedy (2005, p 33) wrote: ". . . [P]iscivorous native Bonneville cutthroat trout and non-native lake trout are stocked into the lake [Bear Lake] every year, which could directly reduce the population size of one or both whitefish species [*P. abyssicola* and *P. spilonotus*] or cause a change in habitat use. A shift in either fish's distribution [within the lake] from . . . these threats may cause overlapping distributions and increased risk of competition and hybridization. Conservation of these fishes depends on conserving the diverse habitat that allows them [to] have different distributions . . . ."

[5]Sigler and Sigler (1996) wrote of this species: "Deterioration of water quality from increased lake productivity or the presence of toxic materials would detrimentally impact this species. However, the lake appears to be less fertile than it was 75 to 80 years ago, and the only potentially toxic material would appear

to be small amounts of fertilizer or pesticides draining off agricultural lands or lakeshore residences." Kennedy (2005, p 33), however, warned: ". . . [I]ncreased nutrient loading [e.g., from run-off of fertilizers] could result in de-oxygenation of the profundal zone and may have severe consequences for profundal Bear Lake whitefish by causing death or immigration into [unsuitable] shallower areas."

*Most important indicators.

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Bonneville cisco (*Prosopium gemmifer*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	estimated no. of individuals see Comments and footnote 2	<0.5 million small (3–5 cm total length) <2 million medium (5–21 cm total length) <0.1 million large (19–26 cm total length)	0.5–1 million small (3–5 cm total length) 2–2.5 million medium (5–21 cm total length) 0.1–0.3 million large (19–26 cm total length)	1–2 million small (3–5 cm total length) 2.5–3 million medium (5–21 cm total length) 0.3–0.5 million large (19–26 cm total length)	>2 million small (3–5 cm total length) >3 million (5–21 cm total length) >0.5 million large (19–26 cm total length)	Luecke (1996, Figure 12)[2]	Luecke (1996) found that almost all of the fishes detected by hydroacoustic methods in Bear Lake were *P. gemmifer*: "As in previous years, midwater trawl catches in 1995 indicated that almost all of the acoustic targets used for density estimates were Bonneville cisco."[2] (86.7% of fishes captured by trawling were *P. gemmifer*.) Note that there is overlap of total lengths of the medium and large size classes reported; also the medium size class was variously reported by Luecke (1996) as 5–21 cm and as 5–22 cm total length.
population	estimated biomass (kg/ha) of population (pelagic and benthic parts of lake combined)	<2.4 kg/ha	2.4–4.2 kg/ha	4.2–6.0 kg/ha	>6.0 kg/ha	Luecke (1996, Figure 15)	
successful reproduction and recruitment	presence and abundance of all size classes (cohorts), small (3–5 cm tot. l.), medium (5–21 cm tot. l.), and large (19–26 cm tot. l.)	more than 1 size class (age cohort) extremely scarce or missing	1 size class (age cohort) extremely scarce (or missing)	all size classes (age cohorts) present but 1 or more under-represented	all size classes (age cohorts) present in good numbers	Luecke (1996)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	type of water body*	other: shallow lakes, lotic waters (e.g., rivers, streams)	—	—	very deep lake(s)	various sources including McConnell et al. (1957), Loo et al. (1964), Sigler and Sigler (1996)	Introductions of this species into other deep lakes and reservoirs have been unsuccessful (Sigler and Sigler 1996).[1]
habitat, life history, foraging, reproduction	variety of water depths[3,*]	unvaried, uniform, lacking shallows or very deep areas	—	—	varied, including shallows (littoral, ≤8 m), medium depths (metalimnetic interface, 11–17 m), and very deep areas (profundal, >37 m)	Luecke (1996), Sigler and Sigler (1996)	*P. gemmifer* inhabits and behaviorally utilizes, both daily and annually, waters of various depths, up to and exceeding 55 m (180 ft) (probably even the deepest part of Bear Lake, which is ≥63 m [208 ft] deep).[3] Loo et al. (1964) found: "The Bonneville cisco was concentrated in the 50- and 100-foot zones. This species was seldom found in water less than 50 feet deep; only two per cent of the Bonneville cisco were caught at the 15-foot station."
spawning	water depth*	<0.5 ft or o40 ft	—	—	0.5–40 ft	White (1974), Sigler and Sigler (1996)	
spawning	substrate[3,*]	other (e.g., marl, sand)	—	—	rock rubble[3]	White (1974), Bouwes and Luecke (1997)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning	inshore (i.e., 3–8 ft from shore, 0.5–40 ft deep) water temperatures in January and early February[4,*]	<33 °F or >42 °F	—	33–35 °F or 39–42 °F	36–38 °F	McConnell et al. (1957) citing another source, White (1974), Sigler and Sigler (1996)	
habitat	available water temperatures (year-round)[4,*]	≤32 °F or ≥59 °F	33–37 °F or 58 °F	38–40 °F or 51–57 °F	41–50 °F	McConnell et al. (1957) citing another source, Loo et al. (1964), Sigler and Sigler (1996)	"The temperature preference of the Bonneville cisco was between 38° and 50° F., with the greatest cisco concentration in waters of 41° to 50° F. at a depth of 50 feet or more" (Loo et al. 1964).
predation on eggs	nonnative egg predators (e.g., common carp and yellow perch)	abundant	fairly common	scarce	none	Bouwes and Luecke (1997)	Bouwes and Luecke (1997) found that predation on *P. gemmifer* eggs was very high, and they commented: "Our results imply that reducing populations of egg predators . . . could improve egg survival of Bonneville cisco. Because several egg predators (Bear Lake sculpin, Bonneville whitefish) are endemic to Bear Lake, management of their abundances for conservation of Bonneville cisco would be counterproductive. Reduction of exotic egg predators such as common carp and yellow perch *Perca Flavescens* [*sic*] would be a relevant management activity."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat, recruitment (oviposition, survival of eggs, larvae, and juveniles)	surface elevation of Bear Lake[5,*] (water management)[3]	<5,911 ft	5,915–5,911 ft	5,919–5,915 ft	5,923 (full pool)–5,919 ft	Albrecht (2004, Figures 10 and 11)[5], Bouwes and Luecke (1997)[3]	The higher the water level in Bear Lake is, the greater the amount of rocky spawning habitat that is available.[3,5]
mortality, population depression due to overharvesting (fishing, using dip nets)	summer sex ratio (males: females)	great divergence from 1:1: ν1:1 (or ο1:1, which is unlikely to occur)	moderate divergence from 1:1	near 1:1	1:1	Sigler and Sigler (1996)	"The catch rate by dip netting is three to five males for each female. The males move inshore earlier than the females and remain there throughout the [breeding] season [January–early February], whereas the females move in, spawn, and then return to deep water. . . . If fishing pressure is depressing the numbers markedly, the summer (mixed) population should show a preponderance of females, indicating overfishing" (Sigler and Sigler 1996).

[1]This species is strictly endemic to Bear Lake (on the Utah–Idaho border, Rich County, Utah, and Bear Lake County, Idaho), though it prehistorically also occurred in Pleistocene Lake Bonneville (of which Bear Lake was not a part). Although it has been stocked in Flaming Gorge Reservoir (on the Utah–Wyoming border), Lake Tahoe (on the Nevada–California border), Twin Lakes (Colorado), and some high elevation lakes in South Dakota, no survival resulting from any of these attempts at introduction has been reported (Sigler and Sigler 1996). For about 12–16 days each year this fish is harvested in large numbers by dip net when it spawns near the shore in Bear Lake.

[2]Luecke stated that the medium size class (boldface type in the ratings) detected by hydroacoustic methods "likely encompasses very few fish [acoustic] targets that were not [Bonneville] cisco. . . . [The] smaller fish targets were likely dominated by age-0 [Bonneville] cisco, but may also include age-0 [Bear Lake] sculpin. The larger fish targets likely corresponded to adult [Bonneville] cisco but may also have included other fishes in that size range." Thus the medium size class (in boldface) is considered the best estimate of Bonneville cisco abundance; the small and large size classes, being less certainly this species, are included here only for reference. Total lengths of Bonneville cisco captured by Luecke (1996, Figure 13) in midwater trawls ranged ~1.5–22.5 cm; individuals larger than 21.6 cm total length are rare (Sigler and Sigler 1996).

[3]Rocky substrates are rare and limited in Bear Lake, representing <1% of available bottom habitat (Albrecht 2004, p 30, citing another source), and they are required, for successful reproduction and recruitment, by all 4 (or 5) of the fish species that are endemic to Bear Lake. Albrecht (2004, p 29) suggested that "potential may exist for in-lake manipulative measures to be undertaken in order to preserve and enhance endemic fish populations by providing rock habitat . . . , particularly at low water lake elevations." He further commented (2004, p 35) that "attention should be directed to preserving and enhancing these important habitat types [i.e., rocky habitats] in Bear Lake . . . ." These management possibilities presumably include not only water management to ensure high lake levels[5] but also artificial addition of rocks or rocklike materials (e.g., scrap concrete) in at least some areas of Bear Lake where rocks are lacking (which is most of the lake). Bouwes and Luecke (1997) commented: "Enhancing the amount of course [*sic*: coarse] spawning substrate would likely improve egg deposition and survival of Bonneville cisco. Higher lake levels inundate large areas of cobble substrates and would likely enhance Bonneville cisco recruitment. Modifying water management practices in the Bear Lake basin could increase water levels in the lake and provide for additional spawning and rearing habitat for this endemic species."

[4]"Each year, hundreds of thousands of Bonneville cisco move out of the depths inshore to spawn in water ranging from a few inches to 40 ft (12.2 m). . . . During the breeding season large schools of cisco move inshore, then swim parallel to it at distances of 3 to 8 ft (0.9 to 2.4 m). The distance from shore depends upon the turbulence of the water, the presence of fishermen, and whether or not there is ice cover, which occurs 4 years out of 5. . . . Bonneville cisco spawn at temperatures ranging from 33° to 42°F (0.5° to 5.6°C). . . . Bonneville cisco prefer temperatures less than 58°F (14.4°C). At temperatures lower than this they are widely scattered through the lake. As the water warms in the spring and early summer, they descend into the deeper, colder water. After Bear Lake is stratified, or formed into three temperature layers, the greatest concentration of Bonneville cisco is in the metalimnion, the middle layer of rapidly changing temperature. Although the cisco is generally at depths of 50 to 100 ft (15.2 to 30.4 m) during the summer, they may leave this area of cool water to move into the warm surface waters to feed" (Sigler and Sigler 1996).

[5]Bear Lake, although formerly natural, is now managed as a reservoir. Maintaining high water levels, at which there are more submerged rocky areas and thus more suitable rocky spawning habitat, is an important management action (Albrecht 2004, Figures 10 and 11; Bouwes and Luecke 1997).

*Most important indicators.

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Colorado pikeminnow (*Ptychocheilus lucius*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population (“genetic effective population”), genetic viability, avoidance of genetic drift	no. of individuals (adults)	<2,217	2,217	>2,217	»2,217	Valdez et al. (2002)	Calculations of genetic effective populations are based on assumptions and best guesses.
population (“minimum viable population”), long-term sustainability	no. of individuals (adults)	<2,553	2,553	>2,553	»2,553	Valdez et al. (2002)	Calculations of minimum viable populations are based on assumptions and best guesses.
population (“carrying capacity”)	density (of adults)	<2/km	2/km	3/km	≥4/km	Valdez et al. (2002)	Estimates of up to 14 adults/km have been made.
spawning migrations, drift of larvae	extent of habitats suitable for all life stages (free of dams, impoundments, etc.)*	<20 mi	20–60 mi	60–100 mi	>100 mi	Valdez et al. (2002) and sources cited therein	Average movements of ~32-34 km and round-trip movements of up to 950 km have been reported. “Larvae . . . may drift 50–120 miles downstream to nursery backwaters” (Valdez et al. 2002)
general habitat	water body*	reservoirs	—	medium-sized rivers	large rivers	various sources including Valdez et al. (2002)	
habitat (adult)	April–June (spring) use of macrohabitats by adults	rapids, riffles	fast runs, eddies, pools, shorelines, off-channel flooded gravel pits	slow runs	backwaters	Osmundson et al. (1995), Valdez et al. (2002)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adult)	July–September (summer) use of macrohabitats by adults	shorelines, off-channel flooded gravel pits	rapids, riffles, backwaters	fast runs, eddies, pools	slow runs	Osmundson et al. (1995), Valdez et al. (2002)	
habitat (adult)	October use of macrohabitats by adults	fast runs, rapids, riffles, shorelines, off-channel flooded gravel pits	backwaters, eddies	pools	slow runs	Osmundson et al. (1995), Valdez et al. (2002)	
habitat (adult)	November–February (winter) use of macrohabitats by adults	fast runs, rapids, riffles, eddies, shorelines, off-channel flooded gravel pits	backwaters	slow runs	pools	Osmundson et al. (1995), Valdez et al. (2002)	
habitat (adult)	March use of macrohabitats by adults	rapids, riffles, shorelines, off-channel flooded gravel pits	eddies, fast runs	shorelines	slow runs, pools	Osmundson et al. (1995), Valdez et al. (2002)	
spawning	water temperature*	<16 °C or >24 °C	16–17 °C	18–19 °C or 23–24 °C	20–22 °C	Hamman (1981), Valdez et al. (2002) and sources cited therein	Spawning occurs after peak spring run-off, during June–August.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
egg survival and hatching success	water temperature (see Comments)	<12 °C or »24 °C	12–20 °C	20–21 °C or 23–24 °C	22 °C	Valdez et al. (2002) and sources cited therein	Although Hamman (1981) found that eggs hatched much sooner in warm water (20–21 °C) than in cold water (12–13 °C), no difference in egg survival, hatching success, and fry survival was observed between the 2 water temperatures. However, Valdez et al. (2002) stated: "Hatching success is greatest at 20–24 °C . . . ."
larval and young-of-year survival and development	larval and young-of-year habitat*[,2]	other	—	—	backwaters[2]	Valdez et al. (2002) and sources cited therein	"It is important to note that these backwaters are formed after cessation of spring runoff within the active channel and are not floodplain features. Colorado pikeminnow larvae occupy these in-channel backwaters soon after hatching. They tend to occur in backwaters that are large, warm, deep, (average, about 0.3 m in the Green River), and turbid . . . " (Valdez et al. (2002).[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality (salinity)	total dissolved solids (conductivity)	>4,400 mg/L	2,775–4,400 mg/L	<560 mg/L or 1,150–2,775 mg/L	560–1,150 mg/L	Pimentel and Bulkley (1983)	Fish tested were "yearlings" 2.5–5.0 cm long, and Pimentel and Bulkley (1983) cautioned that ontogenetic changes in preferences could occur. The tested range was 270–7,400 mg/L. The "poor" rating represents avoided concentrations, "very good" represents the preferred, and "fair" and "good" are interpolations. Oil-shale-process waters and dams could greatly increase TDS concentrations in the Colorado River system.
habitat (larvae, <25 mm total length)	water depth	<0.25 ft or >7.30 ft	0.25–0.40 ft or 5.41–7.30 ft	0.40–0.59 ft or 3.33–5.41 ft	0.59–3.33 ft	Valdez et al. (1987)	"The curve set was given a high confidence rating of A [on a scale of A–D] . . . " (Valdez et al. 1987).
habitat (larvae, <25 mm total length)	water velocity	>0.05 ft/s	0.02–0.05 ft/s	0.006–0.02 ft/s	<0.006 ft/s	Valdez et al. (1987)	"The curve set was given a high confidence rating of A [on a scale of A–D] . . . " (Valdez et al. 1987).
habitat (larvae, <25 mm total length)	substrate	clay, gravel, cobble, boulders, bedrock, other	sand	—	silt	Valdez et al. (1987)	"The curve set was given a high confidence rating of A [on a scale of A–D] . . . " (Valdez et al. 1987).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (larvae, <25 mm total length)	river feature	embayments, isolated pools, shorelines, eddies, concavities, pools, riffles (no usage: runs, rapids, gravel pits, other)	—	—	backwaters[2]	Valdez et al. (1987)	"The curve set was given a high confidence rating of A [on a scale of A–D] . . . " (Valdez et al. 1987).
habitat (young-of-year, 25–149 mm total length)	water depth	<0.17 ft or >2.77 ft	0.17–0.23 ft or 1.80–2.77 ft	0.23–0.27 ft or 1.13–1.80 ft	0.27–1.13 ft	Valdez et al. (1987)	"A high confidence rating of A [on a scale of A–D] was applied to the curve set. . . " (Valdez et al. 1987).
overwinter survival of young-of-year[2]	depth of backwaters[2]	<30 cm	30–75 cm	75–120 cm	>120 cm	Valdez et al. (2002)	The "fair" and "good" ratings are interpolations.
habitat (young-of-year, 25–149 mm total length)	water velocity	<0.48 ft/s	0.18–0.48 ft/s	0.04–0.18 ft/s	<0.04 ft/s	Valdez et al. (1987)	"A high confidence rating of A [on a scale of A–D] was applied to the curve set . . . " (Valdez et al. 1987). (The abscissa of Figure 10B in Valdez et al. [1987] is apparently mislabeled, units being 1/3 of their correct values; e.g., "1.0" ft/s should be 3.0 ft/s).
habitat (young-of-year, 25–149 mm total length)	substrate	cobble, gravel, clay, boulders, bedrock, other	sand	—	silt	Valdez et al. (1987)	"A high confidence rating of A [on a scale of A–D] was applied to the curve set. . . " (Valdez et al. 1987).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (young-of-year, 25–149 mm total length)	river feature	isolated pools, embayments, concavities, pools, eddies, shorelines, runs, riffles, rapids, gravel pits, other	—	—	backwaters[2]	Valdez et al. (1987)	"A high confidence rating of A [on a scale of A–D] was applied to the curve set. . . " (Valdez et al. 1987).
habitat (smaller juveniles, 150–299 mm total length)	water depth	<0.41 ft or >10.10 ft	0.41–0.76 ft or 7.20–10.10 ft	0.76–0.82 ft or 4.41–7.20 ft	0.82–4.41 ft	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (smaller juveniles, 150–299 mm total length)	water velocity	>0.59 ft/s	0.23–0.59 ft/s	0.05–0.23 ft/s	<0.05 ft/s	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (smaller juveniles, 150–299 mm total length)	substrate	cobble, boulders, clay, gravel, bedrock, other	—	sand	silt	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (smaller juveniles, 150–299 mm total length)	river feature	pools, isolated pools, embayments, concavities, riffles, rapids, gravel pits, other	runs, eddies	shorelines	backwaters	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (larger juveniles, 300–399 mm total length)	water depth	<0.65 ft or >11.66 ft	0.65–1.19 ft or 8.27–11.66 ft	1.19–1.78 ft or 6.65–8.27 ft	1.78–6.65 ft	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (larger juveniles, 300–399 mm total length)	water velocity	>0.58 ft/s	0.25–0.58 ft/s	0.05–0.25 ft/s	<0.05 ft/s	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (larger juveniles, 300–399 mm total length)	substrate	gravel, bedrock, clay, other	cobble, boulders	—	sand, silt	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (larger juveniles, 300–399 mm total length)	river feature	pools, isolated pools, embayments, concavities, riffles, rapids, gravel pits, other	runs	backwaters, eddies	shorelines	Valdez et al. (1987)	"A low confidence rating of C+ was applied [to this curve set] . . . " (Valdez et al. 1987).
habitat (adults, ≥400 mm total length)	water depth[3]	<0.69 ft or >12.32 ft	0.69–1.23 ft or 9.56–12.32 ft	1.23–1.66 ft or 6.55–9.56 ft	1.66–6.55 ft	Valdez et al. (1987)	**N.B.**: Use with caution. See footnote 3. Disagreement between the averages shown here and the HSI curve sets for particular rivers and seasons (Valdez et al. 1987) is least to the far right ("very good") and becomes increasingly greater the farther to the left (i.e., greatest for "poor").
habitat (adults, ≥400 mm total length)	water velocity[3]	>2.00 ft/s	1.36–2.00 ft/s	0.82–1.36 ft/s	<0.82 ft/s	Valdez et al. (1987)	**N.B.**: Use with caution. See footnote 3. HSI curve sets (Valdez et al. 1987) for this indicator (velocity, adults) are so different that their combination here may not be meaningful.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adults, ≥400 mm total length)	substrate[3]	clay, bedrock, other	gravel, boulders	cobble	silt, sand	Valdez et al. (1987)	**N.B.**: Use with caution. See footnote 3.
habitat (adults, ≥400 mm total length)	river feature[3]	isolated pools, embayments, concavities, rapids, gravel pits, other (April–June: riffles) (other than April–June: backwaters)	pools, runs	shorelines (other than April–June: riffles)	eddies (April–June: backwaters)	Valdez et al. (1987)	**N.B.**: Use with caution. See footnote 3. Seasonally very discordant data are in parentheses.
habitat (spawning—staging)	water depth	<1.57 ft or >14.74 ft	1.57–2.15 ft or 11.64–14.74 ft	2.15–2.95 ft or 8.67–11.64 ft	2.95–8.67 ft	Valdez et al. (1987)	"The curves . . . were applied to the Green and Yampa rivers with a medium confidence rating of B [on a scale of A–D], since the data were gathered from these rivers, . . . [and] were applied to the Colorado River with a very low confidence rating of D, primarily because the data were not collected from that river system."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (spawning—staging)	water velocity	<0.06 ft/s or >3.27 ft/s	0.06–0.13 ft/s or 2.40–3.27 ft/s	0.13–0.22 ft/s or 1.48–2.40 ft/s	0.22–1.48 ft/s	Valdez et al. (1987)	"The curves . . . were applied to the Green and Yampa rivers with a medium confidence rating of B [on a scale of A–D], since the data were gathered from these rivers, . . . [and] were applied to the Colorado River with a very low confidence rating of D, primarily because the data were not collected from that river system."
habitat (spawning—staging)	substrate	clay, bedrock, other	silt, gravel	boulders	sand, cobble	Valdez et al. (1987)	"The curves . . . were applied to the Green and Yampa rivers with a medium confidence rating of B [on a scale of A–D], since the data were gathered from these rivers, . . . [and] were applied to the Colorado River with a very low confidence rating of D, primarily because the data were not collected from that river system."
habitat (spawning—staging)	river feature	isolated pools, backwaters, embayments, concavities, shorelines, riffles, rapids, gravel pits, other	pools, runs	—	eddies	Valdez et al. (1987)	"The curves . . . were applied to the Green and Yampa rivers with a medium confidence rating of B [on a scale of A–D], since the data were gathered from these rivers, . . . [and] were applied to the Colorado River with a very low confidence rating of D, primarily because the data were not collected from that river system."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (spawning— egg deposition)	water depth	<0.88 ft or >4.22 ft	0.88–1.15 ft or 3.59–4.22 ft	1.15–1.37 ft or 2.88–3.59 ft	1.37–2.88 ft	Valdez et al. (1987)	Valdez et al. (1987) gave this HSI curve a low confidence rating of C (on a scale of A–D) for the Green and Yampa rivers and a very low rating of D for the Colorado River.
habitat (spawning— egg deposition)	water velocity	<0.89 ft/s or >4.82 ft/s	0.89–1.23 ft/s or 4.14–4.82 ft/s	1.23–1.57 ft/s or 3.40–4.14 ft/s	1.57–3.40 ft/s	Valdez et al. (1987)	Valdez et al. (1987) gave this HSI curve a low confidence rating of C (on a scale of A–D) for the Green and Yampa rivers and a very low rating of D for the Colorado River.
habitat (spawning— egg deposition)	substrate	clay, silt, sand, bedrock, other	boulders	gravel	cobble	Valdez et al. (1987)	Valdez et al. (1987) gave this HSI curve a low confidence rating of C (on a scale of A–D) for the Green and Yampa rivers and a very low rating of D for the Colorado River.
habitat (spawning— egg deposition)	river feature	isolated pools, backwaters, embayments, concavities, pools, eddies, shorelines, rapids, gravel pits, other	cobble	—	riffles	Valdez et al. (1987)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation on juveniles (and larvae and eggs)	nonnative fishes (e.g., basses, catfishes, n. pike, carp, shiners)*	abundant	common	scarce	absent	Valdez et al. (2002) and sources cited therein	"Adult red shiner are known predators of larval native fishes of the upper basin . . ., and predation by nonnative fishes such as red shiner may influence within-year-class recruitment of Colorado pikeminnow. . . . Channel catfish and northern pike have been identified as the principal nonnative threats to subadult and adult Colorado pikeminnow in the upper basin" (Valdez et al. 2002).
parasitism (poor condition, lowered fecundity, death)	Asian tapeworm (and other tape-worms), parasitic copepod	present at high infestation rates in this or other fish species	present at moderate infestation rates in this or other fish species	present at low infestation rates in this or other fish species	absent in this or other fish species, including nonnative fishes	Valdez et al. (2002) and sources cited therein	Tapeworms have been reported in as many as 80% of *P. lucius* examined, and "[t]he parasitic copepod (*Lernaea cypinacea*) is common in Colorado pikeminnow" (Valdez et al .2002). It is believed that the Asian tapeworm and the copepod were introduced into the Colorado River system via nonnative fishes.
habitat, successful reproduction, recruitment, etc.	alteration of flow regimes (e.g., dams)*	present in immediate vicinity	—	—	none for ≥240 mi upstream or ≥120 mi downstream	Valdez et al. (2002)	Tailwaters for long distances below dams (e.g., Flaming Gorge, Glen Canyon) are too cold for reproduction, and, of the fishes endemic to the Colorado River system, this species has the highest thermal requirements.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (water quality and quantity, etc.)	resource extraction (oil, gas, minerals), power plants (e.g., nuclear)	existing or planned in region	—	—	none in region	Jacobsen (1982)	

[1]The Colorado pikeminnow (previously known as the Colorado squawfish) formerly was abundant in the larger rivers throughout the Colorado River system of Wyoming, Utah, Colorado, New Mexico, Arizona, California, and extreme northwestern México and was the top-level predator naturally occurring in the system. It survives in the upper Colorado River basin of Utah and Colorado, perhaps into New Mexico in the San Juan River (but with limited, if any, reproduction and recruitment in that river), and it has been reintroduced in Arizona, where there are small numbers in the Verde River (with no successful reproduction and recruitment, presumably due mainly to predation by the introduced flathead catfish, *Pylodictis olivaris*). This species is large (formerly having attained lengths of ~6 ft and weights of ~100 lbs) and engages in long-distance spawning migrations and other movements (100 mi or more).

[2]"After hatching and emerging from the spawning substrate, Colorado pikeminnow larvae drift downstream to backwaters in sandy, alluvial regions, where they remain through most of the first year of life . . . . Backwaters and the physical factors that create them are vital to the successful recruitment of early life stages of Colorado pikeminnow . . . . [A] particular type of backwater is preferred by Colorado pikeminnow larvae and juveniles. Such backwaters are created when a secondary channel is cut off at the upper end, but remains connected to the river at the downstream end. These chute channels are deep and may persist even when discharge levels change dramatically" (Valdez et al. 2002).

[3]Valdez et al (1987) presented 6 sets of habitat suitability index (HSI) curves for adult *P. lucius* (4 rivers, 2 seasons for 2 of these)—with good reason, since variance among these 6 sets of curves is great. **N.B.**: Despite the great variance among the 6 HSI curve sets, these 6 curves sets have been combined (averaged) here, and ratings here represent the averages. **Use these averaged ratings for adult habitat characteristics with caution, or, better, see original curves (i.e., Valdez et al. 1987).**

*Most important indicators.

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bonytail (*Gila elegans*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population (“minimum viable population”), long-term sustainability	no. of individuals (adults)	<4,333	4,333	>4,333	»4,333	Valdez et al. (2002)	Calculations of minimum viable populations are based on assumptions and best guesses.
population (“genetic effective population”), genetic viability, avoidance of genetic drift	no. of individuals (adults)	<3,333	3,333	>3,333	»3,333	Valdez et al. (2002)	Calculations of genetic effective populations are based on assumptions and best guesses.
general habitat	water body*	reservoirs	—	—	large and medium-sized rivers	various sources including Valdez et al. (2002)	
habitat	river characteristics*	—	—	—	deep, swift, rocky, canyon-bound reaches	Valdez et al. (2002)	
habitat	river feature*	areas with swift currents	—	—	pools, eddies, shorelines (without, but occasionally adjacent to, swift currents)	Vanicek and Kramer (1969), Valdez et al. (2002)	**N.B.**: Information for this indicator is based on limited observations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	substrate	—	—	—	silt, cobble, boulders	Vanicek and Kramer (1969), Valdez et al. (2002) and sources cited therein	**N.B.**: Information for this indicator is based on limited observations.
habitat (young)	river feature	swift water	—	—	quiet water, shallow pools	Vanicek and Kramer (1969)	**N.B.**: Information for this indicator is based on limited observations.
habitat (young)	substrate	—	—	gravel	silt, sand	Vanicek and Kramer (1969)	**N.B.**: Information for this indicator is based on limited observations.
habitat	water velocity	high	—	—	low (but sometimes adjacent to areas of swift current)	Vanicek and Kramer (1969), Valdez et al. (2002) and sources cited therein	**N.B.**: Information for this indicator is based on limited observations.
spawning habitat	river feature	—	—	—	shallow pools, eddies	Vanicek and Kramer (1969)	**N.B.**: Information for this indicator is based on limited observations.
spawning habitat	substrate	—	rocky shoals and shorelines (of reservoirs)	—	rubble or boulders covered with silt	Vanicek and Kramer (1969), Valdez et al. (2002)	The "fair" rating perhaps should be "poor", for there is no evidence that breeding has ever been successful in reservoirs.
nursery habitat	river feature	—	—	—	flooded bottomlands	Valdez et al. (2002)	**N.B.**: The information for this indicator is speculative.
spawning	water temperature*	<18 °C	—	—	≥18 °C	Vanicek and Kramer (1969), Valdez et al. (2002) and sources cited therein	Spawning fish have been captured or observed from May to early July.
egg survival, hatching success, and fry survival	water temperature*	<16 °C or »21 °C	16–17 °C	18–19 °C	20 –21 °C	Hamman (1982)	The "good" rating is an interpolation.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality (salinity)	total dissolved solids (conductivity)[3]	<560 mg/L or >6,600 mg/L	560–2,300 mg/L or 5,650–6,600 mg/L	2,300–4,100 mg/L or 4,700–5,650 mg/L	4,100–4,700 mg/L	Pimentel and Bulkley (1983)	Fish tested were young-of-year 2.5–5.0 cm long, and Pimentel and Bulkley (1983) cautioned that ontogenetic changes in preferences could occur. The tested range was 270–7,400 mg/L. The "poor" rating represents avoided concentrations, "very good" represents the preferred, and "fair" and "good" are interpolations.[2]
predation on juveniles, larvae, and eggs; competition	nonnative fishes (e.g., trouts, catfishes, carp, shiners)*	abundant	common	scarce	absent	Valdez et al. (2002) and sources cited therein	Information for this indicator is speculative.
introgressive hybridization	other species of *Gila* (i.e., roundtail chub, *G. robusta*, and humpback chub, *G. cypha*)	abundant	common	rare	absent	Valdez et al. (2002) and sources cited therein	Many hybrids between this and its 2 sympatric congeners have been found, at least in the past. Authors disagree concerning the evolutionary interpretation or implications of such hybridization and its conservational consequences for this species (see Valdez et al. 2002). Since there currently are no reproducing populations of this species in the wild, the conservational importance of such hybridization at this time is debatable. However, if reproducing populations could be reestablished, hybridization could be a serious threat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
parasitism (poor condition, lowered fecundity, death)	Asian tapeworm, parasitic copepod	present at high infestation rates in this or other fish species	present at moderate infestation rates in this or other fish species	present at low infestation rates in this or other fish species	absent in this or other fish species, including nonnative fishes	Valdez et al. (2002) and sources cited therein	Only the parasitic copepod, *Lernea* sp., has been documented from chubs presumed to be this species. The Asian tapeworm is potentially a serious threat.
habitat, successful reproduction, recruitment, etc.	alteration of flow regimes (e.g., dams)*	present in immediate vicinity	—	—	none for ≥100 mi upstream	Valdez et al. (2002)	Tailwaters for long distances below dams (e.g., Flaming Gorge, Glen Canyon) are believed to be too cold for reproduction or even long-term inhabitation.
habitat (water quality and quantity, etc.)	resource extraction (oil, gas, minerals), power plants (e.g., nuclear)	existing or planned in region	—	—	none in region	Jacobsen (1982)	

[1]Formerly the accepted English common name for this species was the bonytail chub, but, as Valdez et al. (2002) have pointed out, this is "a name that has also been applied to other chubs of the Colorado River basin, including the roundtail chub (*Gila robusta*) and the humpback chub (*Gila cypha*)", and "[b]onytail are sometimes confused with the two sympatric species of Colorado River chubs", especially in the case of young fish but also some adults. This species was originally described from specimens reportedly taken from the Zuñi River in New Mexico, which is now dry. It is presumed that the bonytail (*G. elegans*) formerly occurred in the large and medium–sized rivers throughout the Colorado River drainage in Wyoming, Colorado, Utah, New Mexico, Nevada, Arizona, California, and extreme northwestern México. "The species experienced a dramatic, but poorly documented, decline starting in about 1950, following construction of mainstem dams, introduction of nonnative fishes, poor land-use practices, and degraded water quality . . . . Unknown numbers of bonytail were poisoned by the rotenone treatment of the Green River in Flaming Gorge in 1962 . . . . Following closure of the Flaming Gorge Dam in 1963, bonytail were extirpated from about 105 km of the Green River between the dam and the Yampa River, primarily because of previous rotenone poisoning and cold-water releases from dam operations . . . . Bonytail are now rarely found in the Green River and Colorado River subbasins" (Valdez et al. 2002). Although the bonytail is now federally listed as endangered, and hatchery-raised fish have been stocked in a few places (mainly Lake Mohave), " . . . there are no reproducing populations in the wild" (Valdez et al. (2002), the last documented natural reproduction having been in 1961 (in the Green River, Dinosaur National Monument). Thus the bonytail is currently functionally extinct as a naturally occurring species (i.e., its "populations" are not naturally sustainable and viable). Bonytails are long-lived fishes (40+ years), but in the last 40 years (i.e., since 1966) only 117 wild individuals have been captured (Valdez et al. 2002, Table 1) (plus an unknown number in one report and any that may have been taken since 2002) and only in very limited reaches of the Colorado, Green, and lower Yampa rivers, including 3 reservoirs. 70 (60%) of these were from a single reservoir (Lake Mohave). In fact, all bonytails that have been captured in the lower Colorado River basin (i.e., below Lake Powell) since 1974 have been in 2 reservoirs (lakes Mohave and Havasu). "Specimens encountered in reservoirs are believed to be inhabiting their former habitats now inundated by these impoundments" (Valdez et al. 2002).

[2]"Little is known about the specific habitat requirements of bonytail because the species was extirpated from most of its historic range prior to extensive fishery surveys", and "[n]o quantitative data are available for the habitat of this species" (Valdez et al. 2002). Most of what is believed concerning its biology (and much of what is contained in this table) is speculative or hypothetical, being based on fragmentary information and educated guesses. For lack of other or better sources of ecological information concerning the bonytail, a source that Valdez et al. (2002) utilized extensively, and that has been also been used here, is Vanicek and Kramer (1969). It should be noted that Vanicek and Kramer (1969), although they did distinguish bonytails and roundtail chubs, regarded the 2 taxa as subspecies of the same species, which they called the Colorado chub, *Gila robusta*, following the prevailing systematic arrangement of these fishes at the time of their work. Despite their ability to distinguish the 2 taxa (at least those individuals ≥200 mm total length), their detection of differences in growth rates, morphology (proportions), and food habits, and their suggestion that the 2 may be different species, in many cases they did not separate their data and their observations of the ecology of the 2 taxa, even though their observations suggested that the 2 may have been spatially somewhat segregated (e.g., during spawning) within the limited reach of the Green River that they studied.

[3]Pimentel and Bulkley (1983), noting that "[t]he TDS preference of [young-of-year] bonytails (4,100–4,700 mg/liter) . . . was approximately four times greater than present TDS concentrations of the Green and Colorado rivers", speculated: "The high TDS concentration preferred by bonytails may drop as the fish grow older. This TDS preference of the young may be indicative of a habitat preference for warm, shallow backwaters where evaporative loss could greatly increase TDS concentrations."

*Most important indicators.

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humpback chub (*Gila cypha*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population ("genetic effective population"), genetic viability, avoidance of genetic drift	no. of individuals (adults)	<1,667	1,667	>1,667	»1,667	Valdez et al. (2002)	Calculations of genetic effective populations are based on assumptions and best guesses.
population ("minimum viable population"), long-term sustainability	no. of individuals (adults)	<2,067	2,067	>2,067	»2,067	Valdez et al. (2002)	Calculations of minimum viable populations are based on assumptions and best guesses.
population ("carrying capacity")	density (of adults)	<300/km	300–350/km	350–400/km	>400/km	Valdez et al. (2002)	"Based on highest recent preliminary estimates of abundance, [the 3 best] populations support similar densities of adults (i.e., 300–400/km); however, densities in the other populations are substantially lower" (Valdez et al. 2002).
general habitat	water body*	other	—	—	canyon-bound reaches of large rivers (deep water, swift currents, rocky substrates)	Valdez et al. (2002)	See other indicators (river features) below for various life stages. Shallow shoreline habitats and backwaters are required for immature stages.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning	water temperature*	<16 °C or >22 °C	16 °C or 22 °C	17–18 °C or 20–21 °C	19 °C	Valdez et al. (2002)	Typically spawning takes place when water temperatures are 16–22 °C; here it has been assumed that the middle of this range is optimal and that the extremes are marginal, but this assumption may not be accurate. (Compare with hatching success and larval survival temperatures below. It appears that, from spawning to maturation, there is a general increase in favorable temperatures.) Spawning occurs mainly during April–June in the upper Colorado River basin, March–May in the Little Colorado River of the lower basin (Valdez et al. 2002). For long distances below dams, tailwaters are in the "poor" range.
egg survival and hatching success	water temperature*	≤13 °C	14–18 °C	21–22 °C	19–20 °C	Hamman (1982)	Spawning occurs mainly during April–June in the upper Colorado River basin, March–May in the Little Colorado River of the lower basin (Valdez et al. 2002). For long distances below dams, tailwaters are in the "poor" range.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
larval survival	water temperature*	≤13 °C	14–15 °C	16–20 °C	21–22 °C	Hamman (1982)	Spawning occurs mainly during April–June in the upper Colorado River basin, March–May in the Little Colorado River of the lower basin (Valdez et al. 2002). For long distances below dams, tailwaters are in the "poor" range.
juvenile growth	water temperature*	≤14 °C	15–18 °C	19–20 °C	21–25 °C	Valdez et al. (2002) and sources cited therein	Findings from various studies have been combined, and interpolations have been made in the ratings. For long distances below dams, tailwaters are in the "poor" range.
water quality (salinity)	total dissolved solids (conductivity)	>5,100 mg/L	<500 mg/L or 3,800–5,100 mg/L	500–1,000 mg/L or 2,500–3,800 mg/L	1,000–2,500 mg/L	Pimentel and Bulkley (1983)	Fish tested were young-of-the-year, 2.5–5.0 cm long, and Pimentel and Bulkley (1983) cautioned that ontogenetic changes in preferences could occur. The tested range was 270–7,400 mg/L. The "poor" rating represents avoided concentrations, "very good" represents the preferred, and "fair" and "good" are interpolations. Oil-shale-process waters and dams could greatly increase TDS concentrations in the Colorado River system.
habitat (larvae, <21 mm total length)	river feature*	—	—	—	backwaters	Valdez et al. (1990)	**N.B.**: Little is known of larval habitats, and sampling bias may have produced distorted impressions (see Valdez et al. 1990).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (larvae, <21 mm total length)	water depth[2]	<0.13 ft or >7.60 ft	0.13–0.32 or 5.50–7.60 ft	0.32–0.51 ft or 3.28–5.50 ft	0.51–3.28 ft	Valdez et al. (1990)	**N.B.: See footnote 2.**
habitat (larvae, <21 mm total length)	water velocity[2]	>0.51 ft/s	0.19–0.51 ft/s	0.07–0.19 ft/s	<0.07 ft/s	Valdez et al. (1990)	**N.B.: See footnote 2.**
habitat (young of year, 21–74 mm total length)	river feature*	—	—	—	shoreline habitats such as backwaters, eddies	Valdez et al. (1990, 2002)	
habitat (young of year, 21–74 mm total length)	water depth[3]	<0.52 ft or >4.93 ft	0.52–0.88 ft or 4.04–4.93 ft	0.88–1.29 ft or 3.21–4.04 ft	1.29–3.21 ft	Valdez et al. (1990)	"Average depth utilized by this life stage was 2.1 feet with a maximum of 5.1 feet . . . " (Valdez et al. 1990).
habitat (young of year, 21–74 mm total length)	water velocity[3]	>0.50 ft/s	0.25–0.50 ft/s	0.125–0.25 ft/s	<0.125 ft/s	Valdez et al. (1990)	". . . [A]verage velocity was 0.2 feet per second (fps) with a range of 0 to 1.0 fps . . . " (Valdez et al. 1990).
habitat (young of year, 21–74 mm total length)	substrate[3]	gravel, rubble, clay, boulder, bedrock, other	sand	silt	silt	Valdez et al. (1990)	In the "poor" rating, gravel and rubble do provide some habitat for YOYs, but utilization (= suitability) is extremely low, ≤2%, (unlike clay, boulder, bedrock, & other, which are completely unsuitable) (Valdez et al. 1990).
habitat (juveniles, 75–259 mm total length)	river feature*	—	—	—	backwaters, eddies, runs; shorelines with vegetation, talus, and debris fans	Valdez et al. (1990, 2002), Converse et al. (1998)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (juveniles, 75–259 mm total length)	water depth[4]	Green R.: <0.65 or >3.88 ft Colorado R. & Yampa R.: <2.00 or >27.21 ft	Green R.: 0.65–0.97 or 3.34–3.88 ft Colorado R. & Yampa R.: 2.00–3.50 or 22.11–27.21 ft	Green R.: 0.97–1.26 or 2.75–3.34 ft Colorado R. & Yampa R.: 3.50–5.12 or 16.56–22.11 ft	Green R.: 1.26–2.75 ft Colorado R. & Yampa R.: 5.12–16.56 ft	Valdez et al. (1990)	Suitability of water depth for juveniles, as discussed by Valdez et al. (1990), is very different in the different rivers for which data exist. For example, 10 ft would be "poor" in the Green R. but "very good" in the Colorado and Yampa rivers, and 1½ ft would be "poor" in the Colorado and Yampa rivers but "very good" in the Green R.
habitat (juveniles, 75–259 mm total length)	water velocity[4]	<0.006 ft/s or >1.96 ft/s	0.006–0.04 ft/s or 1.39–1.96 ft/s	0.04–0.08 ft/s or 0.81–1.39 ft/s	0.08–0.81 ft/s	Valdez et al. (1990)	
habitat (juveniles, 75–259 mm total length)	substrate[4]	clay, gravel, rubble, other (Green R.: boulders, bedrock)	(Green R.: sand)	(Colorado R. & Yampa R.: silt, sand)	(Colorado R. & Yampa R.: boulders, bedrock) (Green R.: silt)	Valdez et al. (1990)	Locationally discordant data are in parentheses.[4] Notice that boulders and bedrock are rated "very good" in the Colorado R. & Yampa R. but "poor" in the Green R.
habitat (adults, ≥260 mm total length)	river feature*	other	pools	runs, backwaters	deep, offshore habitats, especially large eddies	Valdez et al. (1990, 2002 and sources cited therein)	
habitat (adults, ≥260 mm total length)	water depth[5]	<2.9 ft	2.9–4.0 ft	4.0–5.3 ft	>5.3 ft	Valdez et al. (1990)	
habitat (adults, ≥260 mm total length)	water velocity[5]	>2.96 ft/s	2.08–2.96 ft/s	1.14–2.08 ft/s or 0–0.04 ft/s	0.04–1.14 ft/s	Valdez et al. (1990)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adults, ≥260 mm total length)	substrate[5]	clay, gravel, rubble, other	silt	sand, bedrock	boulders	Valdez et al. (1990)	
introgressive hybridization	other species of *Gila* (i.e., roundtail chub, *G. robusta*, and bonytail, *G. elegans*)	abundant	common	rare (see Comments)	absent (see Comments)	Valdez et al. (2002) and sources cited therein	Even in some reaches where "pure" examples of the 2 indicator congeners, *G. robusta* and *G. elegans*, are very rare or have not been found, 69–95% of *Gila* examples are hybrids and only 5–25% are "pure" *G. cypha* (see Valdez et al. 2002). However, authors disagree concerning the evolutionary interpretation or implications of such hybridization and its conservational consequences (see Valdez et al. 2002).
predation on juveniles (and larvae and eggs)	nonnative fishes (e.g., trouts, catfishes, possibly carp)*	abundant	common	scarce	absent	Valdez et al. (2002) and sources cited therein	Estimates of predation on juveniles by nonnative fishes in some places "suggest loss of complete year classes to predation" (Valdez et al. 2002).
parasitism (poor condition, lowered fecundity, death)	Asian tapeworm, parasitic copepod[6]	present at high infestation rates in this or other fish species	present at moderate infestation rates in this or other fish species	present at low infestation rates in this or other fish species	absent in this or other fish species, including nonnative fishes	Valdez et al. (2002) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, successful reproduction, recruitment, etc.	alteration of flow regimes (e.g., dams)*	present in immediate vicinity	—	—	none for ≥100 mi upstream or ≥5 mi downstream	Valdez et al. (2002)	Tailwaters for long distances below dams (e.g., Flaming Gorge, Glen Canyon) are too cold for reproduction. Although "[h]umpback chub move substantially less than other native Colorado River fishes", and "show remarkable fidelity for given river regions", movements of up to 20 miles have been reported (see Valdez et al. 2002).
habitat (water quality and quantity, etc.)	resource extraction (oil, gas, minerals), power plants (e.g., nuclear)	existing or planned in region	—	—	none in region	Jacobsen (1982)	

[1]Six populations this species are extant, inhabiting limited reaches of the Colorado River drainage in the Colorado, Little Colorado, Green, and Yampa rivers of Arizona, Utah, and Colorado. It is possible that the species formerly occurred more widely in the Colorado River drainage. However, *Gila cypha* was not recognized as a species distinct from the bonytail (*Gila elegans*) until 1946, being the last big-river fish species to be described (i.e., named) from the Colorado River system, nearly a century after the other fish species with which it is sympatric were named. Thus little is known of its historical distribution and its biology under conditions unaltered by human activities.

[2]"Very little is known about recently-hatched humpback chub. The experts believed that larvae use habitat similar to that of larval Colorado squawfish [Colorado pikeminnows], for which there were substantial data . . . . They agreed that the depth and velocity used by larvae of the two species was probably similar, but felt that humpback chub probably use a different substrate, as indicated by the rocky regions in which the juveniles and adults occur; no substrate criteria were developed for the larval stage. Thus the depth and velocity SI [suitability index] curves applied to larval humpback chub were the same as those developed for larval Colorado squawfish, but a very low confidence rating (D [on a scale of A–D]) was given to this curve set because the data were originally developed for another species. . . . The experts felt that these SI curves should only be applied to rearing and nursery areas in the Upper Colorado River Basin, and only at the onset of spawning and immediately after" (Valdez et al. 1990).

[3]"The small amount of field data describing the microhabitat of YOY [young of year] humpback chub allowed for only a low confidence rating (C [on a scale of A–D]) for this curve set . . ." (Valdez et al. 1990).

[4]Valdez et al. (1990) developed 2 sets of habitat suitability index (HSI) curves for juveniles—1 set for the Green River, the other for the Colorado and Yampa rivers—because data from these areas differed. Here the data have been combined as much as possible. Water velocity curves based on the 2 sets of data were very nearly identical, but water depth curves and substrate utilizations were very different. Confidence ratings for the HSI curves for juveniles were C (on a scale of A–D) (Valdez et al. 1990).

[5]HSI curves for adults "received a confidence rating of B [on a scale of A–D]" (Valdez et al. 1990).

[6]Several serious parasites of fishes have been introduced into the Colorado River system through nonnative fishes. Asian tapeworm (*Bothriocephalus acheilognathi*) infestation rates as high as 84.2% in *G. cypha* have been reported. It has been "hypothesized that an observed decline in condition of adult humpback chub in Grand Canyon was a result of recent infestation by the internal Asian tapeworm", and "[i]nfection of humpback chub by the Asian tapeworm is of concern because of possible stress and death to the host" (Valdez et al. 2002, citing works of others). The external parasitic copepod, *Lernaea cyprinacea*, with reported infestations as high as 31% in *G. cypha*, is also of concern. Although the Asian tapeworm requires waters >20 °C in order to complete its life cycle, it is able to survive in fish hosts at cooler temperatures. Optimal temperatures for maturation of the parasitic copepod *Lernaea cyprinacea* are 23–30 °C, but it is able to mature at temperatures as low as 18 °C. Ironically, waters warm enough for successful reproduction of the humpback chub favor these introduced parasites.

*Most important indicators.

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Virgin chub (*Gila seminuda*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	stream feature*	riffles (3%) or other (0%)	—	pools (35%)	runs (62%)	Cross (1978)	Percentages in parentheses are the frequencies of *G. seminuda* occurrences reported by Cross (1978).
habitat (general)	portion of drainage	small tributary (0%), large tributary (0%)	—	—	mainstream (sand) (38%), mainstream (ecotone) (33%)	Cross (1978, 1985)	Percentages in parentheses are the frequencies of *G. seminuda* occurrences within each category reported by Cross (1985) (and do not total 100%). Also see end of footnote 1.
habitat (juveniles, ≤80 mm TL)	water depth[2,] *	≤0.32 ft	0.32–0.42 ft	0.42–0.56 ft	≥0.56 ft	Hardy et al. (1989)[3]	
habitat (subadults, 81–140 mm TL)	water depth[2,] *	≤0.65 ft	0.65–0.83 ft	0.83–1.00 ft	≥1.00 ft	Hardy et al. (1989)[3]	
habitat (adults, >140 mm TL)	water depth[2,] *	≤1.22 ft	1.22–1.80 ft	1.80–3.50 ft	≥3.50 ft	Hardy et al. (1989)[3]	
habitat	cover	none	—	—	boulders, deadfalls, overhanging trees, undercut banks	Cross (1978)	Cross (1978) reported that >½ of his captures of *G. seminuda* were associated with some type of cover, in the order given in the "very good" rating.
habitat (juveniles, ≤80 mm TL)	substrate*	cobble, rock, mud, silt	gravel	—	sand	Hardy et al. (1989)[3]	Cross (1978) reported that *G. seminuda* "occurred over sand and silt substrates in 70% of the collections and over gravel and rubble substrates in 30% of the collections" but did not report frequencies by size or age classes.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (subadults and adults, ≥81 mm TL)	substrate*	gravel, cobble, rock, silt, mud	—	—	sand	Hardy et al. (1989)[3]	Cross (1978) reported that *G. seminuda* "occurred over sand and silt substrates in 70% of the collections and over gravel and rubble substrates in 30% of the collections" but did not report frequencies by size or age classes.
habitat	conductivity (see Comments)	<375 µmhos or »2,600 µmhos	375–987.5 µmhos or 2,200–2,600 µmhos	987.5–1,600 µmhos or 1,800–2,200 µmhos	1,600–1,800 µmhos	Cross (1978)	**N.B.**: Cross (1978) reported capture of *G. seminuda* at conductivities ranging 375–2,600 µmhos (at 25 °C), mean ~1,700 µmhos, which is indicative of tolerated conditions. However, water quality of the Virgin River system is altered and degraded from natural conditions, and conductivities preferred by and healthy for *G. seminuda* are not known. It is known that hypersaline conditions (salinity ~7 ppt, conductivity ~17,000 µmhos at 25 °C) where outflows from Pah Tempe Springs enter the Virgin River are a barrier to upstream distribution of *G. seminuda*.
habitat (juveniles, ≤80 mm TL)	water velocity[4, *]	<0.07 ft/s or >2.25 ft/s	0.07–0.16 ft/s or 1.94–2.25 ft/s	0.16–0.25 ft/s or 1.61–1.94 ft/s	0.25–1.61 ft/s	Hardy et al. (1989)[3]	
habitat (subadults, 81–140 mm TL)	water velocity[4, *]	>3.19 ft/s	<1.16 ft/s or 2.84–3.19 ft/s	1.16–2.46 ft/s or 2.46–2.84 ft/s	2.46 ft/s	Hardy et al. (1989)[3]	
habitat (adults, >140 mm TL)	water velocity[4, *]	>1.91 ft/s	1.69–1.91 ft/s	1.50–1.69 ft/s	≤1.50 ft/s	Hardy et al. (1989)[3]	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	turbidity*	low (clear)	fairly low	fairly high	high (silty, murky)	various authors including Cross (1978)	Cross (1978) attributed the restriction of *G. seminuda* to the mainstream of the Virgin R. and its absence from its tributaries in part to the turbidity of the mainstream (see end of footnote 1).
habitat	water temper-ature[5, *]	<0 °C or >34 °C	0–12 °C or 27.9–34 °C	12–23.3 °C or 24.3–27.9 °C	23.3–24.3 °C	Deacon et al. (1987), with modifications from Cross (1978)	"Reduced flow leads to conditions which result in fish mortalities. Temperatures as high as 35.5°C were recorded in isolated pools in the [Virgin River] mainstream in July. The lethal limit for the Virgin River roundtail chub is probably near this temperature. Chubs collected at 34°C from a stranded pool were under obvious stress" (Cross 1978).
habitat	modifications of habitat*	extensively altered (large irrigation withdrawals, channeliz-ation, organic pollution) (<1%)	slightly modified (partial irrigation withdrawals, irrigation leaching) (20%)	—	unmodified (~80%)	Cross (1978)	Percentages in parentheses are the frequencies of *G. seminuda* occurrences reported by Cross (1978).
predation, competition	nonnative fishes	many (>18.5%)	some (11–18.5%)	few (3.5–11%)	none (0–3.5%)	Cross (1978)	Cross (1978) reported: "Native fishes comprised a mean of 89% (SE = 7.5 . . .) of collections containing the [Virgin River] roundtail chub." Percentages in parentheses are derived from these numbers.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
parasitism (mortality, reduced vigor, decreased reproduction, etc.)	Asian fish tapeworm and other parasites* (see Heckmann et al. 1986)	present	—	—	absent	Heckmann et al. (1986)	The Asian fish tapeworm is "of major concern", and "all cyprinids [in the Virgin River system, including *G. seminuda*,] were infected at levels that could severely damage the populations". "The tapeworm probably arrived [in the Virgin River system] in the spring of 1984 along with the red shiner . . . " (Heckmann et al. 1986). Parasite loads were found to be higher in reaches with poorer water quality and greater habitat disturbance. "Low river flows and increased total dissolved solids appear to be associated with a higher parasite frequency and mean number in fishes of the Virgin River [including *G. seminuda*]" (Heckmann et al. 1986).

[1]This species, federally listed as endangered, was formerly considered to be a subspecies of the roundtail chub, *Gila robusta*. The Virgin chub, *Gila seminuda*, is endemic to the Virgin River (Washington County, Utah; Mohave County, Arizona; and Clark County, Nevada) and the Moapa River (= Muddy River) (Clark County and perhaps Lincoln County, Nevada). The population in the Moapa (or Muddy) River was at one time thought to be taxonomically distinct (a different subspecies) from that in the Virgin River. This table is intended primarily for application to the Virgin River population. Cross (1978) called the Virgin chub "the most endangered species of the native Virgin River ichthyofauna" and warned: "The Virgin River roundtail chub is in danger of extinction. Once present in sizable numbers, the chub has not been collected downstream from Mesquite, Nevada since at least the mid-1960's. It rarely comprised more than 1% of the number of individuals in a sample. More than one-half of the native habitat is unsuitable for the animal for long periods of each year. The Virgin River roundtail chub occurs now only in areas of perennial flow. Disruption of flow in these areas will be followed by the disappearance of the chub." In Cross' 1973–1975 study of Virgin River fishes, this species represented only 1.4% of all *native* fishes (far less if introduced fishes are included). Cross (1978) noted: "The Virgin River roundtail chub was not collected in any of the tributaries to the mainstream [of the Virgin River] during this study and a total of three specimens from tributaries was found in [various institutional] collections . . . . Occurrence of the chub solely in the mainstream probably represents a behavioral response to the high concentrations of suspended sediments [i.e., turbidity], strong flows, and large-river habitat not found in the smaller tributaries."

[2]Cross (1978) reported that the average depth of capture of *G. seminuda* was 67 cm and the average depth of the water that they inhabited was 33 cm. It is possible that the numbers have been reversed. Cross' (1978) samples apparently included various sizes and age classes (the smallest individual was 33.5 mm SL and the largest that he mentioned was 166.7 mm SL). Assuming that the average water depth where Cross (1978) captured *G. seminuda* was 67 cm (2.20 ft), this agrees well with the suitability index models of Hardy et al. (1989), which have been adapted for this table.

[3]Hardy et al. (1989) presented a series of habitat suitability index "curves" (i.e., models) that have been utilized here. However, it should be noted that it is customary, in the presentation of habitat suitability index (HSI) models, to state the assumptions upon which such models are based and to explain the construction of the models, neither of which were done by Hardy et al. (1989). Thus it is impossible to evaluate the HSI models of Hardy et al. (1989).

[4]Cross (1978) reported capture of *G. seminuda* at water velocities ranging 0–1.1 m/s (0–3.61 ft/s), mean 0.34 m/s (1.12 ft/s), which is indicative of tolerated conditions and is in general agreement with the habitat suitability models of Hardy et al. (1989). However, flows in the Virgin River system are greatly altered from natural conditions. Although Cross' (1978) samples apparently included various sizes and ages (the smallest individual was 33.5 mm SL and the largest that he mentioned was 166.7 mm SL), he did not report frequencies of occurrence at different water velocities by size or age classes.

[5]The chubs (*Gila* sp.) used in the tolerance and thermal preference experiments by Deacon et al. (1987) and called by them the "roundtail", "Virgin roundtail", and "Virgin roundtail chub (*Gila robusta seminuda*)" were not adults and were not from the Virgin River but were "young-of-the-year roundtails spawned in captivity from adults captured from the nearby Moapa River [= Muddy River] in Nevada". Also, the former roundtail chub, *Gila robusta* (*sensu lato*), which has undergone taxonomic splitting (e.g., *G. robusta seminuda* to *G. seminuda*) may undergo further splitting in the future. If the chubs from the Muddy River in Nevada used by Deacon et al. (1987) eventually are distinguished from *G. seminuda* taxonomically as a different species (at one time they were believed to represent a different subspecies), then the thermal data in the ratings of this table would not apply to *G. seminuda* and the limited thermal information presented by Cross (1978) that is quoted in the "Comments" column should be used. Also, the ratings, being based on the work of Deacon et al. (1987), are only for "young-of-the-year" (i.e., juveniles or subadults), and, again, the quoted thermal information from Cross (1978) should be considered.

*Most important indicators.

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roundtail chub (*Gila robusta*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of individuals >200 mm TL	<50/km	50–99/km	100–199/km	≥200/km	Brouder et al. (2000)	
habitat (general)	water body	other	—	—	mid-elevation, cool- to warmwater rivers and streams	various authors	
habitat (general)	stream feature (macrohabitat)*	other	glides, runs, riffles	—	deep pools and eddies	Vanicek and Kramer (1969)[3], Karp and Tyus (1990), Bestgen (1985), Bestgen and Propst (1989), Rinne (1992), Rinne and Stefferud (1996), Propst (1999), Voeltz (2002) and sources cited therein	Propst (1999) stated: "Nonnative predators [fishes] . . . and loss of pool habitats with cover are the primary threats to surviving populations of roundtail chub in New Mexico."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal ecology	elevation (see Comments)	>6,600 ft or <3,000 ft (uncertain, maybe lower)	—	3,000–4,000 ft (uncertain)	~4,000–6,600 ft	Bestgen and Propst (1989), other sources	Bestgen and Propst (1989) reported this species at 1,325–2,000 m (4,347–6,562 ft) in New Mexico. Although elevation is a limiting factor in the ecology of this species, little elevational information has been reported, and the limits are somewhat uncertain. The lower limit presented here is an estimate. The actual lower limit may be somewhat lower, especially if chubs reported as this species in nw. México are in fact this species. At lower elevations waters may be too warm in summer, and in some places this species finds refuges from nonnative fish predators only at higher elevations (especially above barriers such as waterfalls).
habitat (general)	water velocity[2]	swift	—	—	none or slow to moderate	Vanicek and Kramer (1969)[3], Bestgen (1985), Bestgen and Propst (1989), Rinne and Stefferud (1996), Olden et al. (2006, Appendix B)	See footnote 2.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (general), thermal ecology	maximum water temperature	>35 °C	30–35 °C	27–30 °C	20–26 °C	Olden et al. (2006, Appendix B), also Bestgen and Propst (1989)	Bestgen and Propst (1989) reported maximum water temperatures in the habitat of this species in the Gila drainage of New Mexico as 20–26.5 °C.
spawning habitat	water temperature*	<14 °C or >24 °C	14–15 °C or 22–24 °C	16–17 °C or 21–22 °C	18–20 °C	Vanicek and Kramer (1969)[3], Karp and Tyus (1990), Kaeding et al. (1990), Brouder et al. (2000), Bezzerides and Bestgen (2002)	Tailwaters of impoundments, for very long distances below dams, are too cold for spawning in this species.
habitat	cover (instream boulders, logs and debris jams, undercut banks, over-hanging vegetation, etc.)*	none	scarce	common	abundant	Bestgen (1985), Bestgen and Propst (1989), Barrett and Maughan (1995), Brouder et al. (2000)	Propst (1999) stated: "Nonnative predators [fishes] . . . and loss of pool habitats with cover are the primary threats to surviving populations of roundtail chub in New Mexico."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation (especially on juveniles, larvae, and eggs); competition	nonnative fishes (e.g., trouts, catfishes, basses, sunfish, carp, shiners)[4,*] (see Comments)	abundant (>70%?)	common (50–70%?)	scarce (25–50%?)	absent or few (<25%?)	Minckley (1973)[4], Bestgen and Propst (1989), Propst (1999)[4], Brouder et al. (2000)[4], other authors	In the Verde R. system of Arizona, Brouder et al. (2000) found this species to be more abundant in stream reaches with fewer nonnative fish. Numbers in parentheses are percent of the ichthyofauna composed of nonnative fishes (generalized from data in Brouder et al. 2000). However, these numbers, while realistic, may not actually represent any truly "good" conditions (e.g., even 10% may be "poor"), and degree of negative impact may depend on the nonnative species involved. Shiners may have less negative impact, but the presence of *any* smallmouth bass or flathead catfish should be regarded as "poor".
parasitism (poor condition, lowered fecundity, death)	Asian tapeworm, parasitic copepod, bass tapeworm	present at high infestation rates in this or other fish species	present at moderate infestation rates in this or other fish species	present at low infestation rates in this or other fish species	absent in this or other fish species, including nonnative fishes	Vanicek and Kramer (1969)[3], Robinson et al. (1998), Brouder et al. (2000), other authors	The parasitic copepod, *Lernaea cyprinacea*, commonly infests this chub species but has not been found to affect its health greatly. The Asian tapeworm has been found in this chub in at least 1 hatchery and is potentially a serious threat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
introgressive hybridization	other species of *Gila* (i.e., bonytail, *G. elegans*, and especially humpback chub, *G. cypha*)[5] (see Comments)	abundant[5]	common[5]	rare[5]	absent[5]	Gerber et al. (2001)[5]	Many hybrids between this and its 2 sympatric congeners have been found. Authors disagree concerning the evolutionary interpretation or implications of such hybridization and its conservational consequences for this species (i.e., whether such hybridization should be considered unnatural or a threat).
movement	linear extent of suitable habitat (by basin) (see Comments)	<34 km (UCRB) or <100 m (LCRB) (uncertain, see Comments)	34–57 km (UCRB) or 100–500 m (LCRB)	57–80 km (UCRB) or 500–1,000 m (LCRB)	>80 km (UCRB) or >1,000 m (1 km) (LCRB)	Kaeding et al. (1990), Bezzerides and Bestgen (2002) and sources cited therein	In the large rivers of the upper Colorado River basin (UCRB), this species often moves long distances, especially during spawning (average 33.9 km, up to ~80 km), but in the smaller rivers and streams of the lower Colorado River basin (LCRB) its movements are small or it is sedentary (0–5.7 km, typically ≤100 m). Ratings for both basins, especially the LCRB, are uncertain.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, reproduction	alteration of natural hydrograph and flow regimes (e.g., by dams, regulation of stream discharge, water withdrawals, diversions)	present in immediate vicinity	—	—	none for ≥100 mi upstream	various authors	Brouder et al. (2000) recommended protection of "areas with a natural hydrograph, more specifically, sections of streams where late-winter/early- spring floods (≥ ~ 40 – 50 m^3/s) occur and areas where an intact riparian corridor exists." "Water diversions seasonally diminish habitat available to roundtail chub in portions of its range. Where this occurs, maintenance of instream habitat enhancing structures (e.g., downed trees) is essential to enabling roundtail chub to survive periods of reduced stream flow" (Propst 1999). For long distances below dams (e.g., Flaming Gorge, Glen Canyon), tailwaters are too cold for reproduction or even long-term inhabitation.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	alteration of river channel (e.g., channelization, levees)*	existing or planned	—	—	none	Propst (1999)	"River channel modification (e.g., levee construction, channel cleaning, and channel straightening) deprives [roundtail] chub of essential pool habitat" (Propst 1999). "[L]oss of pool habitats with cover" is 1 of the 2 "primary threats to surviving populations of roundtail chub in New Mexico" (Propst 1999). Brouder et al. (2000) recommended "protecting and/or restoring stream habitats so that distinct macro-habitats (i.e., runs/glides, riffles, and pools) exist that allow for inter- and intra-specific resource partitioning".
habitat	livestock grazing	intense, unlimited	somewhat limited	very limited	none	Propst (1999)	"Livestock grazing that results in loss of riparian gallery forests and increased bank erosion . . . contributes to habitat deterioration" for this species (Propst 1999).
habitat (water quality and quantity, etc.)	resource extraction (oil, gas, minerals), power plants (e.g., nuclear)	existing or planned in region	—	—	none in region	Jacobsen (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	angling (see Comments)	intense	moderate	little	none	Propst (1999)	"Some anglers confuse roundtail chub with Gila trout, while others believe they compete with gamefishes or are otherwise undesirable . . . . As a consequence of these misperceptions, roundtail chub often are destroyed" (Propst 1999).

[1]This species formerly occurred throughout most of the upper and lower Colorado River basins (in Wyoming, Colorado, Utah, Arizona, and New Mexico), but it has been extirpated from ~45% of its former range in the upper basin and from ~70% of its former range in the lower basin. Its current distribution is mainly the upper Colorado River basin and the Gila River system of the lower Colorado River basin (Bezzerides and Bestgen 2002). It is uncertain whether chubs reported as this species outside the Colorado River basin in river systems of northwestern México (Sonora to Sinaloa) truly represent this species (Voeltz 2002).

[2]Barrett and Maughan (1995) developed habitat suitability index (HSI) curves for this species in 2 streams in central Arizona but warned: "We recommend caution in applying HSI curves for roundtail chub beyond the drainage in which they were developed. If such application is necessary, we recommend using HSI curves from Fossil Creek and then only for summer habitat use. We do not recommend using HSI curves from Wet Beaver Creek." Limited use of the Fossil Creek HSI curves of Barrett and Maughan (1995) has been made in this table. Although habitat characteristics of the roundtail chub have been reported by many authors working in various places within the range of this fish, the findings in different drainages vary greatly and in many cases are inconsistent or conflicting (non-overlapping), as Barrett and Maughan (1995) cautioned. For this reason some well-reported, but inconsistent, habitat characteristics of the roundtail chub (e.g., substrates, water depths, water velocities) have not been included in this table. For example, the HSI curve for substrates used by adults in Fossil Creek (Barrett and Maughan 1995) suggest the following ratings: very good = small boulders; good = gravel; fair = sand, large boulders, large cobble, fines; poor = small cobble, bedrock. However, Rinne (1992) found that adults (and juveniles) preferred sand and gravel in Aravaipa Creek, Arizona; Olden et al. (2006, Appendix B) considered rubble (including cobble and gravel) to be the generally preferred substrate; Vanicek and Kramer (1969) found the species "generally over silt and silt-boulder bottom types"; and Brouder et al. (2000) found that adults did not select for any substrate type in the Verde River system of central Arizona. For reference, reported water depths for juvenile roundtail chubs range from 18 cm to 3 m and for adults from 25 cm to >3 m (Bestgen 1985, Barrett and Maughan 1995, Beyers et al. 2001); reported water velocities for juveniles range from 0 to ≥0.65 m/s and for adults 0 to ≥0.95 m/s (Bestgen 1985, Barrett and Maughan 1995). (Rinne [1992] contains errors: The scale for Figure 2B, velocity, is incorrect, the lowest labeled value for the ordinate or *y*-axis, velocity, would have to be –3 rather than +3 for this scale to be linear; also, values shown for roundtail chub in Figure 2A, depth, do not agree with those stated in the text.) Spawning ecology is not well known in this species, and reported conditions are somewhat inconsistent across studies; some authors have suggested that pools, runs, and riffles, over gravel, sand, and silt substrates, are preferred (Bezzerides and Bestgen 2002 and sources cited therein, Voeltz 2002 and sources cited therein, Brouder et al. 2000); a reported spawning depth of 31.6 cm and a water velocity of 43.8 cm/s have been reported (Brouder et al. 2000).

[3]It should be noted that Vanicek and Kramer (1969), although they did distinguish bonytails and roundtail chubs, regarded the 2 taxa as subspecies of the same species, which they called the Colorado chub, *Gila robusta*, following the prevailing systematic arrangement of these fishes at the time of their work. Despite their

ability to distinguish the 2 taxa (at least those individuals ≥200 mm total length), their detection of differences in growth rates, morphology (proportions), and food habits, and their suggestion that the 2 may be different species, in many cases they did not separate their data and their observations of the ecology of the 2 taxa, even though their observations suggested that the 2 may have been spatially somewhat segregated (e.g., during spawning) within the limited reach of the Green River that they studied.

[4]Minckley (1973) noted the effects of introduction of a predaceous nonnative sport fish on recruitment in the roundtail chub and other native fishes: "A 'population explosion' of smallmouth bass in the upper Salt River tributaries, following their introduction in the mid-1960s suppressed all reproductive success by *G. r. robusta* in the Black River, an area where a large population . . . was present. In fact no young of any native fish species was found by me in the second and third years after the smallmouth became established, and in a 1972 survey, no young of native fishes were in the lower Black River." Brouder et al. (2000) estimated there to be a population of 183 smallmouth bass >100 mm in total length in a 1-km stream reach that they studied and speculated: "If [an] estimated average meal of 2 roundtail chub occurs once a week, a smallmouth bass population of 183 would annually consume 19,302 roundtail chub [in this 1-km reach] alone. Five other nonnative fish species were collected in the upper Verde River . . . all of which were piscivorous and occur at all of the sites sampled." Brouder et al. (2000) recommended: "Suppress non-native fish and possibly crayfish densities at a minimum, seasonally", and avoid the introduction and spread of nonnative fishes. Propst (1999) considered nonnative predators such as channel catfish, flathead catfish, sunfish, and basses to be 1 of the 2 "primary threats to surviving populations of roundtail chub in New Mexico." Propst (1999) further commented: "While it is not likely that nonnative predators can be eliminated from river reaches, efforts to control their abundance (liberalized creel limits and selective removal) and cessation of nonnative stocking are necessary to enhance the survival prospects of extant populations of roundtail chub."

[5]Gerber et al. (2001) found no introgression (from hybridization with 2 other species of *Gila*) in this species in the lower Colorado River basin, but in the upper Colorado River basin "[t]he complete absence of *G. robusta* mtDNA, even in populations of morphologically pure *G. robusta*, indicates extensive introgression [from *G. cypha*] that predates human influence." "This [complete replacement of *G. robusta* mtDNA with that from *G. cypha* in the upper Colorado River basin] was remarkable because the study included large samples of morphologically pure *G. robusta* from the mainstem Colorado River and its tributaries and populations from relatively small and sometimes isolated drainages inhabited only by *G. robusta* . . . . Levels of gene exchange among *G. robusta* and *G. cypha* are far too extensive to be explained by human activity: Total replacement of *G. robusta* haplotypes would probably take much longer than humans have lived in the region."

*Most important indicators.

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least chub (*Iotichthys phlegethontis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body[1]	large, swift rivers, high-gradient streams	vegetated areas of streams, lakes, slow rivers	ponds	spring complexes, spring-fed marshes, other marshes	various authors (e.g., Sigler and Sigler 1987, 1996)	Types of water bodies and aquatic situations currently inhabited by this species do not reflect the full range of conditions formerly utilized.[1] Slow rivers, streams, and lakes were formerly inhabited and may have been important habitats.
breeding and developmental habitat, foraging habitat, food	aquatic vegetation (including filamentous green algae) and emergent vegetation*	rare or absent	sparse	moderately common	dense (but not completely occluding channels)	Sigler and Miller (1963), Lamarra (1981)	
competition, predation on eggs and larvae	mosquitofish (*Gambusia affinis*)*	abundant	uncommon	very rare	absent	Crawford (1978)	
predation	bullfrog (*Rana catesbiana*)	abundant	uncommon	very rare	absent	Sigler and Sigler (1987, 1996)	
predation	sport fishes (e.g., basses, sunfishes)	abundant	uncommon	very rare	absent	Sigler and Sigler (1987, 1996)	
predation, hybridization, competition	Utah chub (*Gila atraria*)	abundant	uncommon	very rare	absent	Sigler and Sigler (1987, 1996)	
hybridization, competition	speckled dace (*Rhinichthys osculus)*	abundant	uncommon	very rare	absent	Sigler and Sigler (1987, 1996)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
climate	elevation	<3,000 ft or >7,500 ft	3,000–4,000 ft or 6,500–7,500 ft	4,000–4,200 ft or 6,240–6,500 ft	4,200–6,240 ft	various sources (Utah Natural Heritage Program data base)	Known occurrences are in the range indicated as "very good". Since this is a broad-niched species with broad environmental tolerances, the degree to which elevation is limiting is uncertain. ("Poor" to "good" ratings are predictions.)
maintenance of aquatic habitat	hydrologic alterations, e.g., ground-water withdrawals, surface water diversions	occurring or planned	—	—	none occurring or planned	USFWS (1995)	
trampling, disturbance, fecal contamination	livestock	present year-round	present only during cool months (September–March)	very limited and only during cool months (September–March)	absent	Sigler and Sigler (1987, 1996)	Crawford (1979) documented spawning from April to August, the peak being the first week in May.
pollution of groundwater and surface water; creation of new roads and accessibility	oil and gas exploration and extraction	occurring or planned	—	—	none occurring or planned	USFWS (1995)	
contamination of water and foods	mosquito abatement (insecticides)	occurring or planned	—	—	none occurring or planned	USFWS (1995)	
contamination and degradation of habitat and foods	agriculture (fertilizers, pesticides, erosion, water demands)	present in immediate vicinity	—	—	absent from surrounding areas		

[1]This species is endemic to the northeastern part of the Great Basin (i.e., northwestern Utah). Although now almost entirely limited to a few spring complexes and spring-fed marshes, many of these being alkaline, the species formerly occurred in most aquatic habitats, both lotic and lentic, in the Bonneville Basin, with the exception of the Great Salt Lake and high-gradient streams and rivers. Based on her observations of its extremely broad tolerances to physical environmental factors including temperature, conductivity, alkalinity, pH, and water level, Crawford (1978) considered the species to be a generalist. She concluded that the probable reason for the decline in its distribution and abundance has not been primarily habitat loss or alteration of the environment, as assumed by others, but competition with and predation by introduced species, especially the mosquitofish, and that the least chub is now limited to the margins of its range and to extreme, suboptimal habitats where it has managed to avoid the predation by and competition with introduced fishes that have eliminated it from the wider geographical area and broader range of habitats that it formerly inhabited (Crawford 1978, Lamarra 1981).

*Most important indicators.

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Virgin spinedace (*Lepidomeda mollispinis*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
non-spawning habitat	part of drainage	—	—	—	clearwater tributary streams, mainstream of river near mouths of tributaries, upper parts of main river drainage	Cross (1975), Deacon et al. (1991)	
spawning habitat	part of drainage	—	—	—	tributary streams	Cross (1975)	
habitat	stream feature	other (0%)	riffles (12%)	pools (34%)	runs (54%)	Cross (1975)	Numbers in parentheses are the frequencies of capture of *L. mollispinis* by Cross (1975).
habitat (general)	portion of drainage	—	mainstream (sand) (23%), small tributary (19%)	mainstream (ecotone) (36%)	large tributary (48%)	Cross (1985)	Percentages in parentheses are the frequencies of *L. mollispinis* occurrences within each category reported by Cross (1985) (and do not total 100%).
habitat	cover	none	—	undercut banks	boulders, overhanging trees and shrubs	Cross (1975), Rinne (1971), Deacon et al. (1991)	"In two thirds of the collections the [Virgin] spinedace was associated with some type of cover . . . " (Cross 1975).
habitat (juveniles, subadults, ≤50 mm TL)	water depth	<0.16 ft	0.16–0.34 ft	0.34–0.50 ft	>0.50 ft	Hardy et al. (1989)[2]	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat ("adults", >50 mm TL)	water depth	<0.56 ft	0.56–0.76 ft	0.76–1.50 ft	>1.50 ft	Hardy et al. (1989)[2]	Deacon et al. (1991) presented a HSI model that, adapted here, would yield the ratings: **poor** <0.38 or >1.77 ft; **fair** 0.38–0.60 or 1.32–1.77 ft; **good** 0.60–0.90 or 0.90–1.32 ft **very good** = 0.90 ft.
habitat (juveniles, subadults, ≤50 mm TL)	water velocity	<0.02 ft/s or >1.89 ft/s	0.02–0.26 ft/s or 1.72–1.89 ft/s	0.26–0.50 ft/s or 1.55–1.72 ft/s	0.50–1.55 ft/s	Hardy et al. (1989)[2]	Cross (1975) reported: "Current velocities ranged from zero to 0.88 m/sec with a mean of 0.41 m/sec (±0.27)." These observed conditions (0–2.89 ft/s, mean 1.35 ft/s) are generally consistent with the habitat suitability index models of Hardy et al. (1989) used in the ratings.
habitat ("adults", >50 mm TL)	water velocity	<0.07 ft/s or >1.93 ft/s	0.07–0.23 ft/s or 1.80–1.93 ft/s	0.23–0.40 ft/s or 1.67–1.80 ft/s	0.40–1.67 ft/s	Hardy et al. (1989)[2]	Cross (1975) reported: "Current velocities ranged from zero to 0.88 m/sec with a mean of 0.41 m/sec (±0.27)." These observed conditions (0–2.89 ft/s, mean 1.35 ft/s) are generally consistent with the habitat suitability index models of Hardy et al. (1989) used in the ratings. Deacon et al. (1991) presented a HSI model that, adapted here, would yield the ratings: **poor** <0.92 or >3.44 ft/s; **fair** 0.92–1.65 or 3.08–3.44 ft/s; **good** 1.65–2.50 or 2.50–3.08 ft/s; **very good** = 2.50 ft/s.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (juveniles, subadults, adults)	substrate* (see Comments)	gravel cobble, rock, mud, silt	—	—	sand	Hardy et al. (1989)[2]	Cross (1975) reported very different substrate associations of *L. mollispinis*: "In 60% of the collections the bottom consisted of rubble or cobbles and in 40% of sand and occasionally mud." Deacon et al. (1991) presented a HSI model that, adapted here, would yield the ratings: **poor** = silt, mud, rock; **fair** = cobble; **good** = gravel; **very good** = sand.
habitat	conductivity (µmhos at 25 °C) (see Comments)	<80 µmhos or >2,700 µmhos	80–168 µmhos or 1,740–2,700 µmhos	168–256 µmhos or 780–1,740 µmhos	256–780 µmhos	Cross (1975)	Cross (1975) reported: "Conductivities ranged from 80 to 2,700 µmhos (at 25 °C) but usually did not exceed 80 µmhos (mean about 300 µmhos)." Although these data are indicative of tolerated conditions, water quality of the Virgin River system is altered and degraded from natural conditions, and conductivities preferred by and healthy for *L. mollispinis* are not known.
habitat	water temperature*	<0 °C or >37 °C	0–10 °C or 31–37 °C	10–22.6 °C or 23.6 –31 °C	22.6–23.6 °C	Deacon et al. (1987)	The work of Deacon et al. (1987) was experimental, under controlled, artificial conditions.
spawning (and gonadal development)	water temperature	<10 °C or >22 °C	10–13 °C or 20–22 °C	13–15 °C or 18–20 ° C	15–18 °C	Rinne (1971), Deacon et al. (1991), Cross (1975)	
foraging	turbidity*	high	—	—	low (i.e., clear)	Cross (1975), Deacon et al. (1991)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
parasitism (mortality, reduced vigor, decreased reproduction, etc.)	Asian fish tapeworm and other parasites (see Heckmann et al. 1986)*	present	—	—	absent	Heckmann et al. (1986)	The Asian fish tapeworm is "of major concern", and "all cyprinids [in the Virgin River system, including *L. mollispinis*,] were infected at levels that could severely damage the populations". "The tapeworm probably arrived [in the Virgin River system] in the spring of 1984 along with the red shiner . . . " (Heckmann et al. 1986). Parasite loads were found to be higher in reaches with poorer water quality and greater habitat disturbance. "Low river flows and increased total dissolved solids appear to be associated with a higher parasite frequency and mean number in fishes of the Virgin River [including *L. mollispinis*]" (Heckmann et al. 1986).
habitat	modifications of habitat*	extensively altered (large irrigation withdrawals, channeliz-ation, organic pollution)	slightly modified (partial irrigation withdrawals, irrigation leaching)	—	unaltered (>90%)	Cross (1975) and other authors	Cross (1975) reported: "in over 90% of the collections the [Virgin] spinedace was collected from habitats that were considered relatively unaltered physically."
predation, competition	nonnative fishes	many (>29%)	some (18.5–29%)	few (8–18.5%)	none (0–8%)	Cross (1978)	Cross (1978) reported: "[N]ative fishes made up an average of 92% (±21) of the [fish] fauna of any collection [containing the Virgin spinedace]." Percentages in parentheses are derived from these numbers.

[1]Two subspecies of the Virgin spinedace, *Lepidomeda mollispinis*, are recognized: *Lepidomeda mollispinis mollispinis* of the Virgin River and its tributaries (Washington County, Utah; Mohave County, Arizona; and Clark County and formerly Lincoln County, Nevada), almost all extant populations being in Utah (1 in Arizona), and *Lepidomeda mollispinis pratensis* of Big Spring (now extirpated) and Condor Canyon, in Meadow Valley, Lincoln County, Nevada, which is federally listed as threatened and has been called the "Big Spring spinedace" in federal documents. This table is applicable to the type race, *L. m. mollispinis*, for which there exists a conservation agreement (in lieu of federal listing) between the U. S. Fish and Wildlife Service and the Utah Division of Wildlife Resources.

[2]Hardy et al. (1989) presented a series of habitat suitability index "curves" (i.e., models) that have been utilized here. However, it should be noted that it is customary, in the presentation of habitat suitability index (HSI) models, to state the assumptions upon which such models are based and to explain the construction of the models (as was done by Deacon et al. 1991), neither of which were done by Hardy et al. (1989). Thus it is impossible to evaluate the HSI models of Hardy et al. (1989).

*Most important indicators.

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southern leatherside chub (*Lepidomeda aliciae*)[1]
Ecological Integrity Table[2, 3]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of individuals/100 m of stream	<10	10–50	50–100	>100	K. W. Wilson *in* Walser et al. (1999), Wilson and Lentsch (1998)	Walser et al. (1999) wrote: "Wilson (1996) found 111 leatherside chub in a 100-m reach . . . of Salina Creek . . . ." Although no such data were reported by Wilson (1996), the accuracy of the statement has been confirmed by K. W. Wilson (pers. comm.). Population estimates in 2 inhabited creeks in the Spanish Fork drainage were 1,139 and 8,369 individuals/km (= 114 and 837/100 m) (C. Keleher *in* Wilson and Lentsch 1998). In Heber Valley, Wilson and Lentsch (1998) detected 3 to 32 individuals/100 m, though in many streams or stream segments the species was not detected (0/100 m).
habitat (general)	type of water body	other	—	—	streams, small rivers	Wilson and Belk (2001)	
habitat	water temperature[3]	warm	—	—	cool to cold	various authors	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	brown trout (and other introduced predatory fishes—see Comments)[4,*]	abundant (≥12/100 m of stream)	common (6–11/100 m of stream)	scarce (1–5/100 m of stream)	none (0/100 m of stream)	Wilson and Belk (2001), also Walser et al. (1999)	"It may be necessary to eradicate or control detrimental nonnative fish where feasible. Targeted species may include brown trout, brook trout, and rainbow trout" (Wilson and Lentsch 1998). Other nonnative fishes known to co-occur with *L. aliciae* include common carp, fathead minnow, and green sunfish (Wilson and Belk 2001), the 1st 2 species being known to prey on eggs and larvae of other fishes and the 3rd species on all life stages and ages small enough to be swallowed.
habitat	mean water velocity (August–November)	>52.9 cm/s	<2.3 cm/s or 27.2–52.9 cm/s	2.3–3.8 cm/s or 18.1–27.2 cm/s	3.8–18.1 cm/s	Wilson and Belk (2001, Fig. 2B)	Velocities were measured August–November when flows were low; during spring run-off, available and perhaps inhabited velocities presumably would be much greater.
habitat	water depth (August–November)	<20.1 cm or >69.5 cm	20.1–25.6 cm or 64.7–69.5 cm	25.6–43.0 cm or 59.2–64.7 cm	43.0–59.2 cm	Wilson and Belk (2001, Fig. 2A)	Depths were measured August–November when flows were low; during spring run-off, available and perhaps inhabited depths presumably would be much greater.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	substrate	rubble, cobble, boulders, large boulders, bedrock (i.e., all particle sizes >74 mm)	sand, silt (<2.50 mm)	gravel (6.25–74 mm)	coarse fines (2.50–6.24 mm)	Wilson and Belk (2001)	
habitat	% sand–silt substrate (<2.50 mm)	>52%	36–52%	18–36%	<18%	Wilson and Belk (2001, Fig. 3A)	
habitat	% coarse fines substrate (2.50–6.24 mm)	>50%	<16% or 46–50%	16–33% or 42–46%	33–42%	Wilson (1996, Fig. 5)	
habitat	% gravel substrate (6.25–74 mm)	>81%	55–81%	28–55%	<28%	Wilson and Belk (2001, Fig. 3B)	
habitat	% over-hanging vegetation	>38%	21–38%	10–21%	<10%	Wilson (1996, Fig. 7)	
habitat diversity for all life stages, winter refugia, etc.	stream complexity (e.g., varying depths, velocities, substrates, aquatic vegetation, woody debris, bends, braids, over-hanging vegetation)[5]	none	little	moderate	great	various sources including Wilson and Lentsch (1998)	Until more is learned of spawning and of the ecology of early life stages of this species (eggs, larvae, and juveniles), stream complexity that maintains diverse aquatic conditions is the best way to ensure that all life history requirements of the species are met.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat quality, habitat fragmentation (eliminating gene exchange and reducing population viability; and limiting access to preferred or seasonally necessary habitats)	stream de-watering (e.g., diversions)[5,*]	occurring (past, present, or future)	—	—	none	Wilson and Belk (2001), Wilson and Lentsch (1998)	"Stream dewatering and chemical treatments were obvious contributors to the decline in occupied range, and it seems likely that these activities may account for much of the fragmented distribution" (Wilson and Belk 2001). Some reaches of inhabited streams are completely dewatered for irrigation during summer (Wilson and Lentsch 1998).
habitat quality, habitat fragmentation (eliminating gene exchange and reducing population viability; and limiting access to preferred or seasonally necessary habitats)	flow alterations (e.g., channelization, diking, barriers, dams)[5,*]	occurring (past, present, or future)	—	—	none	Wilson and Lentsch (1998)	"Channelization and diking of the Provo River has increased water velocity and removed instream structure which restricts leatherside chub to backwaters (the few that exist) and tributaries" (Wilson and Lentsch 1998).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat quality (see Comments)	livestock grazing[5,*]	occurring (past, present, or future)	—	—	none	Wilson and Lentsch (1998)	"Past and current livestock grazing practices adversely impact leatherside chub and their habitat. Poor grazing practices can alter sediment transport regimes and streambank stability and can change water quality, substrate composition and channel structure. Specific ramifications include loss of instream cover, increased water temperature, and loss of preferred substrate" (Wilson and Lentsch 1998).
mortality	chemical treatments (i.e., piscicides such as rotenone)*	occurring (past, present, or future)	—	—	none	Wilson and Belk (2001)	"Stream dewatering and chemical treatments were obvious contributors to the decline in occupied range, and it seems likely that these activities may account for much of the fragmented distribution" (Wilson and Belk 2001).

[1]Johnson and Jordan (2000) and Johnson et al. (2004) demonstrated, based on mitochondrial and nuclear DNA, morphology, and thermal ecology, that what had been considered a single species, the leatherside chub (formerly called *Gila copei* and later *Snyderichthys copei*), is actually 2 species and showed that they are closely related to fishes of the genus *Lepidomeda*. One of these leatherside chubs, *Lepidomeda aliciae*, which they called the southern leatherside chub, occurs only in parts of the Bonneville Basin (viz. the Utah Lake and Sevier River drainage systems [and formerly the Beaver River]) of Utah. Habitat characteristics of the leatherside chub, as a single species, reported by various authors (e.g., Wilson and Belk 2001) before recognition that 2 species are actually involved, have been separated for the 2 species in the preparation of this table. However, such "parsing" is dependent upon authors' specifying localities or drainages. General works that have discussed as 1 species what are now considered to be 2 species and have not specified drainages (e.g., Sigler and Miller 1963 and later works by Sigler and Sigler) have not been utilized in preparation of this table.

[2]Because this table has relied heavily on the works of Wilson (1996) and Wilson and Belk (2001), which considered only adult fish, some of the "ratings" in this table are for adults only. Spawning and nursery sites (i.e., habitats and conditions suitable for eggs, larvae, and juveniles or young-of-year fish) are not addressed in this table, since ecological information pertaining specifically to immature *Lepidomeda aliciae* has not been reported, but it is likely that such sites would be in portions of inhabited streams that are shallower and slower than those preferred and used by adults, such as shallow pools, side channels, backwaters, or

shorelines. Sigler and Miller (1963) wrote of *Gila copei* (*sensu lato*, = *Lepidomeda aliciae* and *L. copei* [*sensu stricto*]): " . . . [T]he adults [live] either in the pools or in the riffles [of creeks and rivers], the young about brush or in quiet pockets near shore." Wilson and Belk (2001) found this species only within the elevational range 1,567–2,195 m (5,141–7,217 ft) and found that its occurrence was negatively correlated with elevation; however, elevations higher or lower than this inhabited elevational range are probably unsuitable only because of the greater abundance of nonnative predatory fishes above and below these elevations, e.g., brown trout at higher elevations and sunfishes at lower elevations (K. W. Wilson, pers. comm.). Also, Wilson (1996) and Wilson and Belk (2001) presented the observed ranges, inhabited by *L. aliciae* during August–November, for several habitat variables that were not found to be significantly correlated with the occurrence of this species and thus their ecological importance to this species is uncertain. These habitat characteristics have not been incorporated in this table; however, for reference, some of these were: stream gradient, 0.10–4.00%; water temperature, 1.01–25.87 °C; conductivity, 15.7–461.0 µmhos/cm; pH, 8.0–9.9; and dissolved oxygen, 3.50–16.81 mg/L. Formerly, seining and selling of *Gila copei* (*sensu lato*) for bait was "a drain on the population" (Sigler and Sigler 1987); although seining of bait fish is still allowed in Utah, collection, possession, or transportation leatherside chubs is now prohibited in this state.

[3]Although thermal preferences and tolerances of *Lepidomeda aliciae* have not been studied, Johnson et al. (2004) experimentally tested growth rate and foraging rate in this species at different temperatures. They found that both growth rate (at 10, 15, 19 and 24 °C) and feeding rate (at 9, 19, and 25 °C) increased with increasing temperature at all temperatures tested. These experiments suggest that ≥24 or 25 °C is ideal for both feeding and growth in this species, and it may be that ≥24 or 25 °C is also favorable for other aspects of the biology of the species and may approach its generally preferred water temperature. This temperature would be most likely available in summer. (Contrastingly, in *L. copei* both growth rate and feeding rate increased with increasing temperatures up to 19 °C but decreased above this temperature. At lower temperatures both growth rate and feeding rate were greater in *L. copei* than in *L. aliciae*.) Sigler and Miller (1963), writing of *Gila copei* (*sensu lato*, = *Lepidomeda aliciae* and *L. copei* [*sensu stricto*]), stated: "This species typically occurs in cool to cold creeks and rivers . . . . [W]ater temperatures from mid-June to mid-September vary between 50° and 74°, usually about 60° to 68° F."

[4]It should be noted that habitat use of *Lepidomeda aliciae* in the presence of introduced brown trout (Walser et al. 1999, as *Gila copei*) is not natural. In streams where the brown trout has been introduced, *L. aliciae* occupies marginal habitats (e.g., side channels, silt substrate) in apparent avoidance of predation by brown trout. Thus, even if habitat that is otherwise ideal for *L. aliciae* is present, it will not be used (at least not fully) by this fish if the exotic predator is present. Wilson and Belk (2001) found that within inhabited drainages "[a]s the number of brown trout increased, the probability of encountering leatherside chub decreased."

[5]Various habitat enhancements for *Lepidomeda aliciae* and other actions to benefit this species were discussed by Wilson and Lentsch (1998): "Actions may include bank stabilization and runoff control structures, riparian fencing and sustainable grazing practices. . . . Maintain and restore where possible natural hydrological characteristics such as flow quantity, timing and duration to maintain active channel and floodplain features (e.g. riparian vegetation, bed structure, and sediment transport regime). Assessment of [a] stream section that is periodically dewatered needs to occur to address instream flow requirements for leatherside chub." This could involve "[c]hanges in water allocation to maintain year round flow" and the need to "adjust flow management to maintain sufficient flows in the side channels which will be suitable habitat and refuge for leatherside chub." Also, "It may be necessary to eradicate or control detrimental nonnative fish where feasible. Targeted species may include brown trout, brook trout, and rainbow trout." In discussing restoration of a river that had been channelized, they also mentioned "reconstruction and realignment of most of the river channel and floodplain into a meandering riffle-pool sequence; removal of existing levees; revegetation of a new floodplain area; and construction of side channels, wetlands, and ponds."

*Most important indicators.

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northern leatherside chub (*Lepidomeda copei*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of individuals/100 m of stream	<10	10–50	50–100	>100	Wilson and Belk (1996), Nadolski and Thompson (2003, 2004)	Wilson and Belk (1996) reported 1.8, 2, 8, 20.9, and 22 adults of this species per 100 m of inhabited streams in extreme s.-c. Idaho. Nadolski and Thompson (2003) found 12, 30, 39, and 93 individuals per 100 m of inhabited streams in n. Utah. Nadolski and Thompson (2004) reported 1, 1, 2, 3, 5, 6, 8, 9, 9, 38, and 131 individuals per 100 m of inhabited streams in n. Utah. (In all of these studies, many streams, or sampled segments of streams, were not inhabited or the species was not detected—i.e., the number of fish per 100 m was 0.)
habitat (general)	type of water body	other	—	—	streams, small rivers	Wilson and Belk (2001)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water velocity (July–October)*	>23.0 cm/s	0–7.5 cm/s	7.5–15.0 cm/s	15.0–23.0 cm/s	Wilson (1996), Wilson and Belk (1996, 2001)	"Water velocity was significantly negatively associated with the presence of [*L. copei*, *sensu stricto*] . . . . They were most likely to be found in water velocities of 15.0– 23.0 cm sec^{-1}, and the probability of occurrence decreased at higher velocities" (Wilson and Belk 2001). Water velocity was the only habitat variable found by Wilson and Belk (2001) to be significantly associated with the presence of this species. **N.B.**: Water velocities were measured at low flows, July–October. During peak flows in spring, this species presumably experiences and tolerates much higher water velocities.
habitat	water temperature[3]	warm	—	—	cool to cold	various authors	
habitat quality, habitat fragmentation (eliminating gene exchange and reducing population viability; and limiting access to preferred or seasonally necessary habitats)	stream de-watering (e.g., diversion)*	occurring (past, present, or future)	—	—	none	Wilson and Belk (2001)	"Stream dewatering and chemical treatments were obvious contributors to the decline in occupied range, and it seems likely that these activities may account for much of the fragmented distribution" (Wilson and Belk 2001).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat diversity for all life stages, winter refugia, etc.	stream complexity (e.g., varying depths, velocities, substrates, aquatic vegetation, woody debris, bends, braids, over-hanging vegetation)	none	little	moderate	great	various sources including Wilson and Belk (1996)	Wilson and Belk (1996), commenting on 1 inhabited site, observed: "This portion of the creek has relatively deep holes (about 1 m) and abundant vegetation cover that would appear to buffer the stream against drought or severe cold periods." Until more is learned of spawning and of the ecology of early life stages of this species (eggs, larvae, and juveniles), stream complexity that maintains diverse aquatic conditions is the best way to ensure that all life history requirements of the species are met.
habitat quality, habitat fragmentation (eliminating gene exchange and reducing population viability; and limiting access to preferred or seasonally necessary habitats)	flow alterations (e.g., channelization, diking, barriers, dams)*	occurring (past, present, or future)	—	—	none	various sources including Wilson and Belk (1996)	Channelization and dikes increase water velocity and remove in-stream structure, potentially limiting this species to backwaters. Wilson and Belk (1996) commented that a reservoir in the drainage that they studied probably is a nearly complete barrier to dispersal of this species and that the populations that it separates may have a high probability of extinction because of their isolation and small sizes, making them "more vulnerable to environmental or demographic perturbations."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat quality (see Comments)	livestock grazing*	occurring (past, present, or future)	—	—	none	Wilson and Belk (1996)	Grazing can lead to unstable stream banks, erosion, altered sediment transport regimes, turbidity, changed substrate composition, increased water temperatures, loss of in-stream cover, and altered channel structure. Wilson and Belk (1996) noted many of these effects at sites where they found and especially where they failed to find this species in s.-c. Idaho.
mortality	chemical treatments (i.e., piscicides such as rotenone)*	planned, occurring, or having occurred (past, present, or future)	—	—	none	Wilson and Belk (2001)	"Stream dewatering and chemical treatments were obvious contributors to the decline in occupied range, and it seems likely that these activities may account for much of the fragmented distribution" (Wilson and Belk 2001).

[1]Johnson and Jordan (2000) and Johnson et al. (2004) demonstrated, based on mitochondrial and nuclear DNA, morphology, and ecology, that what had been considered a single species, the leatherside chub (formerly called *Gila copei* and later *Snyderichthys copei*), is actually 2 species and showed that they are closely related to other fishes of the genus *Lepidomeda*. One of these, *Lepidomeda copei*, which they called the northern leatherside chub, occurs in parts of the Bear and Snake River systems of Utah, Wyoming, and Idaho.

[2]Habitat characteristics of the leatherside chub, as a single species, reported by various authors (e.g., Wilson and Belk 2001) before recognition that 2 species are actually involved, have been separated for the 2 species in the preparation of this table. However, such "parsing" is dependent upon authors' specifying localities or drainages. General works that have discussed as 1 species what are now considered to be 2 species and that have not specified where the generalized information was obtained (e.g., books summarizing the ichthyofaunas of Utah, Idaho, Wyoming, the Great Basin, and America) have not been utilized in preparation of this table. Such works have repeated information from other general sources, applying observations that likely pertain to *L. aliciae* (in southern and central Utah) to *L. copei* (*sensu stricto*) (in northern Utah, Idaho, and Wyoming) when these 2 species were considered to be the same. However, despite known ecological differences between the 2 species (e.g., see Johnson et al. 2004), *L. aliciae* and *L. copei* are similar, closely related fishes that show many ecological similarities. It may be that much of what is known about the ecology of *L. aliciae*, which is by far the better studied and better known of the 2 species thus far, may be applicable to the poorly known *L. copei*. Parts of the ecological integrity table that has been prepared for *L. aliciae* probably could be applied to *L. copei*, but

this should be done only with caution, if at all. For example, it is well known that introduced brown trout displace *L. aliciae* from preferred habitat and reduce or even eliminate populations of *L. aliciae* through predation; brown trout (and other introduced predatory fishes) may be expected to affect *L. copei* similarly. (Even such introduced species as the common carp and the fathead minnow, though generally not thought of as predatory, are known to prey heavily on eggs and larvae of other fishes and to reduce or even eliminate recruitment of some native fish species in the Intermountain West.) There is also a negative relationship between elevation and the occurrence of *L. aliciae*, and this too will likely be found to be true for *L. copei*. Very little has been reported concerning the ecology of immature *L. aliciae*, and some of the "ratings" in this table are for adults only. In Idaho, Wilson and Belk (1996) "encountered numerous young-of-year [*L. copei*] in a pool formed by a road culvert" at one site and "several hundred juveniles in pools formed by culverts on both sides of the road" at another location. it is likely that spawning and nursery sites (i.e., habitats and conditions suitable for eggs, larvae, and juveniles or young-of-year fish) are in portions of inhabited streams that are shallower and slower than those preferred and used by adults, such as shallow pools, side channels, backwaters, or shorelines.

[3]Although thermal preferences and tolerances of *Lepidomeda copei* (*sensu stricto*) have not been studied, Johnson et al. (2004) experimentally tested growth rate and foraging rate in this species at different temperatures. They found that growth rate (at 10, 15, 19 and 24 °C) increased steadily with increasing temperature up to 19 °C and leveled off above this temperature. Feeding rate (at 9, 19, and 25 °C) also increased with temperature up to 19 °C but decreased above this temperature. Since these experiments suggest that ~19 °C is ideal for both feeding and growth in this species, it may be that ~19 °C is also favorable for other aspects of the biology of the species and may be close to its generally preferred water temperature. This temperature would be most likely available in summer. (Contrastingly, in *L. aliciae* both growth rate and feeding rate increased with increasing temperature at all temperatures tested. At lower temperatures both growth rate and feeding rate were greater in *L. copei* than in *L. aliciae*.) Sigler and Miller (1963), writing of *Gila copei* (*sensu lato*, = *Lepidomeda aliciae* and *L. copei* [*sensu stricto*]), stated: "This species typically occurs in cool to cold creeks and rivers . . . . [W]ater temperatures from mid-June to mid-September vary between 50° and 74°, usually about 60° to 68° F."

*Most important indicators.

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woundfin (*Plagopterus argentissimus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat	substrate	—	—	—	5–10-cm diameter "rock" (i.e., cobble)	Greger and Deacon (1982)	
spawning habitat	water depth	—	—	—	7–10 cm	Greger and Deacon (1982)	
spawning habitat	water temperature	—	—	—	25 °C	Greger and Deacon (1982)	"Spawning of woundfin occurs primarily in the spring when water temperatures reach about 25–26 C during the diurnal temperature cycle" (Greger and Deacon 1982).
spawning habitat	water velocity	—	—	—	0.06–0.09 m/s	Greger and Deacon (1982)	
spawning success	mean flow during spawning (April–June)	<200 cfs or >900 cfs	200–400 cfs or 800–900 cfs	400–600 cfs or 700–800 cfs	600–700 cfs	Deacon and Hardy (1982)	Other (mostly earlier) authors have suggested that much lower flows in spring are favorable, but Deacon and Hardy (1982) strongly argued that this is not so.
juvenile habitat	shallow areas at margins of stream or river	absent	—	—	present	Cross (1978) and other authors	
habitat (general)	stream feature	other (0%)	pools (5%)	riffles (20%)	runs (75%)	Cross (1978)	Percentages in parentheses are the frequencies of woundfin occurrences reported by Cross (1978).
habitat (general)	portion of drainage	large tributary (0%)	small tributary (19%)	mainstream (ecotone) (55%)	mainstream (sand) (92%)	Cross (1985)	Percentages in parentheses are the frequencies of woundfin occurrences within each category reported by Cross (1985) (and do not total 100%).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (juveniles, subadults, ≤40 mm TL)	water depth[2, *]	<0.22 ft or >2.46 ft	0.22–0.46 ft or 2.00–2.46 ft	0.46–0.67 ft or 1.54–2.00 ft	0.67–1.54 ft	Hardy et al. (1989)[3]	
habitat (adults, >40 mm TL)	water depth[2, *]	<0.16 ft or >2.25 ft	0.16–0.32 ft or 1.73–2.25 ft	0.32–0.48 ft or 1.38–1.73 ft	0.48–1.38 ft	Hardy et al. (1989)[3]	
habitat (general)	cover	none	—	—	overhanging deadfalls, brush, or trees	Cross (1978)	Cross (1978) reported that ½ of his captures of woundfins were associated with some type of cover, usually overhanging live or dead vegetation.
habitat (juveniles, subadults, ≤40 mm TL)	substrate*	rock, silt, mud	gravel, cobble	—	sand	Hardy et al. (1989)[3]	Cross (1978) reported that the woundfin "was collected over sand (60 percent of all collections), rubble and cobble (30 percent), and mud (10 percent) substrates" but did not report frequencies by size or age classes.
habitat (adults, >40 mm TL)	substrate*	gravel, cobble, rock, silt, mud	—	—	sand	Hardy et al. (1989)[3]	Cross (1978) reported that the woundfin "was collected over sand (60 percent of all collections), rubble and cobble (30 percent), and mud (10 percent) substrates" but did not report frequencies by size or age classes.
habitat (general)	turbidity*	low (clear)	fairly low	fairly high	high (silty, murky)	Williams (1977)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (general)	water temperature	<0 °C or >39 °C	0–10 °C or 32–39 °C	10–18.5 °C or 20.5–32 °C	18.5–20.5 °C	Deacon et al. (1987)	Water temperatures in the Virgin Rive can fluctuate by 15–20 °C daily, reaching 36 °C in some areas. This species has relatively great thermal tolerances and preferences. "At higher temperatures . . . the red shiner may have an advantage over woundfin, while at lower temperatures (below 25 C), the reverse may be true" (Deacon et al. 1987). The work of Deacon et al. (1987) was experimental, under controlled, artificial conditions. Cross (1978) reported capturing woundfins under natural conditions at water temperatures ranging 10.0–35.5 °C, mean 23.7 °C.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (general)	conductivity (see Comments)	<150 µmhos or »2,650 µmhos	150–575 µmhos or 1,925–2,650 µmhos	575–1,000 µmhos or 1,200–1,925 µmhos	1,000–1,200 µmhos	Cross (1978)	**N.B.**: Cross (1978) reported capture of woundfins at conductivities ranging 150–2,650 µmhos (at 25 °C), mean ~1,100 µmhos, which is indicative of tolerated conditions. However, water quality of the Virgin River system is altered and degraded from natural conditions, and conductivities preferred by and healthy for woundfins are not known. It is known that hypersaline conditions (salinity ~7 ppt, conductivity ~17,000 µmhos at 25 °C) where outflows from Pah Tempe Springs enter the Virgin River are a barrier to upstream distribution of the woundfin.
habitat (juveniles, subadults, ≤40 mm TL)	water velocity[4, *]	<0.03 ft/s or >2.16 ft/s	0.03–0.14 ft/s or 1.81–2.16 ft/s	0.14–0.25 ft/s or 1.44–1.81 ft/s	0.25–1.44 ft/s	Hardy et al. (1989)[3]	
habitat (adults, >40 mm TL)	water velocity[4, *]	<0.12 ft/s or >2.34 ft/s	0.12–0.46 ft/s or 1.96–2.34 ft/s	0.46–0.78 ft/s or 1.57–1.96 ft/s	0.78–1.57 ft/s	Hardy et al. (1989)[3]	
competition	introduced fishes (e.g., red shiner)*	abundant	common	scarce	absent	various authors including Lentsch et al. (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	introduced fishes (e.g., mosquito-fish, green sunfish, bluegill, largemouth bass, black bullhead)*	abundant	common	scarce	absent	various authors including Lentsch et al. (1995)	
parasitism (mortality, reduced vigor, decreased reproduction, etc.)	Asian fish tapeworm and other parasites (see Heckmann et al. 1986)*	present	—	—	absent	Heckmann et al. (1986)	The Asian fish tapeworm is "of major concern", and "all cyprinids [in the Virgin River system, including the woundfin,] were infected at levels that could severely damage the populations". "The tapeworm probably arrived [in the Virgin River system] in the spring of 1984 along with the red shiner . . . " (Heckmann et al. 1986). Parasite loads were found to be higher in reaches with poorer water quality and greater habitat disturbance. "Low river flows and increased total dissolved solids appear to be associated with a higher parasite frequency and mean number in fishes of the Virgin River [including the woundfin]" (Heckmann et al. 1986).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, water quality	hydrological alterations (irrigation withdrawals and returns, diversions, dams, agricultural and municipal effluents, channelizations, etc.)	existing or planned	—	—	none	Cross (1978), Deacon and Hardy (1982), Heckmann et al. (1968), Lentsch et al. (1995), other authors	Heckmann et al. (1986, pp 672–674) provided a particularly good discussion of ecological consequences of disturbance factors.

[1]The woundfin formerly occurred in the Gila River system (Arizona) and the Virgin River system (Utah, Nevada, and Arizona), both being parts of the lower Colorado River drainage. The species is extirpated from the Gila River system and survives only in parts of the Virgin River system (Washington County, Utah; Mohave County, Arizona; and Clark County, Nevada). Attempts to reestablish the species in the Gila River system and to introduce it outside of its historical range in Arizona have thus far been unsuccessful.

[2]Cross (1978) reported that the average depth of capture of woundfins was 43 cm and the average depth of the water that they inhabited was 25 cm. It is possible that the numbers have been reversed. Cross' (1978) samples apparently included various sizes and age classes, although he was not explicit. Assuming that the average water depth where Cross (1978) captured woundfins was 43 cm (1.41 ft), this agrees well with the suitability index models of Hardy et al. (1989), which have been adapted for this table.

[3]Hardy et al. (1989) presented a series of habitat suitability index "curves" (i.e., models) that have been utilized here. However, it should be noted that it is customary, in the presentation of habitat suitability index (HSI) models, to state the assumptions upon which such models are based and to explain the construction of the models, neither of which were done by Hardy et al. (1989). Thus it is impossible to evaluate the HSI models of Hardy et al. (1989).

[4]Cross (1978) reported capture of woundfins at water velocities ranging 0–1.13 m/s (0–3.71 ft/s), mean 0.42 m/s (1.38 ft/s), which is indicative of tolerated conditions (bearing in mind that flows in the Virgin River system are greatly altered from natural conditions) and is in general agreement with the habitat suitability models of Hardy et al. (1989). Although Cross' (1978) samples apparently included various sizes and ages of woundfins, he did not report frequencies of occurrence at different water velocities by size or age classes. Spawning woundfins preferred velocities of 0.06–0.09 m/s (0.20–0.30 ft/s) in experiments conducted by Greger and Deacon (1982) (see spawning habitat indicator above), which also is in general agreement with the habitat suitability index models of Hardy et al. (1989), and it is expected that water velocities selected and suitable for spawning would be low, to allow eggs to settle to selected substrates and to avoid their displacement by swift currents.

*Most important indicators.

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desert sucker (*Catostomus clarkii*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body*	other	—	—	desert and mountain streams (large and small)	Smith (1966)	
habitat	elevation*	<2,000 ft or >8,000 ft	—	—	2,000–8,000 ft	Smith (1966)	
habitat (general)	portion of drainage (see Comments)	mainstream (sand) (8%)	—	small tributaries (62%)	mainstream (ecotone) (79%), large tributaries (72%)	Cross (1985)	Percentages in parentheses are the frequencies of *C. clarkii* occurrences within each category reported by Cross (1985) (and do not total 100%). Cross (1975) had reported that 60% of his captures were in tributary creeks and 40% were in middle and upper reaches of the mainstream (of the Virgin River) and that this species "was collected from every creek tributary to the mainstream [Virgin River], occurring in more than 90% of the collections." **N.B.**: Whether this pattern exists in other river systems is not known.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	stream feature (see Comments)	other	riffles (10%)	pools (30%)	runs (60%)	Cross (1975)	**N.B.**: Ratings are based on the frequencies of occurrence reported by Cross (1975), which are shown in parentheses. However, **runs, pools, and riffles all may be important in the life history of this species**. Runs may be feeding areas for adults, and pools may provide resting or hiding areas. Riffles are believed to be used as spawning sites. Shallows (e.g., shorelines and other shallows) may be important habitat for larvae and juveniles.
habitat	cover	none	undercut banks	deadfalls	boulders, overhanging trees and shrubs	Cross (1975)	Cross (1975) reported that >79% of his captures of this species in the Virgin River were associated with some type of cover. Rankings are the frequencies observed by Cross (1975).
habitat	aquatic vegetation	—	—	—	algae, watercress, pondweed	Smith (1966)	The importance, if any, of this indicator is not known.
habitat (juveniles, ≤80 mm TL)	water depth[3]	<0.25 ft or >2.82 ft	0.25–0.33 ft or 2.47–2.82 ft	0.33–0.42 ft or 2.11–2.47 ft	0.42–2.11 ft	Hardy et al. (1989)[4]	
habitat (subadults, 81–150 mm TL)	water depth[3]	<0.22 ft or >3.01 ft	0.22–0.32 ft or 2.54–3.01 ft	0.32–0.41 ft or 2.08–2.54 ft	0.41–2.08 ft	Hardy et al. (1989)[4]	
habitat (adults, >150 mm)	water depth[3]	<0.30 ft or >3.19 ft	0.30–0.43 ft or 2.86–3.19 ft	0.43–0.57 ft or 2.52–2.86 ft	0.57–2.52 ft	Hardy et al. (1989)[4]	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (juveniles, ≤80 mm TL)	water velocity[5] (see Comments)	<0.12 ft/s or >2.42 ft/s	0.12–0.32 ft/s or 2.28–2.42 ft/s	0.32–0.51 ft/s or 2.14–2.28 ft/s	0.51–2.14 ft/s	Hardy et al. (1989)[4]	Smith (1966) stated: "Current velocity is variable, ranging from the swift waters of the Virgin River in Arizona (observed current velocity of 4 to 6 feet per second) and the montane tributaries of the Gila system to pools or sluggish streams with little current."
habitat (subadults, 81–150 mm TL)	water velocity[5] (see Comments)	<0.12 ft/s or >2.50 ft/s	0.12–0.29 ft/s or 2.06–2.50 ft/s	0.29–0.45 ft/s or 1.85–2.06 ft/s	0.45–1.85 ft/s	Hardy et al. (1989)[4]	Smith (1966) stated: "Current velocity is variable, ranging from the swift waters of the Virgin River in Arizona (observed current velocity of 4 to 6 feet per second) and the montane tributaries of the Gila system to pools or sluggish streams with little current."
habitat (adults, >150 mm)	water velocity[5] (see Comments)	<0.13 ft/s or >2.73 ft/s	0.13–0.27 ft/s or 2.52–2.73 ft/s	0.27–0.43 ft/s or 2.31–2.52 ft/s	0.43–2.31 ft/s	Hardy et al. (1989)[4]	Smith (1966) stated: "Current velocity is variable, ranging from the swift waters of the Virgin River in Arizona (observed current velocity of 4 to 6 feet per second) and the montane tributaries of the Gila system to pools or sluggish streams with little current."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water temperature*	<0 °C or >37 °C	0–10 °C or 30–37 °C	10–18.5 °C or 20.5–30 °C	18.5–20.5 °C	Deacon et al. (1987)	The work of Deacon et al. (1987) was experimental, under controlled, artificial conditions. Smith (1966) mentioned that observed temperatures of inhabited waters in summer during the day ranged 16–28 °C and that inhabited waters in high-elevation and northern locations in winter approach freezing. Cross (1975) reported: "Temperatures varied from 10° to 35° C with a mean value of 20.4° C (±7)." Sigler and Sigler (1996) stated that "water temperatures vary seasonally and fluctuate from 45° to 85°F (7.2° to 29.4°C) from spring to September; however, they may invade trout [i.e., cold] waters."
habitat	conductivity (at 25 °C)	<60 µmhos or >2,700 µmhos	60–348 µmhos or 1,932–2,700 µmhos	348–636 µmhos or 1,164–1,932 µmhos	636–1,164 µmhos	Cross (1975)	Cross (1975) reported captures at conductivities ranging 60–2,700 (mean 780) µmhos. Ratings are interpolations (above and below the mean) from these data.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
uncertain (perhaps competition or predation)	no. of other fish species (including native species)	>4	4	3	≤2	Cross (1975)	Cross (1975) reported that this species "was most abundant (40% to 90% of the [ichthyo-] fauna) and found in the largest numbers in streams with two or fewer additional [fish] species. In more speciose streams the desert sucker generally comprised less than 40% of the [ichthyo-] fauna and was found in smaller numbers."
predation, competition, parasites	nonnative fishes*	many (>27%)	some (18–27%)	few (9–18%)	none or extremely few (0–9%)	Cross (1978)	Cross (1975) reported that where he captured desert suckers in the Virgin River system, "native fishes comprised an average of 93% (±20) of the [ichthyo] fauna." Percentages in parentheses are derived from these numbers.
hybridization	other species of suckers, *Catostomus*, esp. those of subgenus *Pantosteus* (particularly *Catostomus discobolus*, the bluehead sucker) (see Comments)	≥3 or ≥1 co-occurring in same microhabitats or ≥1 under stressful conditions (e.g., reduced depths and flows)	2, ecologically segregated	1, ecologically segregated	none	various authors	Hybrids between this species and at least 3 other sucker species have been reported. However, natural hybridization in many other sucker species is well known, and it is possible that such hybridization may be of little conservational importance for the desert sucker despite the concerns of some authors (e.g., Sigler and Sigler 1996).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	habitat alteration*	extensive (large irrigation withdrawals, channeliz-ation, organic pollution)	slight (partial irrigation withdrawals, irrigation leaching)	—	none	Cross (1975)	Cross (1975) reported that 80% of his captures of this species in the Virgin River were from habitat that was considered physically unaltered.

[1]This species inhabits parts of the lower Colorado River drainage (but perhaps not including the Colorado River itself, despite Sigler and Sigler's [1996] assertion otherwise) below the Grand Canyon in the Gila, Virgin, Bill Williams, and pluvial White and Carpenter river systems, in se. Nevada, sw. Utah, c. and s. Arizona, w.-c. New Mexico, and extreme n. Sonora. Several of its populations are morphologically distinct. Most of these are allopatric, but some may be sympatric or nearly so. For example, in the Virgin River system there are 2 morphological forms, 1 inhabiting tributaries and the other the mainstream of the Virgin River, and "[t]he populations live within a few feet of each other where the Beaver Dam Wash joins the Virgin River" (Smith 1966). Minckley (1973) only reluctantly treated the various morphologically distinctive populations as a single species, implying that they represent a complex of at least 4 species. If so, the name *Catostomus clarkii* would likely apply only to populations in the Gila River drainage of Arizona, New Mexico, and Sonora.

[2]Most of the ecological information pertaining to this species that has been found and utilized in this table comes from studies of this species in the Utah and Arizona portions of the Virgin River system (e.g., Cross 1975, 1985, Deacon et al. 1987, Hardy et al. 1989), and this table thus may be expected to have greatest applicability in this part of the species' range.

[3]Cross (1975) reported that the average depth of capture of the desert sucker was 56 cm and the average depth of the water that they inhabited was 41 cm. It is possible that the numbers have been reversed. Cross' (1975) samples apparently included various sizes and age classes (≤30 mm to ≥198.9 mm SL). Whether the average water depth where Cross (1975) captured *C. clarkii* was 41 cm (1.35 ft) or 56 cm (1.84 ft), either agrees well with the habitat suitability index models of Hardy et al. (1989), which have been adapted for this table. According to Smith (1966): "Depth of capture is usually less than 2 ft [61 cm]."

[4]Hardy et al. (1989) presented a series of habitat suitability index "curves" (i.e., models) for the desert sucker in the Virgin River system that have been utilized here. However, it should be noted that it is customary, in the presentation of habitat suitability index (HSI) models, to state the assumptions upon which such models are based and to explain the construction of the models, neither of which were done by Hardy et al. (1989). Thus it is impossible to evaluate the HSI models of Hardy et al. (1989). The HSI models of Hardy et al. (1989) for the desert sucker were limited to the Virgin River system, but they disagreed in some ways with the findings of Cross (1975) concerning the ecology of this species in that river system (e.g., preferred substrates). For example, the HSI models of Hardy et al. (1989) indicate sand to be by far the most suitable substrate for all size or age classes of the desert sucker in the Virgin River system, with most other substrates having poor suitability for all age or sizes classes and a few substrates rating "fair" for some size classes. Although he did not separate size or age classes, Cross (1975) reported that ⅔ of his captures were over rubble–cobble substrates and ⅓ were over sand and sediments, in strong disagreement with the HSI models of Hardy et al. (1989). Cross (1975) wrote: "The predilection of *P. clarki* [i.e., *C. clarkii*] for rocky substrates is demonstrated by a collection made . . . in March 1975 . . . . Two riffles separated by a sand bar were seined; depth and current velocity were similar for both; one riffle had a rock substrate while the other was sand. *P. clarki* comprised 44% of the fishes from the rocky riffle and was absent from the sandy riffle." Smith (1966), discussing the desert sucker

throughout its range, wrote: "Observed bottom materials include sand, rubble, boulders, mud, and bedrock." Because of the disagreement concerning substrate suitability in the Virgin River system (Hardy et al. 1989 vs. Cross 1975) and uncertainty concerning substrate suitability elsewhere, substrates have not been included as indicators in this table.

[5]Cross (1978) reported capture of the desert sucker at water velocities ranging 0.08–1.10 m/s (0.26–3.61 ft/s), mean 0.42 (± 0.27) m/s (1.38 ± 0.89 ft/s), which is indicative of tolerated conditions and is in general agreement with the habitat suitability models of Hardy et al. (1989). However, flows in the Virgin River system are greatly altered from natural conditions. Although Cross' (1978) samples apparently included various sizes and ages (he mentioned young as small as 15–30 mm SL and an adult as large 198.9 mm SL), he did not report frequencies of occurrence at different water velocities by size or age classes.

*Most important indicators.

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bluehead sucker (*Catostomus discobolus*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body[2,*]	lentic waters (e.g., reservoirs, lakes, ponds)	small streams	medium-sized streams	large streams, rivers	Smith (1966), Sigler and Sigler (1996), Bezzerides and Bestgen (2002)	
habitat	water depth	<0.5 m or >3.0 m	0.5–1.0 m or 2.0–3.0 m	1.5–2.0 m	1.0–1.5 m	Beyers et al. (2001)	**N.B.**: Indicator "ratings" are based on only 1 study (i.e., Beyers et al. 2001).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, reproduction	water temperature in summer*	>83 °F (>28.3 °C) or <60 °F (<15.6 °C)	76–83 °F (24.6–28.3 °C)	68–76 °F (20.0–24.6 °C)	60–68 °F (15.6–20.0 °C)	Smith (1966), Sigler and Sigler (1996), Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	"Spawning occurs in the spring and early summer at lower elevations and warmer waters, and mid- to late summer in higher, colder waters. Spawning is initiated at about 60°F (15.6°C)" (Sigler and Sigler 1996). "Water temperatures during spawning generally range from 15.6 to 24.6 °C . . . " (Bezzerides and Bestgen 2002, citing others). Olden et al. (2006, App. B) considered the temperature preference of this species to be in the "cool" range (18–26 °C), its critical thermal tolerance (maximum) to be in the "moderate" range (30–35 °C), and the temperature at which its spawning is initiated to be 16 °C.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adults)	current (velocity)	none, slow or very fast	—	—	moderate to fast	Smith (1966), Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	"The range of current velocity occupied by members of this species [*C. discobolus*] is great . . . Maximum currents are between 8 and 15 feet per second . . . " (Smith 1966). "Bluehead sucker adults are almost always found in areas with moderate to fast current . . . " (Bezzerides and Bestgen 2002, citing others). Olden et al. (2006, Appendix B) also considered the current preference of this species to be moderate to fast.
habitat (adults)	substrate	—	sand, silt	gravel	rocks, boulders	various sources including Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	Olden et al. (2006, Appendix B) considered the substrate preference of this species to be rubble (including cobble and gravel). Spawning has been observed over gravel (Bezzerides and Bestgen 2002, citing another source).
habitat	elevation*	>2,225 m (>7,300 ft) or <381 m (<1,250 ft)	—	—	≤2,225 m (≤7,300 ft)	various sources including Bezzerides and Bestgen (2002, p 58)	The lowest elevation inhabited by this species is in the Colorado River (or its tributaries) upstream from Lake Mead, probably ~1,250 ft. The highest elevational record for this species in Utah is 7,295 ft (2,223 m) (Utah Natural Heritage Program database 2008).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization, genetic swamping	presence of other species of *Catostomus* (e.g., *C. latipinnis*, flannel-mouth sucker, *C. platyrhynchus*, mountain sucker, *C. ardens*, Utah sucker, and *C. commersoni*, white sucker)	C. commersoni or ≥3 species	2 species (not including *C. commersoni*)	1 species (not including *C. commersoni*)	none	Smith (1966), Sigler and Sigler (1996), Bezzerides and Bestgen (2002)	Discussing limiting factors for *C. discobolus*, Sigler and Sigler (1996) wrote: "Hybridization with other species of the genus *Catostomus*, such as flannelmouth and white sucker, dilute their genetic structure." (In most, if not all, places where *C. discobolus* occurs with the white sucker, *C. commersoni*, the latter is a nonnative, introduced species.) Bezzerides and Bestgen (2002, pp 56, 71–72) have noted that hybridization with *C. commersoni* has increased dramatically in many of the rivers of the upper Colorado River basin but that we lack understanding of "how to manage these systems to reduce the effects of hybridization."
competition, predation, hybridization, diseases and parasites	nonnative fishes (numbers of both species and individuals)[2]	many	moderate numbers	few	none	various sources	
habitat degradation, thermal ecology (metabolism, foraging success, reproduction, larval and juvenile survival, growth)	flow alterations (e.g., reservoir construction and operation, diversions, withdrawals])[2,*]	present	—	—	absent	Bezzerides and Bestgen (2002, Table 11)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
uncertain (perhaps migration or dispersal) see Comments	linear extent of unobstructed, suitable habitat (without dams, etc.)[2]	<1.6 km	1.6–10 km	10–20 km	>20 km	sources reviewed by Bezzerides and Bestgen (2002)	Although movements of up to 35 km have been reported in this species, most marked and recaptured individuals have been found not to have moved far, if at all.

[1]This species is found in various river systems in parts of Idaho, Wyoming, Utah, Colorado, Arizona, and New Mexico, where it occurs in mountain streams and lower elevation rivers. Adults inhabit rivers and streams with water depths up to 3 m, moderate to fast current, rocky substrates, and cool temperatures. Larvae and juveniles utilize shallower, slower, and perhaps warmer shorelines, backwaters, and tributaries. Smaller tributaries to larger rivers may in fact be of critical importance to this species.[2] Various morphological types exist within this species, seemingly representing specialized adaptations to particular ecological conditions, including differing water velocities. Bezzerides and Bestgen (2002) commented: ". . . [T]he bluehead sucker has been largely ignored by scientists. As a result, little is known about the distribution and abundance, ecology, and status of this comparatively common fish."

[2]Bezzerides and Bestgen (2002, pp 72–73), discussing *C. discobolus* (and 2 other fish species) in the upper Colorado River basin, noted (citing others): "Use of smaller tributary systems for spawning, rearing, and/or adult habitat is well-documented for . . . bluehead sucker . . . . Several authors have attributed the success and overall persistence of [this] species to tributary use. . . . [T]ributary streams may provide permanent or seasonal refugia from habitat alteration by mainstem dams and high densities of non-native fishes. Tributary streams often have physical characteristics vastly different from mainstem habitats, especially where mainstem reservoir construction has occurred . . . . In mainstem river reaches altered by reservoir construction, tributary streams may supply habitats similar to pre-dam mainstem habitats . . . . Many tributaries are also noted to have lower numbers of non-native species, especially in upstream reaches . . . . Evidence of the importance of tributaries is found where resident populations of [this] species are present in tributary streams, but few or no individuals are present in nearby mainstem rivers or impoundments . . . . Additional evidence is found where reproduction occurring in tributary systems may maintain populations in mainstem habitats where reproduction is limited . . . ."

*Most important indicators.

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gvo

flannelmouth sucker (*Catostomus latipinnis*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water body[2,*]	lentic waters (e.g., reservoirs, lakes, ponds)	small streams	medium-sized streams	rivers, large streams	Sigler and Sigler (1996), Bezzerides and Bestgen (2002)	
habitat	water depth see Comments	<0.5 m or >2.5 m	0.5–1.0 m or 2.0–2.5 m	1.5–2.0 m	1.0–1.5 m	Beyers et al. (2001)	**N.B.**: Indicator "ratings" are based on only 1 study (i.e., Beyers et al. 2001). Sigler and Sigler (1996), writing of this species stated: ". . . [D]epths are 3 to 20 ft (0.9 to 6.1 m)."
reproduction (spawning migrations), etc.[2]	connectivity of mainstem rivers to smaller tributaries[2]	impeded by barriers (e.g., dams)	some movements possible, but limited	unimpeded in spring	unimpeded year-round	various sources including Bezzerides and Bestgen (2002)[2]	
nursery habitat	aquatic complexity	none (all run, no slackwater areas)	limited (very few slackwater areas)	moderate (slackwater areas and patchy)	abundant (including many slackwater areas)	various sources	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
reproduction	water temperature in spring (spawning) (March and April in the lower Colorado River basin, May and June in the upper Colorado River basin)	<6 °C or >18.5 °C	6–8 °C or 16–18.5 °C	8–10 °C or 14–16 °C	10–14 °C	Sigler and Sigler (1996), Bezzerides and Bestgen (1996, citing others), Olden et al. (2006, Appendix B)	"Males begin to ripen in the spring not long after the ice goes out at about 43° or 44°F (6.1° or 6.7°C), the females later, probably at 50°F (10°C)" (Sigler and Sigler 1996). "Water temperatures commonly reported with spawning activity range from 6 to 18.5 °C . . . " (Bezzerides and Bestgen 2002, citing others). Olden et al. (2006, Appendix B) indicated the temperature at which its spawning is initiated to be 11 °C. The "ratings" are interpolations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	water temperature in summer*	<10 °C or >30 °C	10–17.5 °C or 29–30 °C	17.5–25 °C or 27–29 °C	25–27 °C	Deacon et al. (1987), Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	In experiments with this species from the Virgin River, Utah, Deacon et al. (1987) concluded that its preferred temperature is 25.9 °C (modal variation being 10–27 °C), its critical thermal maximum (CTM) is ~31–37 °C. Noting that summer water temperatures in the Virgin River often exceed 30 °C and reach 36 °C in some areas, they commented: "This [its CTM] may partly explain the near absence of the flannelmouth sucker in Virgin River below Mesquite, Nevada." Olden et al. (2006, App. B) considered the temperature preference of this species to be in the "warm" range (>26 °C) and its critical thermal tolerance (maximum) to be in the "moderate" range (30–35 °C).
habitat (adults)	current (velocity)	—	slow or very fast	fast	moderate	Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	Olden et al. (2006, Appendix B) listed the current preference of this species to be "moderate". However, Bezzerides and Bestgen (2002) noted: "Flannelmouth suckers use a wide variety of habitats . . . " and have been collected ". . . in all habitat types including fast current, riffles, eddies, and stagnant backwaters in the Green River, Colorado and Utah."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (adults)	substrate	—	—	mud, silt, sand	gravel, cobble, boulders	various sources including Bezzerides and Bestgen (2002), Olden et al. (2006, Appendix B)	Olden et al. (2006, Appendix B) considered the substrate preference of this species to be rubble (including cobble and gravel). "The . . .eggs . . . are usually deposited over sand and gravel bars in shallow water . . . " (Bezzerides and Bestgen 2002, citing other sources).
habitat	elevation*	>1,980 m (>6,497 ft)	1,880–1,980 m (6,168–6,497 ft)	1,700–1,880 m (5,577–6,168 ft)	<1,700 m (<5,577 ft)	Utah Natural Heritage Program database (2008) and other sources see Comments	Bezzerides and Bestgen (202, p 42) noted that historically "[i]n the LCRB [lower Colorado River basin], flannelmouth suckers were present in rivers and streams from near sea level to around 1,700 meters elevation." In a fish distribution study in Wyoming, no *C. latipinnis* were found above 1,880 m elevation, and the authors hypothesized that colder water temperatures limited the distribution of this species at higher elevations (Bezzerides and Bestgen 2002, p 37, citing others). The Utah Natural Heritage Program database (2008) contains Utah records of this species up to 1,980 m (6,497 ft) elevation.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization, genetic swamping	presence of other species of suckers (e.g., *C. ardens*, Utah sucker, *C. clarkii*, desert sucker, *C. commersoni*, white sucker, *C. discobolus*, bluehead sucker, and *Xyrauchen texanus*, razorback sucker)	C. commersoni or ≥3 species	2 species (not including *C. commersoni*)	1 species (not including *C. commersoni*)	none	Bezzerides and Bestgen (2002)	Bezzerides and Bestgen (2002, pp 41, 71–72) have noted that hybridization with *C. commersoni* has increased dramatically in many of the rivers of the upper Colorado River basin but that we lack understanding of "how to manage these systems to reduce the effects of hybridization." (In most places where *C. latipinnis* occurs with the white sucker, *C. commersoni*, the latter is a nonnative, introduced species.)
competition, predation, hybridization, diseases and parasites	nonnative fishes (numbers of both species and individuals)[2]	many	moderate numbers	few	none	various sources	
habitat degradation, thermal ecology (metabolism, foraging success, reproduction, larval and juvenile survival, growth)	flow alterations (e.g., reservoir construction and operation, diversions, withdrawals])[2,*]	present	—	—	absent	Bezzerides and Bestgen (2002, Table 11)	
spawning migration	linear extent of unobstructed, suitable habitat (without dams, etc.)[2] see Comments	<60 km	60–100 km	100–200 km	>200 km	sources reviewed by Bezzerides and Bestgen (2002)	**N.B.**: The importance of this indicator is uncertain and may vary with location.[3]

[1]This species inhabits the Colorado River drainage in parts of Wyoming, Utah, Colorado, New Mexico, Nevada, Arizona, and historically California, Sonora, and Baja California Norte. "Except for speckled dace, *Catostomus latipinnis* was and probably is the most widely distributed and abundant native fish in the CRB [Colorado River basin]" (Bezzerides and Bestgen 2002, citing others). "Interestingly, these fish [i.e., *C. latipinnis*] originally adapted to historic Colorado River conditions, have adapted to today's changed habitat in the Colorado River Basin better than several other native fishes" (Sigler and Sigler 1996).

[2]Bezzerides and Bestgen (2002, pp 72–73), discussing *C. latipinnis* (and 2 other fish species) in the upper Colorado River basin, noted (citing others): "Use of smaller tributary systems for spawning, rearing, and/or adult habitat is well-documented for flannelmouth sucker . . . . Several authors have attributed the success and overall persistence of [this] species to tributary use. . . . [T]ributary streams may provide permanent or seasonal refugia from habitat alteration by mainstem dams and high densities of non-native fishes. Tributary streams often have physical characteristics vastly different from mainstem habitats, especially where mainstem reservoir construction has occurred . . . . In mainstem river reaches altered by reservoir construction, tributary streams may supply habitats similar to pre-dam mainstem habitats . . . . Many tributaries are also noted to have lower numbers of non-native species, especially in upstream reaches . . . . Evidence of the importance of tributaries is found where resident populations of [this] species are present in tributary streams, but few or no individuals are present in nearby mainstem rivers or impoundments . . . . Additional evidence is found where reproduction occurring in tributary systems may maintain populations in mainstem habitats where reproduction is limited . . . ."

[3]Bezzerides and Bestgen (2002, pp 37–39) reviewed numerous studies that showed long-distance movements in this species, including some up to 231 km. They noted that "movement patterns appear to be dependent upon location and life history stage. Long distance migrations are documented for *C. latipinnis*, but do not appear widespread. . . . Extirpation of flannelmouth sucker above headwater dams . . . suggests that, although not common, long distance migrations may be important for maintenance of relatively isolated headwater populations. . . . Flannelmouth sucker may or may not migrate to spawning grounds depending on habitat availability and homing behaviors . . . ." Further, for some (but not all) populations, connectivity of mainstem rivers to smaller tributaries and unblocked migratory access to and from headwaters may be very important (see footnote 2).

*Most important indicators.

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gvo

June sucker (*Chasmistes liorus*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat (riverine)	general characteristics*	calm backwater areas	—	—	shallow riffles associated with deeper pools of rivers or streams	Shirley (1983)	
spawning habitat (riverine)	substrate	sand, silt	—	—	typically 47% medium to coarse gravel (8–50 mm), 37% small cobble (60–100 mm), 13% fine gravel (4–8 mm), and 3% sand (1–4 mm)	Shirley (1983) (but see also Radant et al. 1987)	
spawning habitat (riverine)	water depth[3]	<1.0 ft or >2.5 ft	1.0–1.3 ft or 2.2–2.5 ft	1.8–2.1 ft	1.4–1.7 ft	Shirley (1983) (but see also Radant et al. 1987)	
spawning habitat (riverine)	channel velocity[3]	<0.4 ft/s or >3.3 ft/s	0.4 ft/s or 2.6–3.3 ft/s	0.5 ft/s	0.6–2.5 ft/s	Shirley (1983) (but see also Radant et al. 1987)	
spawning habitat (riverine)	bottom velocity[3]	0 ft/s or >2.0 ft/s	0.1 ft/s or 2.0 ft/s	0.8–1.9 ft/s	0.2–0.7 ft/s	Shirley (1983)	
spawning habitat (riverine)	mean daily water temperature[3]	<6 °C or >16.5 °C	6–8.7 °C or 14.7–16.5 °C	8.8–11.5 °C or 13.0–14.6 °C	11.6–12.9 °C	Shirley (1983)	The “fair” and “good” ratings are interpolations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
transport from oviposition sites to larval development sites (riverine)	flow (mean)[3, *]	<300 cfs	≥300 cfs	>300 cfs	»300 cfs	Keleher et al. (1999)	Although a number of studies have assumed that lower flows are adequate, Keleher et al. (1999), in a well-reasoned discussion, concluded: "At flow rates less than 300 cfs, larval [June] suckers drifting at the average velocity would not get through the [Provo River] system prior to daylight, making them vulnerable to visual predators present in the river." Results of experiments conducted by Wilson and Thompson (2001) support this conclusion.
larval habitat (development)	water temperature (daily mean)[3]	<10 °C or >21 °C	10–12 °C or 19–21 °C	12–15 °C or 16–19 °C	15–16 °C	Modde and Muirhead (1990)	
larval habitat (cover, food)	general characteristics*	high velocity or cool or cold water or no aquatic vegetation	—	—	low velocity, warm water with abundant aquatic vegetation (e.g., backwaters)	Crowl et al. (1998)	
adult habitat (cover, food)	general characteristics*	—	—	—	shallows with macrophyte beds (e.g., lake shorelines, bays)	Lentsch et al. (1999)	"Artificial macrophyte beds have been successful in terms of providing small patches of habitat. These are invariably utilized by small June suckers. Other means of increasing habitat complexity should be investigated" (Lentsch et al. 1999).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	nonnative predaceous fishes (e.g., basses, walleye, sunfishes)	abundant	common	scarce	none	various authors including Lentsch et al. (1999)	Control (removal) of nonnative fishes may be necessary if they are present in abundance.
competition	nonnative zooplanktivores (e.g., juvenile gizzard shad)	abundant	common	scarce	none	Crowl et al. (1995), Lentsch et al. (1999)	Control (removal) of nonnative fishes may be necessary if they are present in abundance. "Educational information should be made available to the public at large and fishermen, specifically, to educate them as to the needs of the [June sucker] and the adverse impacts of cetin activities, such as illegal introductions of nonnative fish like gizzard shad" (Lentsch et al. 1999).
degradation of habitat and water quality (destruction of cover provided by aquatic plants, increased turbidity)	nonnative scavengers (e.g., common carp)	abundant	common	scarce	none	various authors including Lentsch et al. (1999)	Control (removal) of nonnative fishes may be necessary if they are present in abundance.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
alteration of hydrology (e.g., flow and temperature regimes, habitat complexity, and thus cover, food)	channelizations, diversions, dams, weirs, etc.*	existing or planned	—	—	none	Lentsch et al. (1999)	Formerly ". . . the Provo River was braided and meandering prior to emptying into Utah Lake. Seven separate channels existed prior to channelization of the river, providing a variety of habitat types, structure and flows. . . . The lower Provo River has been drastically altered from its historic channel configuration and no longer provides the cover and variety of habitats necessary for successful recruitment. The potential for restoring important components, such as restoration of aquatic vegetation, instream structure, channel complexity, and off-channel habitats, of the historic Provo River habitat should be explored" (Lentsch et al. 1999).
water quality	agricultural, industrial, and municipal effluents	present	—	—	none	Lentsch et al. (1999)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning	law enforcement and other protection during spawning runs	none	—	—	present	Lentsch et al. (1999)	Lentsch et al. 1999) recommended to "[m]aintain presence of law enforcement officials and biologists in the Provo River to protect the June sucker during the spawning run. . . . The law enforcement presence, as well as increase in public contacts, will be important in reducing illegal activities related to June sucker."

[1]What is currently called the June sucker (*Chasmistes liorus*) may not be the species to which that name was originally given but instead may be a hybrid swarm resulting from interbreeding of the original June sucker and the Utah sucker (*Catostomus ardens*). The subspecific name *Chasmistes liorus mictus* has been assigned to June suckers taken since 1939, which are considered hybrids, and the name *Chasmistes liorus liorus* to those collected before 1900, which are considered pure-bred, though such taxonomy, being in clear violation of the International Code of Zoological Nomenclature, is invalid and should not be used. However, an alternate hypothesis, not involving hybridization, also has been proposed. The natural range of the June sucker was Utah Lake and, during spawning, its tributaries, mainly the lower Provo River. Additionally, several artificial "refuge" populations have been established elsewhere in northern Utah. In the late 19th century the June sucker was astoundingly abundant in Utah Lake, but drought, overexploitation, and destruction and alteration of habitat have critically reduced its population and resulted in its federal listing in 1986 as endangered.

[2]A brief synopsis of the life history of this species may aid in the use of this table: Adults live in a shallow, turbid lake (Utah Lake). In June, they move up a tributary stream or river (e.g., the Provo River) where they rest in pools and spawn over gravel in shallows (riffles). The fertilized eggs fall to the bottom and develop for a period of days (dependent upon temperature). "Swim up" of larvae occurs in the middle of night, and larvae are swept downstream toward the lake in darkness, thus avoiding heavy predation by visual predators. When the larvae reach backwaters and other areas of low flow, they cease their passive drift and settle out, preferably in areas with aquatic vegetation and abundant plankton where they can complete larval development. Presumably as fingerlings, they move into the lake, where they prefer areas with emergent aquatic vegetation that provide cover and food. The main problem affecting survival of developing larvae, and thus recruitment, is the stretch of the Provo River below a weir and above the river's entrance to Utah Lake; this stretch has low flow and backwaters, such as the larvae seek for their development, but lacks the necessary protective cover and food provided by stands of aquatic vegetation. Like larvae, adults are planktivores. Current understanding of the ecology of adult June suckers in the lacustrine situation is very limited, but studies in progress seek to determine whether there is habitat segregation and spatial segregation between adult June suckers and Utah suckers in Utah Lake.

[3]Indicators of spawning conditions are for the spawning period, which for the June sucker is perhaps late May to early July, but primarily mid-June, hence this sucker's common name.

*Most important indicators.

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razorback sucker (*Xyrauchen texanus*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning migrations and other movements	length of suitable aquatic habitat	<20 km in rivers or <8 km in reservoirs	20–60 km in rivers or 8–14 km in reservoirs	60–100 km in rivers or 14–20 km in reservoirs	>100 km in rivers or >20 km in reservoirs	Valdez et al. (2002) and sources cited therein	In both rivers and reservoirs some razorback suckers make very long migratory movements for spawning, although at other times they tend to be relatively sedentary. For example, Tyus (1987) found that 28 of 52 tagged individuals moved an average of 59.3 km in ≤8 years, the longest movement being 206 km in 5 years, and other studies have documented movements of >100 km in rivers. Reported movements and apparent spawning migrations in reservoirs have involved distances of 8–24 km.
population ("minimum viable population")	no. of individuals (adults)	<5,763	5,763	>5,763	»5,763	Valdez et al. (2002)	Calculations of minimum viable populations are based on assumptions and best guesses.
general habitat	water body*	other (e.g., irrigation canals)	small rivers, reservoirs	medium rivers	large rivers	various authors	Although aging adults survive in the rated aquatic situations ("fair"–"very good"), larvae and juveniles do not, presumably because of predation by nonnative fishes.
breeding habitat	river feature (April–June)*	rapids, riffles	slow runs, fast runs, eddies, shorelines	pools, off-channel flooded gravel pits	backwaters	Osmundson et al. (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	river feature (July)	fast runs, rapids, eddies, off-channel flooded gravel pits	riffles, shorelines	slow runs, pools	backwaters	Osmundson et al. (1995)	
habitat	river feature (August– October)	fast runs, rapids, riffles, shorelines, backwaters, off-channel flooded gravel pits	eddies	pools	slow runs	Osmundson et al. (1995)	
habitat	river feature (November–March)	fast runs, rapids, riffles, shorelines, off-channel flooded gravel pits	backwaters	slow runs, eddies	pools	Osmundson et al. (1995)	
habitat (activity, feeding, survival, maturation, reproduction, etc.)	water temperature (summer)*	>29 °C or <12 °C	26.9–29 °C or 12–17.5 °C	24.8–26.9 °C or 17.5–22.9 °C	22.9–24.8 °C	Bulkley and Pimentel (1983)	Tailwaters of impoundments are typically much too cold. It is likely that the drop in water temperature below the dam after impoundment of the Green River to create Flaming Gorge Reservoir has caused the disappearance of *X. texanus* for 105 km downstream to the confluence of the Yampa River, where warmer water enters the Green River (Bulkley and Pimentel 1983).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning	water temperature*	<6 °C or >22 °C	6–9.5 °C or 19–22 °C	9.5–15 °C or 15–19 °C	15 °C	Tyus (1987), Valdez et al. (2002) and sources cited therein	
hatching success	water temperature*	<10 °C or >30 °C	10–15 °C or 25–30 °C	15–20 °C or 20–25 °C	20 °C	Marsh and Minckley (1985), Valdez et al. (2002) and sources cited therein	
spawning and nursery habitat	aquatic feature*	—	mouths of tributaries to rivers	shoals, shallow near-shore areas (e.g., on outwash fans) of reservoirs; low-velocity shoreline habitats in alluvial reaches of rivers	off-channel flooded gravel pits, backwaters, inundated floodplains, broad alluvial flatwater areas of rivers	Valdez et al. (2002) and sources cited therein	
spawning and nursery habitat	substrate	mud, silt, fines, sediment	—	coarse sand	cobble, gravel	Valdez et al. (2002) and sources cited therein	
spawning and nursery habitat	water velocity	»1.0 m/s	≥1.0 m/s	<1.0 m/s	0 m/s or «1.0 m/s	Valdez et al. (2002) and sources cited therein	
spawning and nursery habitat	water depth	»1.0 m	—	—	<1.0 m	Valdez et al. (2002) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
survival of eggs, larvae, and, fry (i.e., recruitment)	nonnative fishes*	present	—	—	absent	Minckley et al. (1991), Valdez et al. (2002), and others	Presence or absence of nonnative fishes is the most important single factor in the ecology of this species. If nonnative fishes are present, the likelihood of successful recruitment is very low or nonexistent. However, nonnative fishes are so well established throughout the Colorado River system that to eradicate them from any water body suitable for *X. texanus*, other than off-channel pools or ponds not connected to rivers, may be a practical impossibility. Attempts to control nonnative fishes in rivers and reservoirs for the benefit of *X. texanus* thus far have not restored recruitment.
hybridization	white sucker (*Catostomus commersoni*) and possibly other species of suckers	present in large numbers	present in moderate numbers	present in small numbers	absent	Valdez et al. (2002) and sources cited therein	Hybridization with the flannelmouth sucker is known to have occurred historically, presumably under completely natural conditions. Hybridization with the nonnative white sucker is considered to be a potential threat in the upper Colorado River basin (Valdez et al. 2002).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality (survival, food sources)	pollution (from oil and gas extraction, mining, agricultural runoff, industrial and municipal effluents, etc.)	existing	—	—	none	Valdez et al. (2002) and sources cited therein	
spawning, nursery, and adult habitats, water temperatures, food sources	alteration of natural flow regimes (impoundments, channelizations, diversions, levees, etc.)*	existing or planned	—	—	none	Valdez et al. (2002) and sources cited therein	Restoration and maintenance of high spring flows resulting in inundation of floodplains is of importance to all life stages and especially for reproduction. "These [flooded] areas provide warmwater temperatures, low-velocity flows, and increased food availability" (Valdez et al. (2002).

[1]Numerous studies have found that, although adult razorback suckers exist and spawn, there is little or no recruitment of young into most populations, which are found to consist of ever-fewer individuals of increasingly greater age (being a long-lived species, ≥44 years). Minckley et al. (1991), reviewing and discussing the many factors that have been thought negatively to impact the razorback sucker, wrote: "We nonetheless conclude that predation by non-native fishes is the single most likely factor precluding recruitment of razorback suckers in nature . . . ." Not only are large, aggressively predatory nonnative fishes such as basses, sunfishes, and catfishes considered seriously to contribute to this problem, but even small, seemingly comparatively innocuous nonnative species such as mosquitofish and red shiners, though tiny in comparison to the mass of an adult razorback sucker, are thought to be capable of effectively eliminating all razorback sucker larvae from breeding and nursery areas. Even planktivorous fishes such as threadfin shad may consume larval razorback suckers, and "[t]hreadfin shad might also compete with razorback sucker larvae if planktonic foods are in short supply" (Minckley et al. (1991). Thus there may be no nonnative fishes that are not potentially threats to the razorback sucker. "Nonnative fishes dominate the ichthyofauna of Colorado River Basin rivers", and "[a]t least 67 species of nonnative fishes have been introduced in to the Colorado River Basin during the last 100 years" (Valdez et al. 2002). Attempts to control and to reduce the populations of nonnative fishes in various places where *X. texanus* still exists and to augment its populations through release of small hatchery-raised razorback suckers have thus far not resulted in appreciable recruitment.

[2]The razorback sucker formerly occurred in the mainstem Colorado River and its larger tributaries, from northwestern México through Arizona and Utah to Colorado and Wyoming (and perhaps New Mexico) and was formerly abundant. Its decline began with the construction of large dams throughout the Colorado River system, and its geographic distribution is now fragmented and consists of only a few populations. (Its scientific name, *texanus*, is a misnomer resulting from confusion at the time of its description in 1860 concerning the origin of the type specimen[s], which were believed to have been collected from the largest river in Texas, the Colorado River, which originates in Texas and drains ultimately to the Atlantic Ocean, rather than the Colorado River that originates in Colorado but

drains west from the continental divide ultimately to the Pacific Ocean.) Ecologically, conditions in the upper Colorado River basin and the lower Colorado River basin are noticeably different (e.g., seasonality of reproduction, water temperatures, water depths), resulting in different ecological characteristics of the razorback sucker in these 2 regions. Also, the razorback sucker survives not only in somewhat "natural" (though very much altered) lotic, riverine habitats but also in artificial lentic, lacustrine habitats (i.e., reservoirs). Thus it is not surprising that studies of this species in different places and situations—upper versus lower basin, riverine versus lacustrine—have yielded very different results. Complicating understanding of the ecological requirements of the razorback sucker even further is the fact that successful reproduction and recruitment in this species is now virtually nonexistent anywhere. Thus attempts (1) to understand what ecological "integrity" or "health" would be in this species and (2) to combine the diversity observed in its ecology in different places into a single table are challenging tasks.

*Most important indicators.

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Bear Lake sculpin (*Cottus extensus*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of adults (>35 mm total length) (in Bear Lake)	<1.5 million	1.5–2 million	2–2.5 million	>2.5 million	Lay and Wurtsbaugh (1996, Figure 18)	
successful reproduction and recruitment	presence and abundance of all size classes (cohorts), especially young-of-year and adults	1 or more size classes (cohorts) absent	1 or more size classes (cohorts) rare	1 or more size classes (cohorts) uncommon	juveniles, young-of-year, subadults, and adults all present in abundance	Lay and Wurtsbaugh (1996)	Abundant presence of both young-of-year (15-20 mm total length) and adults (>40 mm total length) is adequate (i.e., there should be abundance peaks pf sculpins ~20 mm and ~55 mm total length) (see data in Lay and Wurtsbaugh 1996, Figure 16). Juveniles are unlikely to be sampled unless special capture methods are used, and subadults may not be readily distinguishable from adults. (Maximum total length in this species seldom exceeds ~120 mm.)
habitat	type of water body*	other: shallow lakes, lotic waters (e.g., rivers, streams)	—	—	very deep lake(s) or possibly reservoir(s)	various sources including Sigler and Sigler (1996)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, life history, foraging, reproduction	variety of water depths*	unvaried, uniform, lacking shallows or very deep areas	—	—	varied, including shallows (littoral, ≤8 m), medium depths (metalimnetic interface, 11–17 m), and very deep areas (profundal, >37 m)	Lay and Wurtsbaugh (1996), Sigler and Sigler (1996)	*C. extensus* inhabits and behaviorally utilizes, both daily and annually, waters of various depths, up to and exceeding 55 m (180 ft) (probably even the deepest part of Bear Lake, which is ~63 m [208 ft] deep).
reproduction (spawning and egg-laying habitat)	rocky shallows along shoreline[2,*]	absent	—	—	present[2]	various sources including Sigler and Sigler (1996)	"Temperature for initiation of spawning for Bear lake sculpin is 40°F (4.4°C). Spawning takes place in late winter to early spring, April to May, and near shore. They lay their eggs on the underside of rocks" (Sigler and Sigler 1996).[2]
protective cover (e.g., protection from predation), habitat	microhabitat (substrate or bottom cover)[2,*]	marl	sand	boulders, rocky rubble[2]	patches of macrophytic vegetation (*Chara*, muskgrass)	Wurtsbaugh and Lay (1996)	Wurtsbaugh and Lay (1996) found *C. extensus* in areas of macrophytic vegetation and boulders during both day and night but in areas of sand only at night; marl without macrophytic vegetation and areas with filamentous algae were never used. They commented, however, that the inhabited patches of macrophytic vegetation were usually small (<1 m^2) and often were located in expanses of the sand and marl habitats.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
spawning habitat, recruitment (oviposition, survival of eggs, larvae, and juveniles) also general habitat and protective cover	surface elevation of Bear Lake[3,*] (water management)	<5,911 ft e.g., from water withdrawals that lower lake levels, subjecting macrophytic vegetation to wave action and exposing rocks, which provide daytime cover and spawning habitat (see Comments)	5,915–5,911 ft	5,919–5,915 ft	5,923 (full pool)–5,919 ft	Albrecht (2004, Figures 10 and 11)[3], also Wurtsbaugh and Lay (1996), Sigler and Sigler (1996)	"Spawning takes place . . . near shore. They lay their eggs on the underside of rocks. . . . When water levels drop to where there is no rocky cover [in shallows near shore], spawning success is probably minimal. . . . Suitable water quality and water levels high enough to cover rocks and rubble for spawning are the principal needs for these sculpin. They can survive in the deep-water marl bottom, but without some type of inshore cover, it is doubtful they can spawn with any degree of success" (Sigler and Sigler 1996). The higher the water level in Bear Lake is, the greater the amount of rocky spawning habitat that is available Albrecht (2004, Figures 10 & 11).[2,3]
survival, reproduction, and recruitment	degradation of water quality	occurring	—	—	none	Sigler and Sigler (1996)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	nonnative sport fishes (e.g., lake trout)	present, abundant	present, moderately common	present but scarce	none	Sigler and Sigler (1996)	*C. extensus* is preyed upon heavily by lake trout, a nonnative species, as well as by cutthroat trout, which, though native, has increased in abundance in Bear Lake unnaturally as a result of stocking. Since *C. extensus* is very abundant in the 1 lake where it naturally occurs, it appears to be able to withstand such heavy predation and to maintain a viable population, thus the importance of this indicator is questionable.

[1]This species occurs naturally only in Bear Lake (on the Utah–Idaho border, Rich County, Utah, and Bear Lake County, Idaho). It has also been introduced into Flaming Gorge Reservoir (on the Utah–Wyoming border, Daggett County, Utah, and Sweetwater County, Idaho), where its fate is unknown (Sigler and Sigler 1996).

[2]Rocky substrates are rare and limited in Bear Lake, representing <1% of available bottom habitat (Albrecht 2004, p 30, citing another source), and they are required, for successful reproduction and recruitment, by all 4 (or 5) of the fish species that are endemic to Bear Lake. Albrecht (2004, p 29) suggested that "potential may exist for in-lake manipulative measures to be undertaken in order to preserve and enhance endemic fish populations by providing rock habitat . . . , particularly at low water lake elevations." He further commented (2004, p 35) that "attention should be directed to preserving and enhancing these important habitat types [i.e., rocky habitats] in Bear Lake . . . ." These management possibilities presumably include not only water management to ensure high lake levels[3] but also artificial addition of rocks or rocklike materials (e.g., scrap concrete) in at least some areas of Bear Lake where rocks are lacking (which is most of the lake).

[3]Bear Lake, although formerly natural, is now managed as a reservoir. Maintaining high water levels, at which there are more submerged rocky areas and thus more suitable rocky spawning habitat, is an important management action (Albrecht 2004, Figures 10 and 11).

*Most important indicators.

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western toad (*Bufo boreas*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population (viability)	average observed total of breeding adults at breeding site and average no. of egg masses	<20 breeding adults producing <4 egg viable masses	20 breeding adults producing 4 egg viable masses	>20 breeding adults producing >4 egg viable masses	»20 breeding adults producing »4 egg viable masses	Loeffler (2001)	Observed presence of subadults of different ages (sizes), which indicates that recruitment is occurring, is also important.
breeding and developmental sites	types of water bodies*	lotic: rivers, streams or lentic but very small or uniformly shallow: temporary pools, small puddles (see Comments)	lotic: low-velocity, low-gradient streams, springs	—	lentic and large enough not to dry up and deep enough not to freeze at night during summer: lakes, ponds (especially beaver ponds), large pools (including artificially created ponds and pools[3])	various authors including Holland (2002), Carey et al. (2005)	Lotic waters can be too cold and too swift, but lentic waters can be too small, allowing desiccation, or too shallow, allowing freezing. Desiccation was the main cause (63.6%) of egg mortality observed by Carey et al. (2005), who wrote: "Desiccation of egg masses appears to be the single largest source of egg mortality." Although small water bodies such as puddles and small pools may provide suitable thermal conditions for development, the risk of desiccation before completion of larval development is very high in such sites. "Many of the shallower pools at [one] site held tadpoles and metamorphic animals [western toads] killed by freezing or drying."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
embryonic development (solar warming of oviposition sites)	long axis of water body (maximizing length of N shore)	N–S	NE–SW or NW–SE	—	E–W	see Comments	"Boreal toads typically lay eggs on the north, northwest, or northeastern shores of large ponds or lakes—areas that receive the most daily sunlight" (Carey et al. 2005). This implies that water bodies that are elongate E–W, thus maximizing length of the N shore, will usually provide the most suitable and the most abundant habitat for embryonic and larval development. This indicator should be applied in conjunction with the indicator below.
oviposition sites (solar warming of oviposition sites to facilitate embryonic development)	slope and water depth near shore* (especially N shore—see indicator above)	steep slope, ≥10 cm deep	—	—	gentle slope, <10 cm deep	Holland (2002), Carey et al. (2005)	"In most cases, egg laying occurs in shallow water (<10 cm) on gently sloping pond edges. Solar radiation warms shallow water to temperatures as high as 30 °C during the day . . . . The importance of egg laying in sunlit, shallow water is highlighted by the fact that tadpole development does not occur at constant, cold temperatures and requires high water temperatures for at least a portion of the day" (Carey et al. 2005).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
embryonic and larval development	daytime water temperature in shallows during summer*	≤10 °C or ≥37 °C	11–15 °C or 36 °C	16–27 °C or 35 °C	28–34 °C	Beiswenger (1978), Carey et al. (2005)	"Ratings" are based on the laboratory experiments of Beiswenger (1978) and Carey et al. (2005). "The tendency of boreal toads [*Bufo boreas boreas*] to lay eggs in the shallow areas of large bodies of water or in small puddles that warm rapidly on sunny days is related to the fact that developing larvae require temperatures above 10 °C . . . " (Carey et al. (2005). Carey et al. (2005, Table 31-2) attributed 9% of egg mortality to freezing and an additional ~5% to "temperatures".
growth of (metamorphosed, terrestrial) subadults	daytime air temperature during summer	≤7 °C	—	—	≥25 °C	Carey et al. (2005)	In experiments conducted by Carey et al. (2005) over a 4-week period, terrestrial individuals held at 7 °C lost weight and did not grow; those held at 25 °C gained an average of 40% of initial weight and grew an average of 7% in length; those subjected to cycling between 7 and 25 °C every 12 h gained 29% in weight and 4% in length. (7 and 25 °C approximate night and daytime summer temperatures in suitable habitat.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
evaporative water loss (dehydration) in adults	shrub cover (see Comments)	≤4%	5–20%	21–35%	>35%	Bartelt (2000, Chapter 1, Table 2)	Bartelt (2000) found that adults selected for shrub cover, and he (p 97) recommended 40–50% shrub cover. (The "fair" and "good" ratings are interpolations from his data [Chapter 1, Table 2].) Bartelt's data are from a national forest; whether his quantitative data would apply in other *B. boreas* habitats in the s. Rocky Mtns. & Utah is uncertain (e.g., in shrub steppe or in piñon–juniper woodland, possibly much greater shrub cover would be necessary to prevent dehydration.)
hibernation sites	habitat features (overwintering retreats)	—	—	—	rodent burrows (especially ground squirrels), interstices of beaver dams, overhanging stream banks, rocky chambers near streams, cavities under boulders or tree roots	various authors	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
tadpole mortality, predator avoidance causing reduced developmental rate	aquatic predators, especially predaceous diving beetle (*Dytiscus* spp.) larvae and tiger salamander (*Ambystoma tigrinum*) larvae	abundant	fairly common	scarce	none	Livo (1999, Figure 23)	"Excluding cold ponds, sites with current or historical boreal toad breeding records contained significantly fewer *Ambystoma tigrinum* and *Dytiscus* sp. than ponds that lacked records of breeding by boreal toads" (Livo 1999).
mortality, morbidity	pathogens: e.g., chytridiomycosis (chytrid fungus, *Batrachochytrid-ium dendrobatidis*) & red-leg (bacterium, *Aeromonas hydrophila*)*	present in this or other amphibians in the vicinity	—	—	absent in this and other amphibians in the vicinity	various authors including Loeffler (2001)	
habitat, thermal ecology	elevation (Utah)[2] (see Comments)	Utah: <5,151 ft or >10,564 ft s. Rocky Mountains: <7,100 ft or >11,942 ft	5,151–7,000 ft or 10,000–11,942 ft (very uncertain, see Comments)	7,000–8,000 ft or 9,000–10,000 ft (uncertain)	8,000–9,000 ft (uncertain)	various authors including Hogrefe et al. (2005)	Within the overall range of *B. boreas* and even the race *B. b. boreas*, this species and subspecies, as currently recognized, is known to inhabit elevations ranging 0–11,942 ft. In the s. Rocky Mountains the inhabited range is 7,100–11,942 ft, and in Utah it is 5,151–10,564 ft. The "ratings" are uncertain and, except for the "poor" rating, may have little meaning.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation and loss, direct mortality	reservoir construction, roads, mining, timber harvest, recreation, water management	existing or planned in wetlands or in terrestrial habitats within 2.5 km of breeding sites	—	—	none in wetlands and none in terrestrial habitats within 2.5 km of breeding sites	Hammerson (1999), Bartelt (2000), Loeffler (2001), Hogrefe et al. (20005)	Bartelt (2000) recommended protecting wetlands and "the integrity of terrestrial habitats within a 2.5 km radius of breeding sites", including careful protection of shrub cover and coarse woody debris (such as slash, which should not be burned), and avoiding clear-cuts (selective cuts being a better form of timber harvest). Bartelt (2000), noting *B. boreas* mortality, probably of females, on national forest roads, also suggested implementation of "toad tunnels" (culverts) under roads and "toad crossing signs".
water quality for development, mortality	acid and metal contamination of water draining from mines (including inactive or abandoned mines)	present	—	—	none	Porter and Hakanson (1976), Carey et al. (2005)	Porter and Hakanson (1976), noting the complete absence of any amphibians from 1 county in Colorado despite abundant seemingly suitable habitat, found that the effluent of a representative inactive mine in that county was so toxic "that it required diluting approximately one thousand times before [boreal] toad larvae could survive in it."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, habitat degradation	livestock grazing and trampling in wetlands	intensive and occurring in warm months (especially late summer)	limited to winter months	none	none	Bartelt (2000), also Loeffler (2001) and sources cited therein	Bartelt (2000) "observed sheep trampling a large number of metamorphic [western] toads and extensive amounts of riparian habitat", which "probably destroyed half of [western] toad reproduction for the past decade" at this site, and recommended "that extra effort be made to exclude livestock from breeding sites and riparian habitats, especially during times of [*B. boreas*] metamorphosis."

[1]Geographical differences in morphology and voice have long been known to exist within this species, which occurs from Alaska south to Baja California del Norte and east to Yukon, Alberta, Montana, Wyoming, Colorado, and New Mexico, with 2 currently recognized races. However, a study using molecular genetics (mtDNA) has suggested that *Bufo boreas* may in fact be a complex of several currently unrecognized species. Goebel (2005, Figure 30-3) indicated that toads of this species from north-central Utah belong to her "southern Rocky Mountain" clade (se. Wyoming, n. and c. Colorado [and presumably n. New Mexico, where it is believed to be extirpated]) and those from extreme northwestern Utah, though not sampled, may, on geographical grounds, belong to her "northwest" clade (British Columbia, Alberta, Washington, Oregon, n. California, nw. Nevada, Idaho, Montana, nw. Wyoming [and presumably Yukon and Alaska]). However, those from southern Utah were the most divergent of all clades in her analysis of the entire *Bufo boreas* species group (Goebel 2005, Table 30-2), and she even referred to them using the new name "*Bufo sevieri*" while noting that she employed this name "for discussion purposes only" and that the name, without a formal description, does not meet nomenclatural requirements for recognition (i.e., it is a *nomen nudum*). Although it is unfortunate that she chose knowingly—and needlessly—to create a *nomen nudum*, which is a violation of the International Code of Zoological Nomenclature and a name that should not be used by others, Goebel or some other author may formally describe and name such toads from southern Utah as a new species. If it is concluded that some or all of Goebel's clades merit specific recognition, the 3 clades that occur (or are presumed to occur) in Utah (including the 1 presumed to occur in the nw. corner of the state) could come to be considered different species, and it could be that only those in the nw. corner of Utah would continue to be regarded as *Bufo boreas*. (See also Hogrefe et al. [2005] concerning results of other molecular genetics studies of the western toad in Utah.)

[2]**This table is intended for use primarily in the southern Rocky Mountains (se. Wyoming, Colorado, and New Mexico) and in Utah.** Unrecognized cryptic species may exist within what is currently regarded as a single species, *Bufo boreas* (the western toad), and even within 1 of its races, *Bufo boreas boreas* (often called the boreal toad), as currently understood (see footnote 1). Moreover, differences in the biology of the race *Bufo boreas boreas* in different geographic areas exist. For example, along the Pacific coast (Alaska, British Columbia, Washington, Oregon, and California) this race occurs as low as sea level; in the southern Rocky Mountains (se. Wyoming, Colorado, and New Mexico), nominally the same race occurs within the elevational range 7,100–11,942 ft; in Utah the inhabited elevational range of this race is 5,151–10,564 ft. (Even within Utah, the subspecies *Bufo boreas boreas* may prove to be more than 1 species—see footnote 1.) Holland (2002) summarized some of the ecological requirements for this species in the southern Rocky Mountains: "Ideal boreal toad breeding sites presumably

contain still water, very shallow margins, and persistent water levels. Egg masses are typically deposited in the shallowest available areas of the breeding site. . . . For a wetland to be considered suitable it should contain at least 1 gradually sloping bank with water ≤ 10-cm deep during the breeding season. Potential sites should also be examined in August to ensure that breeding site persistence is sufficient to allow completion of the larval period. In addition, a deeper area of water may be necessary to provide tadpoles with a night refuge of warmer water . . . . An old, but active, American beaver pond complex seems an ideal model for a breeding locality because shallow, eutrophicated ponds exist in concert with water level maintenance by beaver." Holland (2002) found that both increased variation in daily water temperature and increased variation in water levels during summer had negative effects on tadpole development in this species. Terrestrial habitats of this species, even within Utah, are varied and include sagebrush steppe, piñon–juniper woodland, and mixed and coniferous forests of various species compositions. Adult males typically remain within a few hundred meters of breeding sites throughout the year, while adult females usually do not, often moving several kilometers from breeding sites after breeding in spring or early summer.

[3]Pearl and Bowerman (2006) reported that *Bufo boreas* in Oregon bred in 6 newly constructed artificial ponds the first spring following construction of the ponds (2–9 months after construction) and that these artificial ponds were "0.1–4.8 km from the nearest potential source breeding sites." "Five of the 6 colonized ponds were small (≤500 m^2 of surface area), and all ponds had little or no aquatic macrophytic vegetation." Although they "observed little or no recruitment of juveniles (<100 observed) at 4 of these [6] sites", "[l]arge numbers of juvenile *B. boreas* were recruited at the other 2 sites: 10,000s at [1 site] and 1000s–10,000s at [another]." "Both [of the latter 2] ponds were constructed with an impermeable liner and, to date, have little or no macrophytic vegetation." They commented: "Our observations indicate that *B. boreas* can rapidly locate new breeding sites in semiarid landscapes where no surface water existed prior to pond excavation." They also reviewed other studies Montana and Washington, including 1 that found that "*B. boreas* was the most common anuran breeding in 22 newly created ponds" in an area buried by debris from the eruption of Mount St. Helens. From such studies it appears that **construction of artificial ponds in otherwise dry habitats up to 5 km (or perhaps farther) from known breeding sites can provide habitat enhancement for this species in the form of usable new breeding sites**. Pearl and Bowerman (2006) also noted that "vegetative succession in and around wetlands is an important factor in breeding site suitability for a variety of north temperate anurans . . ." and that, presumably because of such vegetative succession, some other species of toads "are reduced [as breeders] in older or undisturbed ponds". This suggests that **construction of artificial ponds could be used as a means of revitalizing breeding habitat for this species that may have become decadent or senescent as a result of vegetative succession within and around older breeding sites** that have become choked with aquatic vegetation, heavily colonized by predators, infested with parasites or pathogens, or densely shaded by surrounding trees. If artificial ponds are constructed with the intention of benefiting this species, information pertaining to some of the "Indicators" (rows) in this table should be considered in the design of such artificial ponds (e.g., slope and depth along north shore, orientation of long axis).

*Most important indicators.

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Arizona toad (*Bufo microscaphus*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding habitat	water flow*	lentic (no flow) (e.g., ponds, sloughs, marshes)	—	—	lotic (flowing) (e.g., streams), usually swiftly flowing	Blair (1955), Sullivan (1986)	Lentic situations, in addition to being unsuitable habitat for this species, are favorable for *B. woodhousii*, which hybridizes with *B. microscaphus*.
breeding habitat	water depth	deep	—	—	shallow	Degenhardt et al. (1999), Sullivan (1986)	
breeding habitat	in-stream pools	absent	—	—	present	Dahl et al. (2000)	
breeding habitat	tree canopy cover of streams	>20%	—	—	<20%	Dahl et al. (2000)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal biology	elevation (**N.B.**: varies regionally —see Comments)	<1,300 ft or >8,900 ft	—	—	1,300–8,900 ft	Blair (1955), Sullivan (1986), Degenhardt et al. (1999)	This species occurs from 2,539 ft (774 m) to 6,569 ft (2,002 m) in sw. Utah (Utah Natural Heritage Program data, 2007); earlier Blair (1955) had found it in sw. Utah from ≤2,800 to 5,800 ft (853–1,768 m). It is found at 400–2,000 m (1,312–6,562 ft) in w. Arizona and at 1,000 to ≥2,600 m (3,281 to ≥ 8,530 ft) in e. Arizona (Sullivan 1986). In sw. New Mexico it occurs at 1,900–2,700 m (6,234–8,858 ft) (Degenhardt et al. 1999). However, Stebbins (2003) stated the elevational range of this species as ~600–6,000 ft (190–1,829 m); the lower end of this range is here considered questionable and the upper end was probably based on Blair (1955).
hybridization, competition	presence of *Bufo woodhousii**	present	—	—	absent	Blair (1955), Sullivan (1986, 1993), Sullivan and Lamb (1988), Stebbins (2003)	The most serious threat to *B. microscaphus* is hybridization with *B. woodhousii*. Such hybridization largely is the result of human alteration of stream flow by impounding streams. Blair (1955) commented that "hybrids are found wherever the two species occur together."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hybridization, competition	dams, impound-ments, other alterations of that reduce flow or create lentic habitats*	existing or planned	—	—	none	Blair (1955), Sullivan (1986, 1993), Stebbins (2003)	". . . *B. microscaphus* is present at a number of historic localities, but absent from those where the riparian corridor has been altered dramatically through the construction of impoundments" (Sullivan 1993). Further, damming or impounding streams allows *B. woodhousii* to invade areas inhabited by *B. microscaphus* and thus to leads to hybridization.

[1]This species has had an unstable taxonomic history; it has been included within other species and has had other currently recognized species included in it. As currently taxonomically restricted, *Bufo microscaphus* has no subspecies (its former subspecies having been elevated to specific status) and occurs (discontinuously) only in sw. Utah, se. Nevada (where mostly extirpated or hybridized), w.-c. to e.-c. Arizona, and sw. New Mexico (and does not occur in California or in México).

[2]Plant associations have not been included in this table because they appear to be relatively unimportant in determining the presence of *B. microscaphus*. Degenhardt et al. (1999), writing of this species in New Mexico, commented: "It is generally found in unaltered riparian areas grown to sycamore or cottonwood, and in grasslands, piñon–juniper, or ponderosa pine . . . ." In Utah it is commonly found in piñon, juniper, and/or oak woodlands and near the lower edges ponderosa pine forests. However, the presence of unaltered flowing streams (for breeding) is much more important than is plant association in determining the suitability of habitats within its range. Although elevation has been included as an indicator in the table, the inhabited elevational ranges differ considerably in different parts of the range of this species (and in some places only barely overlap—e.g., New Mexico vs. w. Arizona), as noted in the Comments.

*Most important indicators.

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Great Plains toad (*Bufo cognatus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	plant association (w. and s. portion of range, including Utah)*	forest, alpine tundra	woodland	semidesert shrublands, agricultural areas	desert grassland, desert riparian situations, desert scrub	Krupa (1990), Degenhardt et al. (1999), Hammerson (1999), Brennan and Holycross (2006)	On the Great Plains this species inhabits mainly prairies.
habitat, thermal biology	elevation (Utah)*	>6,000 ft	—	5,000–6,000 ft	<5,000 ft	Krupa (1990), Degenhardt et al. (1999), Hammerson (1999)	Rangewide, this species occurs from near sea level to ~8,000 ft (~2,440 m) (Stebbins 2005). Degenhardt et al. (1999) reported that this species occurs from ~900 m (2,953 ft) to ≥1,900 m (6,234 ft) in New Mexico. Hammerson (1999) stated that in Colorado it occurs generally below 6,000 ft (1,830 m) but also is found at 7,500–8,000 ft (2,285–2,440 m) in 1 area (in s.-c. Colorado). Linsdale (1940) provided elevations for 3 of 6 Nevada localities, these 3 ranging 1,300–4,000 ft (396–1,219 m); the other 3 localities probably were within or below this elevational range.
reproduction (mating, oviposition, larval development)	breeding sites (w. and s. portion of range)	streams, rivers	—	irrigation ditches, livestock tanks	temporary rain-filled ditches, temporary pools	Degenhardt et al. (1999), Brennan and Holycross (2006)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation, competition, spread of amphibian diseases	American bullfrog (*Rana catesbeiana*)	present	—	—	absent	see Comments	The presence of introduced American bullfrogs is known negatively to affect other species of amphibians.
tadpole mortality, predator avoidance causing reduced developmental rate	aquatic predators, especially predaceous diving beetle (*Dytiscus* spp.) larvae and tiger salamander (*Ambystoma tigrinum*) larvae	abundant	fairly common	scarce	none		
mortality, morbidity	pathogens: e.g., chytridiomycosis (chytrid fungus, *Batrachochytrid-ium dendrobatidis*) & red-leg (bacterium, *Aeromonas hydrophila*)*	present in this or other amphibians in the vicinity	—	—	absent in this and other amphibians in the vicinity	see Comments	Reports of disease in this species have not been found, but these diseases are known or are believed to have devastating effects on populations of a variety of amphibians, including other species of toads, in Utah and adjacent states.

[1]This species occurs from s.-c. Canada to c. México, mainly in the prairies of the Great Plains and in desert grasslands of the deserts of the southwest. It was formerly rare in Utah and has not been detected in this state in many years. Although it has been reported from 12 localities in Utah, most of these have been considered suspect or questionable in a recent evaluation of the status of the species in Utah (Mulcahy et al. 2002). Mulcahy et al. (2002) regarded only two localities for this species in Utah as "legitimate, verified records", both of these being in the vicinity of the town of Green River, Emery County. They did note, however, three other reported localities (Krupa 1990)—1 in western Grand County (presumably not far from the town of Green River) and 2 in San Juan County—for which they were unable to locate voucher specimens and thus could draw no conclusions about the validity of the records. The most recent valid Utah record of this species for which the date is known is from 1962, but no adequate effort has been made to look for it since that time. Almost nothing concerning the ecology, including habitat, of this species in Utah has not been reported. Thus, for this table, other sources have been used, especially those that deal with this species in adjacent states. **This table is intended for use primarily in the arid southwest and intermountain west.**

*Most important indicators.

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Columbia spotted frog (*Rana luteiventris*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (general, including adult summer)	permanent water or wetlands*	other (e.g., high-gradient streams, rivers, lakes, reservoirs, ditches)	stock ponds	slow-moving (low-gradient) streams; oxbows; sloughs	spring- or seep-fed pools; spring complexes; marshes	Tanner (1931), Morris and Tanner (1969), Ross and Peterson (1998), and others in Ross and Peterson (1998), Turner (1958, 1960)	This species is less selective of types of water bodies and uses a wider range of aquatic situations in the main parts of its range than near its southern range limits (e.g., Utah). (See guidelines for creation or modification of habitat for this species.[2])
habitat (overwintering)	type of water body	other	deep, undercut stream banks; animal burrows under tree roots adjacent to streams; beaver dams in streams; shallow seeps	oxbows; beaver ponds; stock ponds	springs (especially deep holes in the bottoms of spring heads); spring-fed pools; spring-fed streams	Turner (1960), Ross and Peterson (1998), Patla (1997), Perkins and Lentsch (1998), Bartelt and Peterson (1994)	**N.B.**: Non-freezing water is of critical importance in hibernation, and this may be achieved by at least slight surface flow, connection to underground flow, or water depth. Adequate oxygenation is also necessary, and this can also be achieved through at least slight flow. Several deep (1–1.5 m) holes should exist or be created in the bottom of the water body (e.g., spring, pool, stream, pond) (Ross and Peterson 1998).
habitat (overwintering)	distance of over-wintering site from summer-use site(s) (breeding, development, and adult foraging)	>200 m	100–200 m	50–100 m	0–50 m	Patla (1997), Ross and Peterson (1998), and others in Ross and Peterson (1998)	Adult foraging sites may be somewhat farther from overwintering sites (i.e., up to 300 m).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (breeding)	type of water body	other	flooded swales in pastures	stock ponds; distal parts of warm, saline spring complexes	small beaver ponds; oxbows	Morris and Tanner (1969), Ross et al. (1992, 1993), Hovingh (1993), Ross and Peterson (1998)	Shallow (typically <19 cm), standing (no or only slight flow) water, usually with interspersion of open water and emergent vegetation (~50:50) and usually over fine substrates, is of importance, oviposition occurring within 10 m (usually ≤2 m) of shoreline, often on the N or NW side of a small wetland where it receives solar radiation (Ross and Peterson 1998, Morris and Tanner 1969, Ross et al. 1992, Patla [in Ross and Peterson 1998]).
habitat (breeding)	dissolved oxygen (at breeding sites)	<3 ppm	—	—	≥3 ppm	Perkins and Lentsch (1998), Ross and Peterson (1998)	
habitat	emergent aquatic plant species	none	—	grasses	cattail (*Typha*), bulrush (*Scirpus*), sedge (*Carex*), rush (*Juncus*), spikerush (*Eleocharis*)	Morris and Tanner (1969), Hovingh (1993), Ross et al. (1992, 1993)	Interspersion of vegetated and open water (~50:50) is optimal (Ross and Peterson 1998).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	submerged and floating aquatic plant species	none	—	—	muskgrass (*Chara*), filamentous algae (*Spirogyra*), watercress (*Nasturtium officinale*), duckweed (*Lemna*), water-starwort (*Callitriche palustris*)	Turner (1958, 1960), Morris and Tanner (1969), Ross et al. (1992)	Interspersion of vegetated and open water (~50:50) is optimal (Ross and Peterson 1998).
habitat	abundance or density of emergent, floating, and submerged vegetation	none (i.e., completely open water) or complete closure	very sparse or very dense	somewhat sparse or somewhat dense	interspersed with open water (50:50)	Ross and Peterson (1998)	This indicator apparently is of less importance than others. Reported inhabited sites with viable populations vary from 0–100% open water (i.e., complete closure to completely open) despite the assertion (Ross and Peterson 1998) that 50:50 is ideal.
habitat (breeding)	water depth (particularly that that is available on the north side of the wetland or water body)	>40 cm	30–40 cm	20– 30 cm	<20 cm	Ross et al. (1993)	
habitat	water turbidity	very turbid	somewhat turbid	slightly turbid	clear	Ross et al. (1993) and others	
habitat	substrate (of water body)*	—	—	—	deep organic mud (“muck”) or silt	Morris and Tanner (1969), Ross et al. (1992, 1993)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
adult overwintering habitat (hibernacula)	dissolved oxygen (at hibernation sites)	<3.7 ppm	—	—	≥3.7 ppm	Bull and Hayes (in Ross and Peterson 1998)	
adult overwintering habitat	winter water temperature (at hibernation sites)	«0 °C	<0 °C	0–1 °C or »5 °C	1–5 °C	Ross and Peterson (1998), Patla (1997)	**N.B.**: Non-freezing water (i.e., water that is renewed and does not freeze solid, to the bottom) is of critical importance in hibernation, and non-freezing may be achieved by (1) at least slight surface flow, (2) connection to underground flow, or (3) water depth.
adult summer habitat	summer water temperature	>30 °C or «12 °C	23–30 °C	20–23 °C or 12–15 °C	15–20 °C	Ross and Peterson (1998), Perkins and Lentsch (1998)	
larval habitat	spring and early summer water temperature	>30 °C or <12 °C	25–30 °C or 12–15 °C	15–20 °C	20–25 °C	Ross and Peterson (1998)	
egg (embryonic) development	spring water temperature	<6 °C or >28 °C	6–10 °C or 24–28 °C	10–11 °C or 15–24 °C	11–15 °C	Licht (1971), Johnson (1965), Ross et al. (1992)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
egg (embryonic) development	fluorine content of pond water	>30 ppm	25–30 ppm	<25 ppm	«25 ppm	Cameron (1940)	Cameron (1940) found that fluorine in water caused premature hatching of eggs and retarded development of embryos of leopard frogs. The effects of fluorine were greatest in distilled water and well water and much less pronounced in pond water. The concentrations used in the indicator ratings assume that development takes place in pond, not spring, water. N.B.: The effects of fluorine on embryos of the Columbia spotted frog have not been studied.
egg (embryonic) development	fluorine content of spring water	>3 ppm	2–3 ppm	1–2 ppm	<1 ppm	Cameron (1940)	Cameron (1940) found that fluorine in water caused premature hatching of eggs and retarded development of embryos of leopard frogs. The effects of fluorine were greatest in distilled water and well water and much less pronounced in pond water. The concentrations used in the indicator ratings assume that development takes place in spring, not pond, water. N.B.: The effects of fluorine on embryos of the Columbia spotted frog have not been studied.
oviposition	early spring water temperature	<6 °C or >25 °C	6–8 °C or 18–25 °C	8–10 °C or 11–18 °C	10–11 ° C	Morris and Tanner (1969), Ross et al. (1992, 1993)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation and competition	American bullfrog (non-native), northern leopard frog*	present in large numbers	present in moderate numbers	present in small numbers	absent	Ross et al. (1993), Dumas (1964)	Dumas (1964) found differential mortality in experimental mixed populations of Columbia spotted frogs and northern leopard frogs in ne. Oregon and hypothesized that Columbia spotted frogs are may be "particularly sensitive to the growth-inhibiting factor released by [northern leopard frog] tadpoles" that has been reported by other authors.
predation	predaceous fishes (e.g., introduced mosquitofish, sport fishes)*	present in large numbers	present in moderate numbers	present in small numbers	absent	Ross et al. (1993)	
predation	crayfish	present in large numbers	present in moderate numbers	present in small numbers	absent	Ross and Peterson (1998)	
habitat	beavers	absent	scarce	moderately common	abundant	Ross and Peterson (1998), Munger and Carrigan (in Ross and Peterson 1998)	The presence and activities of beavers should be maintained and encouraged.
habitat loss	dewatering (from draining, withdrawal for irrigation, and diversion)	existing or planned	—	—	none		
contamination	herbicides and pesticides (e.g., for mosquito abatement and agricultural pests)	present at site	present nearby	present in general vicinity	none	Ross et al. (1993)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water quality (contaminants)	distance to paved roads	<100 m	100–200 m	200–300 m	>300 m	Construction, use, and maintenance of roads can alter hydrology, increasing run-off, erosion, and siltation. Run-off from pavement contains oil, grease, and particulate matter from tires and asbestos brake linings. Other potential threats include spills from tanker trucks and herbicide use on rights-of-way.[3]	
habitat degradation	livestock (habitat degradation, trampling)	present in large numbers at all times	present in large numbers only in winter or present in small numbers at all times	present in small numbers and only in winter	absent at all times		

[1]This species, formerly included in *Rana pretiosa*, the Oregon spotted frog, is found from extreme southern Yukon, southeastern Alaska, and British Columbia southward to Wyoming, Nevada, and Utah. **This table is intended for use primarily in Utah**, at the southeastern extreme of the species' distribution, where conditions are warmer and drier than in other parts of its range. In Utah the species occurs mainly from ~4,000 to ~7,000 ft elevation, but elsewhere its elevational range is much greater: from near sea level to ~10,000 ft (Stebbins 2003). Licht (1975) showed that life history features of what is now considered the Columbia spotted frog in sw. British Columbia (70 m elevation) and in nw. Wyoming (2,600 m elevation) are very different, apparently as a consequence of very different environmental conditions such as temperature regimes.

[2]If wetlands (ponds) are constructed or modified, they should be fishless, <0.5 ha, with no dimension >100 m, and having a curvilinear (oxbow-like) shape, slight or slow through-flow, deep mud or silt bottom, shallow (1–25 cm) unshaded areas on N and NW sides, deeper (26–99 cm) areas on the S side, several deep holes (100–200 cm) near the S bank, interspersed (50:50) aquatic vegetation and open water, and some woody debris (logs) in various locations (including near the shallows and near the deep holes) (Ross and Peterson 1998).

[3]Roundup®, which is commonly used on rights-of-way by state DOTs, has been shown to be highly toxic to some amphibians, especially tadpoles of the northern leopard frog (*Rana pipiens*). In experimental settings, "[l]eopard frogs were completely exterminated with Roundup (P = 0.004)" (Relyea 2005).

*Most important indicators.

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relict leopard frog (*Rana onca*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of adults/m stream length	<0.05	0.05–0.50	0.50–1.00	>1.00	Bradford et al. (2004)	The largest known extant population was found to have ~637 adults along ~450 m of stream (i.e., ~1.42 adults/m); another population had ~36 adults along 555 m of stream (i.e., ~0.06 adults/m) (Bradford et al. 2004).
habitat (general)	desert riparian areas with **permanent water** (perennial springs, spring runs, spring and stream pools, streams, ponds, and wetlands)*	absent	—	—	present	Platz (1984), Jennings et al. (1995), Tanner (1929, 1931), RLFCT (2004b)	All known localities (historical or contemporary) are near rivers, "and many localities are virtually at the river" (RLFCT 2004b).
deep-water habitat (escape from predators)	pool depth*	«12 in.	<12 in.	12–16 in.	>16 in.	Platz (1984), RLFCT (2004a, 2004b)	
shallow-water habitat (basking, foraging, and breeding and early development)	shallows, edges, back-waters*	absent	present but scarce	present in moderate abundance	present and abundant	Platz (1984), RLFCT (2004b)	Platz hypothesized that backwaters are necessary for breeding.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (cover)	aquatic and emergent vegetation (e.g., watercress, bulrushes)*	absent or so dense as to leave little or no open water	extremely scarce, providing little cover or very dense, leaving little open water	providing some cover and leaving some open water	present and abundant, providing good cover at water margins, but also leaving much open water	Platz (1984), Jennings et al. (1995)	Aquatic and emergent vegetation is a necessary component of suitable habitat (Platz 1984), especially around margins of water, but habitat becomes unsuitable if vegetation encroaches and becomes so dense that it leaves no open water (see Bradford et al. 2004).
habitat (predation and competition)	American bullfrog (*Rana catesbeiana*)*	present	—	—	absent	Jennings (1988), Jennings and Hayes (1994)	
habitat (hybridization and competition)	other frogs of the leopard frog complex (e.g., *Rana pipiens*, *R. yavapaiensis, R. berlandieri*)*	present	—	—	absent	RLFCT (2004b), various other authors	
habitat (predation)	aquatic turtles (e.g., spiny softshell, painted turtle, pond slider, common snapping turtle)	present	—	—	absent	RLFCT (2004b)	Although predation on this species by turtles has not been documented, turtles are potential predators of the species. Except for (possibly) the spiny softshell, aquatic turtles within the range of *R. onca* are nonnative.
habitat (predation)	predatory or sport fishes (e.g., centrachids, ictalurids, salmonids)	present	—	—	absent	Jennings (1988), Jennings and Hayes (1994), RLFCT (2004b)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (predation)	crayfish (e.g., red swamp crayfish, *Procambarus clarkii*, virile crayfish, *Orconectes virilis*)	present	—	—	absent	Jennings (1988), Jennings and Hayes (1994), RLFCT (2004b)	
habitat (quality)	invasive plants (e.g., sawgrass, cattail, bulrush, tall whitetop, tamarisk)	abundant, dominant, supplanting low-growth species and choking open water, forming a monoculture	common but not crowding out low-growth species or filling in open water	scarce	absent	RLFCT (2004b)	Invasive plants (whether native or nonnative) can form dense stands eliminating the open water and low-growth plant species that form suitable habitat. Consider removal or control measures if invasive plants alter and dominate habitat.
climate	elevation	»3,000 ft	>3,000 ft	≤3,000 ft	<3,000 ft	Platz (1984)	All historical records of occurrence are from sites below 3,000 ft. Whether this truly represents an elevational limit is not known.
habitat (quality)	ungulates (e.g., bighorns, feral burros, livestock)	see comments[2]	see comments[2]	see comments[2]	see comments[2]	Bradford et al. (2004), RLFCT (2004b)	Evaluation should be made on a site-specific basis and with caution.[2]
habitat (quality, nonnative predators and competitors, disease, etc.)	recreation and other human presence and activity[3]	present	—	—	absent	RLFCT (2004b)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (quality)	agriculture and silviculture (chemical pollution, e.g., pesticides and herbicides; water withdrawal)	present in immediate vicinity	present nearby	present in the general area	absent throughout greater surrounding landscape	RLFCT (2004b)	Run-off and wind-blown agricultural chemicals are toxic or potentially toxic to this species and components of its habitat (plants, food species, etc.). Groundwater pumping is common agricultural practice and may cause aquifer depletion and reduced flow of springs and streams.
water quality (contaminants)	distance to paved roads	<100 m	100–200 m	200–300 m	>300 m	Run-off from pavement containing oil, grease, and particulate matter from tires and asbestos brake linings; potential threat from spills from tanker trucks; herbicide use on rights-of-way[4]; highway construction and maintenance.	Vehicular traffic can cause direct frog mortalities, with population effects up to 2 km from the road (see discussion in RLFCT 2004b), and "[t]he building of roads and their subsequent use and maintenance can alter hydrology of an area by increasing runoff, erosion, and siltation . . . " (RLFCT (2004b).
habitat (quality)	distance to unpaved roads	<100 m	100–200 m	200–300 m	>300 m	RLFCT (2004b)	". . . {G]raders conducting road maintenance at [a stream crossing] routinely push soil and debris into relict leopard frog habitat" (RLFCT 2004b).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (water quality, plant community)	fire (including planned or controlled burns)	intentional (e.g., controlled burns)	no intentional fires (e.g., controlled burns)	some prevention	actively and aggressively prevented (e.g., fire prevention plan exists)	RLFCT (2004b)	Fire and its products (smoke, ash) are generally considered detrimental to this species and its habitat, degrading water quality, flow regime (increased run-off), and plant community (sometimes favoring invasive species). However, it can sometimes be beneficial. Caution and site-specific evaluation are appropriate if controlled burns are considered.
natural hydrology	water withdrawal (e.g., diversions, ground-water pumping) and other hydrological alterations (dams, flow regimes)	present or planned	—	—	absent	Jennings (1988), Jennings and Hayes (1994), RLFCT (2004b)	

[1]This species was thought to be extinct until 1991, when 3 populations were discovered in Nevada at springs along the Overton Arm of Lake Mead (Jennings et al. 1995) (although 1 of these has since been extirpated), and at least 3 populations were later found at springs along the Black Canyon reach of the Colorado River below Lake Mead (Jaeger et al. 2001, Bradford et al. 2004). The species has not been detected in Utah since 1950 (Platz 1984).

[2]Although Bradford et al. (2004) concluded that trampling by ungulates was important in keeping vegetation from choking some aquatic sites, the reverse effect has been observed at other sites, where grazing has eliminated vegetation from water margins, encouraged colonization of deeper water by emergent plants, and resulted in choking of open water (RLFCT 2004b). In general, grazing is believed to degrade, rather than to improve, habitat through loss of vegetative cover at water margins (thus also increasing water and ground temperatures as well as accelerating desiccation during warm months), decreased water quality (increased turbidity and organic wastes), destruction of banks (undercuts), and trampling of egg masses and all other life stages, especially during reproductive periods (RLFCT 2004b).

[3] "Recreational users deliberately introduce many nonnative species, including aquarium and sport fish, bullfrogs, turtles, snails, and alligators. . . . [M]ulticolored aquarium gravel can often be found where unwanted pets have been freed. Feeding these exotic species is a favorite activity of many visitors [at one inhabited site]. Recreational users may also, either through transfer of mud on their shoes or by releasing aquatic fauna, introduce or spread disease. At [one site], visitors build rock and sandbag dams to form pools, sometimes altering water flow to relict leopard frog habitat downstream. Other activities such as bathing, where soap or detergents are used, could degrade habitat quality" (RLFCT 2004b).

[4]Roundup®, which is commonly used on rights-of-way by state DOTs, has been shown to be highly toxic to some amphibians, especially tadpoles of the northern leopard frog (*Rana pipiens*). In experimental settings, "[l]eopard frogs were completely exterminated with Roundup (P = 0.004)" (Relyea 2005).

*Most important indicators.

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desert tortoise (*Gopherus agassizii*)
Ecological Integrity Table[1, 2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of adults	<10/mi^2	10–100/mi^2	100–200/mi^2	>200/mi^2	Brussard et al. (1994, II.A)	Up to 350 adult desert tortoises per square mile are estimated to occur in some areas (Brussard et al. 1994, Table 6).
population	number of adults in population	<2,000	2,000–3,500	3,501–5,000	>5,000	Brussard et al. (1994, II.A.2)	
habitat	size*	<200 mi^2	200–500 mi^2	500–1,000 mi^2	>1,000 mi^2	Brussard et al. (1994, II.A.4 & II.A.5)	"Desert tortoises require a great deal of space to survive . . . . Over its lifetime each desert tortoise may require more than 1.5 square miles of habitat and may make forays of more than 7 miles at a time . . . . In drought yeas desert tortoises forage over larger areas . . . Brussard et al. (1994). PVA models involve assumptions and estimates that may be incorrect by an order of magnitude. Although Brussard et al. (1994) noted that 200 mi^2 may be adequate in some cases based on PVA modeling, they considered preserves of <500 mi^2 to be "unacceptable except as the only alternative . . . (requires particularly intense management)".

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography[2]	—	—	rolling hills, mountainous slopes, rock outcrops, badlands, sand dunes, lava flows	flats, valleys, alluvial fans, bajadas, rocky slopes, washes	Brussard et al. (1994), Barrett et al. (1994), Luckenbach (1982)	Conditions in the "very good" rating are used by this species in most areas of the eastern Mojave desert; those in the "good" rating are used, in addition to those in the "very good" rating, in the western part of the Mojave desert (only in California) and are not necessarily less "good" than those rated "very good".
habitat, cover	plant community[2]	—	—	—	"scattered shrubs and abundant inter-shrub space for growth of herbaceous plants"	Brussard et al. (1994), Barrett et al. (1994)	"The desert tortoise is most commonly found within the desert scrub vegetation type, primarily in creosote bush scrub vegetation," but also inhabits other desert scrub types as well as desert woodlands and scrub-steppe situations in desert and semidesert grasslands (Barrett et al. 1994, Luckenbach 1982). (See also Brussard et al. 1994, especially Table 2.)
food sources	plants[2]	—	—	—	forbs, grasses, cacti, shrubs	Brussard et al. (1994), Luckenbach (1982), Stebbins (1985), other authors	". . . [D]esert tortoises eat a wide variety of herbaceous vegetation, particularly grasses and the flowers of annual plants . . . " (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, cover	creosote bush (see Comments)	absent	—	—	present	Brussard et al. (1994), Luckenbach (1982), Stebbins (1985)	**N.B.**: **Use indicator with caution.** Creosote bush is often present in the habitat of the desert tortoise and can be a useful indicator of its presence, but there are **many exceptions**. The shrub may be present and the tortoise absent, and vice versa. "Desert perennials are poorly adapted to burning and are poor colonizers . . . . Creosote, for example, can require hundreds of years to recolonize and recover . . ." (Brussard et al. 1994).
burrow and nest sites	substrates[2]	—	—	rocky	sand, sandy gravel, sandy loam, light gravel–clay, heavy gravel	Brussard et al. (1994), Barrett et al. (1994), Luckenbach (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
climate, habitat	elevation	>4,000 ft	—	—	≤4,000 ft	Barrett et al. (1994), Luckenbach (1982), Stebbins (1985)	"Although desert tortoise populations are not generally known to inhabit elevations much above 4,000 feet," they have been reported from as high as 7,000 ft on Mount Charleston, Nevada, 7,400 ft in the Clark Mountains, California, and 7,300 ft in Death Valley National Monument, California (see Luckenbach 1982, Barrett et al. 1994). Occurrences above 4,000 ft are quite uncommon and above 5,200 ft are very rare.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	upper respiratory tract disease (URTD)*	present in local population or trans-locations, relocations, or releases of captives known to be occurring	absent from local population but present in region or trans-locations, relocations, or releases of captives suspected to be occurring	seemingly absent from region and trans-locations, relocations, or releases of captives seemingly not occurring	absent from region and trans-locations, relocations, or releases of captives not occurring	Brussard et al. (1994), Barrett et al. (1994)	"A serological test has been developed to determine exposure status of desert tortoises to URTD . . . . Predisposing factors such as habitat degradation , poor nutrition , and drought are . . . likely involved . . . . Controlling human-related spread of URTD . . . , improving habitat conditions, and monitoring health status of desert tortoise populations are some of the more important management tools which can be used in controlling URTD in wild populations of the desert tortoise. URTD appears to be spreading . . . . Wild desert tortoises with signs of URTD are commonly found near cities and towns with concentrations of captive[s] . . . ."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation	common ravens[3,*] (and other predators such as dogs, coyotes)	abundant	fairly common	rare	absent	Brussard et al. (1994), Barrett et al. (1994)	During the period 1968–1988, raven populations in the Mojave desert increased 15-fold, and these increases "seem to be due to increased food supplies, (e.g., roadkills, landfills, trash, garbage dumps, agricultural developments), as well as new sites for perches and nests (e.g., fence posts, power poles and towers, signs, buildings, bridges, and freeway access-ramps)" (Brussard et al. 1994). Raven predation on juvenile tortoises is believed to have eliminated recruitment of immature tortoises into the adult population in some areas (see Brussard et al. 1994). "Domestic and feral dogs are a new, and probably significant, source of mortality . . . " (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation (fire and mortality)	exotic ephemeral species such as red brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), and split grass (*Schismus barbatus*)*	abundant, ineradicable	fairly common and widespread	scarce, patchy, potentially eradicable	none	Brussard et al. (1994)	Livestock grazing favors bromes and other invasive exotic plants, which dominate ecosystems (displacing food sources) and increase the frequency and intensity of fire (eliminating shrub cover). Where species such as red brome, cheatgrass, or split grass are present, a fire plan should exist. (See Duck et al. 1995 for discussion of fire-fighting in desert tortoise habitat in the northeastern Mojave desert.)
mortality	capture, collection (for pets [including commercial trade], food, "science")[4,*]	known to take place regularly	believed to take place irregularly	believed not to take place	none (adequate law enforcement and education, including signage)	Luckenbach (1982), Brussard et al. (1994), Barrett et al. (1994)	". . . 12.5 to 43.7% of desert tortoises with radio transmitters were poached or suspected of being poached from [one] research site . . . between 1987 and 1991. . . . Even in remote areas, desert tortoises on permanent study plots have been collected and later have appeared in cities or towns dozens of miles away from the plots" (Brussard et al. 1994).
genetic "pollution", disease, disturbance of social structure of native population	relocation, trans-location, and release of captives[4]	known to take place regularly	believed to take place irregularly	believed not to take place	none (adequate law enforcement and education)	Luckenbach (1982), Brussard et al. (1994)	"Illegal relocations by desert residents and visitors occur frequently and must be treated as an on-going threat. . . . Releases of captives has been, and continues to be, a problem . . . " (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	shooting (and other vandalism: beheading, severing of other body parts, and over-turning)[4,*]	regularly occurring (inadequate, ineffective law enforcement and education)	rarely occurring (law enforcement and education somewhat effective)	*seemingly* not occurring (*seemingly* adequate law enforcement and education)	not occurring (adequate law enforcement and education) (rating may not be realistically achievable[5])	Brussard et al. (1994), Barrett et al. (1994)	Recent studies have shown shooting to be a very important mortality factor, accounting for 28.9% or more of deaths in some places (Brussard et al. 1994). At one site, "40.7% of desert tortoises found dead between 1981 and 1987 showed signs of gunshots and other vandalism" (Brussard et al. 1994). Proximity to roads and to towns may increase likelihood. "Fencing the Desert Tortoise Natural Area did not effectively reduce the frequency with which carcasses bearing gunshot holes were encountered, at least in the vicinity of the interpretive center . . . " (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
direct mortality (crushing), destruction of burrows, habitat degradation (loss of soil, annual and perennial plants, grasses, sol compaction)	off-highway or off-road vehicle (OHV or ORV) use[4]	regularly occurring, legal	regularly occurring, but illegal (inadequate enforcement)	irregularly occurring, illegal (inadequate enforcement)	none (illegal, with adequate enforcement)	Luckenbach (1982), Brussard et al. (1994), Barrett et al. (1994)	"ORV activities are among the most destructive, widespread, and best documented of threats to the survival of desert tortoises and other vertebrates, and to the integrity of their habitats . . . . The list of impacts from ORV use is extensive, including: mortality . . . on the surface and below ground; collapsing of . . . burrows; . . . destruction of plants used for food, water, and thermoregulation; damage or destruction of the mosaic of cover provided by vegetation; . . . noise pollution; . . . damage or destruction of soil crusts; soil erosion; proliferation of weeds; and increases . . . of wild fires" (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation (erosion, soil compaction, loss and alteration of natural vegetation, trampling, etc.), competition (for foods), mortality and injury (trampling), destruction of burrows (trampling)	livestock grazing[6]	high-density and/or in spring or summer and/or every year	low-density and in winter only and not in successive years	none	none	Brussard et al. (1994), Barrett et al. (1994), Luckenbach (1982)	Although winter grazing will not reduce many of the negative impacts, it will minimize above-ground trampling of tortoises and competition for annual grasses and annual forbs. ". . . [S]heep damaged 10% and destroyed 4% of 164 freshly-used desert tortoise burrows on a study plot . . . during less than 2 weeks of grazing . . . . Juvenile desert tortoise burrows are particularly vulnerable to trampling because of their locations and the shallow soil covering protecting the tunnels." Juveniles are also more affected in other ways: access to remaining foods, quality of remaining foods (protein content), ability to locomote across a churned landscape.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, capture, fragmentation of habitat and populations	distance to roads (dirt, paved, highways, freeways), railroads[7]	<2 mi	2–5.5 mi	5.5–7 mi	>7 mi	Brussard et al. (1994)	"Desert tortoise populations are depleted up to a mile or more on either side of roads when average daily traffic is greater than 180 vehicles . . . . Numbers of juvenile desert tortoises on permanent study plots . . . were significantly lower adjacent to well-used dirt and paved roads . . . . The breeding cohort of desert tortoises was severely depressed on a . . . study plot about 2 miles from Interstate 40 . . . . Even dirt roads with relatively low vehicle use can contribute to depressions in local desert tortoise densities . . . " (Brussard et al. 1994). Proximity to railroads is believed to have similar effects; tortoises get caught between the tracks, overheat, and die, or are crushed on tracks.
habitat degradation, mortality	energy and mineral exploration and extraction	existing (or planned), taking place in spring, summer, and fall (March–October) or year-round	existing (or planed), taking place in winter (November–February)	none	none	Brussard et al. (1994)	"The types of impacts are numerous, including: (1) cross-country travel by vehicles during the exploration phase; (2) construction of roads; (3) disturbance of soil surface and vegetation . . . ; (4) production of toxic products or by-products; (5) development of small towns and settlements . . ." (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, habitat fragmentation, favoring of predators (ravens)	utility and energy corridors	existing or planned	—	—	none	Brussard et al. (1994)	In addition to the obvious effects of direct mortality and habitat disturbance and fragmentation, ". . . the temporary opening of deep trenches for pipelines can form significant 'pit traps' into which desert tortoises may fall . . . . Towers supporting transmission lines also provide predatory birds with new perching and nesting sites which are otherwise scarce in the generally treeless habitat . . . " (Brussard et al. 1994).
mortality (capture, shooting and vandalism, road kills, ORV use, release of captives, dogs, ravens, etc.), habitat alteration	proximity of towns and cities	<30 mi	30–40 mi	40–50 mi	>50 mi	Brussard et al. (1994)	"At Edwards Air Force Base, the civilian population of about 13,000 people affected desert tortoise populations for more than 30 miles in any direction" (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat alteration, degradation, and destruction; mortality	agriculture	existing or planned	—	—	none	Brussard et al. (1994)	"Most agricultural developments, such as alfalfa farming, draw water from local or regional ground water aquifers and require clearing of native vegetation, plowing of previously undisturbed soils, and applications of pesticides and/or fertilizers. All such activities either kill desert tortoises directly, obliterate their habitats, lower primary productivity, or otherwise negatively impact wildlands" (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predators (ravens), mortality	dumping of garbage, trash; release of balloons	regularly occurring, legal	regularly occurring, illegal (inadequate enforcement)	irregularly occurring, illegal (inadequate enforcement)	none (illegal, with adequate enforcement)	Brussard et al. (1994)	"Turtles and tortoises are known to eat . . . balloons, plastic, and other garbage . . . [and] [s]uch objects can become lodged in the gastrointestinal tract or entangle heads and legs, causing death." Desert tortoises have been observed eating trash, and metal foil and glass chips have been found in their scats. An individual was found with a rubber band entangling its mouth and forelegs, and another with string tangled around a leg, which required amputation of the limb. Remnants of 130 balloons were found on a square-mile tortoise study plot ~9 miles from the nearest town; some of the balloons had been released 100–200 miles from the plot (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality; habitat loss, alteration, and degradation; predation; capture; etc.	distance to military operations	<30 mi	30–40 mi	40–50 mi	>50 mi	Brussard et al. (1994), Barrett et al. (1994)	Negative impacts from military operations are too many to list (see Brussard et al. 1994). Effects of tank maneuvers and bombing exercises are especially severe. Predators (especially ravens) are favored. Training exercises have caused tortoise populations to drop by 81%. "Desert tortoise populations and habitat are still recovering from [tank maneuvers] that occurred almost 50 years ago. . . . At Edwards Air Force Base, the civilian population of about 13,000 people affected desert tortoise populations for more than 30 miles in any direction" (Brussard et al. 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation, mortality	harvest and vandalism of vegetation (especially cacti and tree yuccas)	regularly occurring, legal	regularly occurring, illegal (inadequate enforcement)	irregularly occurring, illegal (inadequate enforcement)	none (illegal, with adequate enforcement)	Brussard et al. (1994)	"Cacti and tree yuccas . . . are the primary targets of both legal and illegal harvesters. Harvesting operations impose much the same negative impacts as ORV activities: crushing of desert tortoises and their burrows, removal of vegetative cover, compaction of soils, and inhibition of annual and grass germination. . . . Vandalism of vegetation is common in some parts of the desert. Tree yuccas and cacti are frequent targets and are shot or set on fire, sometimes setting off wild fires . . . . [U]se of semi-automatic and automatic weapons to vandalize vegetation is increasingly frequent . . . " (Brussard et al 1994).

[1]This table is intended for use with the Mojave desert population, north and west of the Colorado River (i.e., southeastern California, southern Nevada, northwestern Arizona, and southwestern Utah), which is federally listed as threatened. It is not intended for application to the Sonoran desert population, east and south of the Colorado River (i.e., southwestern Arizona, Sonora, and northwestern Sinaloa), which does not have protected federal status. The ecology of the desert tortoise in the Sonoran desert of Arizona and México differs considerably from its ecology in the Mojave desert.

[2]Even within the Mojave desert portion of its range addressed in this table, the ecology of this species varies greatly. As noted by Brussard et al. (1994, I.F.1): ". . . populations within the Mojave region exhibit different habitat preferences, food habits, periods of activity, selection of sites for burrowing and egg-laying, and social behavior . . . ." Consequently, it has not been possible to define and to rate ecological factors such as substrates, plant associations, available food plants, etc., very precisely, even for the Mojave desert population. For details concerning the ecology of particular, local populations, see Brussard et al. (1994, especially Tables 2, 3, and 5).

[3]Removal of artificial perch sites and nest sites used by common ravens (e.g., utility poles, transmission towers, fence posts, other structures), garbage dumps, and artificial water sources may reduce raven predation on immature desert tortoises.

[4]Brussard et al. (1994, II.C.2) recommended various means, including interpretive kiosks, "to disseminate information about the desert tortoise and the need for regulated access and use of habitat. Education programs should include such topics as: husbandry and adoption programs for captive tortoises, the illegality of releasing captive tortoises to wild lands, the illegality of translocating wild tortoises from one site to another, and the role of euthanasia in managing captive and wild populations where disease is a serious threat to the survival of the species. Education efforts should be focused on groups that use the desert on a regular basis, such as rockhounders. A permit system would offer one way to do this."

[5]"People who vandalize desert tortoises are difficult to identify and classify, thus increasing the problem of apprehending and educating them. Some who are suspected of shooting desert tortoises claim to be hunting rabbits . . ." (Brussard et al. 1994). "In 1991, local residents of Mesquite, Nevada, and St. George, Utah, threatened to undertake 'reprisal' killings of desert tortoises in response to the recent Federal listing, economic hardships, and perceived loss of local self-government (Tim Duck, BLM, pers. comm. to David J. Morafka). Residents threatened to shoot desert tortoises or flip them over to immobilize them" (Brussard et al. 1994). "Approximately 10 percent of [desert tortoise] shell remains from a study plot near Littlefield, Arizona, had gunshot wounds" (Barrett et al. 1994).

[6]Livestock grazing should be completely eliminated in areas supporting desert tortoises, and desert tortoise preserves should be fenced (Brussard et al. 1994). Feral horses and burros should be eliminated (Brussard et al. 1994).

[7]Desert tortoise barrier fences along roadways and railroads and tortoise underpasses (culverts) beneath roads and railroads may reduce vehicular mortality, shooting and vandalism, and capture and collection of desert tortoises. Roads should be closed, if possible, or access should be limited (e.g., locked gates) (Brussard et al. 1994).

*Most important indicators.

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western banded gecko (*Coleonyx variegatus*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (see Comments)	<1/ha	1–5/ha	6–10/ha	>10/ha	Parker (1972)	**N.B.**: The ratings are uncertain. Parker (1972) estimated either 12 or 25/ha in s. Arizona; not only are the 2 estimates discordant (i.e., >2-fold difference in the 2 estimates), but also his sample size was very small.
habitat	biome*	other	—	other arid areas	desert	various sources	
habitat	plant association	other	sagebrush, chaparral, piñon–juniper	desert grassland, mesquite–catclaw	creosote bush	Stebbins (2003) and other sources	
activity, foraging, growth	summer ambient nighttime temperatures	<15 °C or >40 °C	15–23 °C or 34–40 °C	24–27 °C or 31–33 °C	28–30 °C	Klauber (1945), Vance (1973), Parker and Pianka (1974)	
successful reproduction	average length of frost-free warm season*	<160 days	—	—	≥160 days	Parker and Pianka (1974)	
habitat	aspect (if any)	—	N	E, W	S	Parker (1972)	
habitat, cover	substrate (see Comments)	—	sandy, clayey	gravelly	rocky	Stebbins (2003) and other sources	"Often associated with rocks, and may seek shelter under them or in crevices. In some parts of range occurs on barren dunes" (Stebbins 2003).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal biology	elevation*	>4,900 ft	—	—	≤4,900 ft	Nickerson and Mays (1970), Stebbins (2003)	Stebbins (2003) gave the upper elevational limit as "around 5,000 ft." Seemingly the highest reported elevation is 4,900 ft in se. Arizona (Nickerson and Mays 1969 [1970]). At the northern limit of its range, *C. variegatus* has been found as high as 4,587 ft in sw. Utah (Utah Natural Heritage Program data 2007) and as high as 4,500 ft in adjacent se. Nevada (La Rivers 1942).

[1]*Coleonyx variegatus* occurs in Sonoran and Mojave deserts of the American southwest and nw. México.

*Most important indicators.

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desert iguana (*Dipsosaurus dorsalis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of individuals[2]	<10/ha	10–20/ha	20–300/ha	>300/ha	Howland (1988), Krekorian (1983, 1984), Parker (1972), Coombs (n.d.)	Accurate population densities are difficult to estimate. Temperature and precipitation affect activity and thus detectability. Reproductive adult females are not detectable from mid-June through early July (Norris 1953). Density estimates typically exclude hatchlings, which can be the most numerous age class.
food	spring annuals, summer- and autumn- blooming perennials	scarce	uncommon	common	abundant	Minnich and Shoemaker (1970), Mautz and Nagy (1987), Coombs (n.d.)	
habitat (construction of burrows)	substrate (soil type)	bedrock	very rocky	partially rocky; coarse soil (gravelly); clay soil; silty soil	sand (e.g., dunes) or sandy	Norris (1953)	
habitat	minimum temperature in hibernation burrows	< –7.17 °C	–7.17 to 0 °C	> 0 °C	»0 °C	Brattstrom (1965), Lowe et al. (1971)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food and water requirements upon emergence from hibernation	spring precipitation	light	fairly light	moderate	heavy	Norris (1953)	"In the northern portions of the range of *Dipsosaurus* extremely dry spring conditions may cause a considerable mortality of juveniles and adults alike during the critical period of emergence" (Norris 1953). The emergence period is critical because the lizards emerge desiccated (dehydrated) and emaciated (in need of plant food sources such as blossoms and new foliage). Ratings are to be understood as relative to the range of precipitation that occurs in deserts.
survival of hibernation	winter precipitation	heavy	moderate	fairly light	light	Norris (1953)	Norris (1953) believed that winter precipitation facilitating thermal conductance and cooling of soil subjects juveniles, which use shallow burrows for hibernation, to killing temperatures.[3] Ratings are to be understood as relative to the range of precipitation that occurs in deserts.
climate	summer daytime air temperatures	<18 °C or >50.5 °C	18–27 °C or 47.5–50.5 °C	27–38 °C or 45–47.5 °C	38–45 °C	Cowles and Bogert (1944), Norris (1953), Howland (1988), Pianka (1971)	This species is quite capable of behavioral thermoregulation, and ratings are to be understood as preferences rather than strict limitations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
plant association (food, protection from predators and excessive heat)	creosote bush (*Larrea tridentata*)[1]	scarce or absent	uncommon	common	abundant and dominant	Norris (1953) and many other authors	This is the most important indicator for northern and central populations. The northern range limits of the lizard and this plant closely coincide (Norris 1953).
edaphic conditions (egg hatching success)	soil temperature and water potential (pKa)	<28 or >38 °C or < –1000 pKa or suitable conditions for too short a time (<80 d) or too late in season	—	—	28–38 °C and –1,000 to –50 pKa for 45–80 d	Muth (1980)	Muth (1980) observed suitable conditions in the field only early (not late) in the reproductive season, only at depths ≥22 cm, and only in unvegetated washes (not near creosote bushes).[4]
suitable habitat and climate (possibly associated with minimum winter temperature)	elevation[5]	>5,000 ft	3,200–5,000 ft	1,600–3,200 ft	below sea level to 1,600 ft	Norris (1953), [Johnson et al. (1948)], Stebbins (1985 [2003])	Higher elevations are inhabited only in hot, southern parts of range. In general, the farther north, the lower the elevation must be for this species.
competition for food, habitat degradation, destruction of burrows, trampling of lizards in shallow burrows	livestock (grazing)	present in large numbers; or present in late spring and summer	present in moderate numbers; or only in late autumn and winter	present in low numbers and only in winter	absent	Coombs (n.d.)	Coombs considered livestock to be a serious threat at the only location where this species occurs in Utah.

[1]**This table is intended primarily for use in America north of México**, where this species is confined to desert habitats. In southern parts of its range, in México, this species utilizes certain habitats (plant associations) that are not present in America; in such areas the table may still be applied, but the plant

association given here (creosote bush) should not be used. "Southern populations seem to be distributed in relation to soil types and humidity rather than plant associates" (Norris 1953).

[2]The density ratings may be conservationally unrealistic in some places, particularly at the northern edge of the range of this species. For example, density of the single Utah population of this species has been estimated as 0.5 individual/ha (Coombs n.d.). In contrast, densities in the range of 300–400 individuals/ha are not uncommon (and estimated densities of up to 700 individuals/ha have been suggested) in optimal habitat in more central parts of the Mojave Desert; even higher densities may exist in subtropical habitats in México, where "[i]t is often exceptionally abundant" (Norris 1953).

[3]Krekorian (1984), however, considered winter precipitation to be of critical importance for the plants that are the foods of this species and thus highly positive in its effects on the lizard (i.e., the reverse of the ratings given here). Since Krekorian's evaluation of winter precipitation agrees with Norris' conclusions about spring precipitation, the source of the apparent disagreement may be different definitions of winter and spring. Furthermore, if Norris' hypothesis is correct, it should be of much more importance in areas with colder winters (i.e., sites at higher latitudes, higher elevations, and farther inland).

[4]Although natural oviposition sites have not been found, incubation experiments have indicated that in burrows where eggs are laid (1) soil temperature must be within the range 28–38 °C, (2) soil water potential must be within the range –50 (or perhaps 0) to –1,000 kPa, and (3) these conditions must prevail for 45–80 days, depending on temperature (Muth 1980). Lower water potentials and higher temperatures both were found to cause deformities or resulted in egg death. Burrows used for retreats by adults are typically associated with creosote bushes, but, at Palm Desert in southern California, soil temperatures and water potentials found in the root zone of creosote bushes were not within the required ranges long enough for eggs to complete incubation; however, in unvegetated washes, away from creosote bushes, soil conditions suitable for successful egg development were found early (but not late) in the reproductive season at depths ≥22 cm (Muth 1980). Although the experimental evidence shows that characteristics of oviposition sites are of critical importance to reproduction and thus the survival of a population and may limit the range of the species, there are practical limitations and difficulties in applying these soil characteristics under real conditions encountered in the field: (1) The required incubation conditions have not been confirmed in the field, (2) they necessitate guessing where oviposition occurs since it is not known where natural incubation takes place, (3) they are multivariate (temperature, water potential, time, [and depth and season]), acting in concert with varying effects (i.e., not conforming to the univariate structure of this table), and (4) they are not easily determined in the field.

[5]The upper elevational limit is lower at higher latitudes. For example, in Utah, at the northern limit of the species' range, the elevational limit is ~2,500 ft, which is near the lowest elevation in the state.

*Most important indicators.

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common chuckwalla (*Sauromalus ater*[1])
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density	≤6/ha	7–14/ha	15–30/ha	≥31/ha	Abts (1987), Johnson (1965)	
habitat (retreats, avoidance of predation)	rock crevices*	none	few	some	abundant	various (e.g., Stebbins 1985)	
microhabitat	maximum summer temperatures in retreats (e.g., rock crevices)	>45.6 °C	43.3–45.6 °C	42.0–43.3 °C	<42.0 °C	Cowles and Bogert (1944), Brattstrom (1965)	
microhabitat	minimum winter temperatures in retreats (e.g., rock crevices	< –5 °C	–5–0 °C	>0 °C	»0 °C		It is highly likely that winter low temperatures limit occurrence of this species. However, neither critical thermal minimum nor supercooling potential has been determined for this species. Indicator ratings represent estimates.
habitat	physiography/ landform*	flats, fine substrates, few or no large rocks	few rocky situations or boulders	some rocky situations, boulders	boulder-strewn slopes, rocky outcrops and hillsides, lava flows	various authors (e.g., Stebbins 1985)	
climate (survival of eggs and hatchlings)	summer rainfall (July–August)	low	fairly low	fairly high	high	Abts (1988)	Summer rainfall is necessary to prevent desiccation of eggs and to provide food for hatchlings.
climate (quality and quantity of food in spring and summer)	winter rainfall, esp. early winter, October–January	low	fairly low	fairly high	high	Nagy (1973), Abts (1987)	Winter rainfall is necessary to ensure availability and quality of food resources (annual plants) in spring and summer, which enables reproduction.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
climate	summer daytime air temperatures	«23.8 °C or >50 °C	<23.8 °C or 43.3–50 °C	23.8–27.0 °C or 42.0–43.3 °C	27.0–42.0 °C	Cowles and Bogert (1944)	
climate	elevation*	>6,000 ft	4,000–6,000 ft	2,500–4,000 ft	0–2,500 ft	Stebbins (1985)	Higher elevations are inhabited only in southern parts of the species' distribution. At the northern limit of its range (i.e., in Utah), the species occurs only as high as ~4,000 ft and is uncommon and of very patchy occurrence above 3,000 ft.
climate	creosote bush (*Larrea tridentata*) in vicinity	absent (*see comments*)	scarce (*see comments*)	common (*see comments*)	abundant (*see comments*)	various authors (e.g., Stebbins 1985)	**Use indicator with caution**: Creosote bush is **not** a necessary component of suitable habitat for this species, which is absent from many places where creosote bush is abundant and is present in other places where creosote bush is absent. Rather, creosote bush is merely an indicator of general desert climatic conditions that are inhabitable by this species. Even where both the plant and the reptile are present in the same general area, the shrub may be restricted to flats near (e.g., within sight of) rocky slopes inhabited by the lizard, but spatial overlap (true co-occurrence) may be slight or non-existent.

[1]Until 1998 almost all literature referred to this species as *Sauromalus obesus*. Hollingsworth (1998) synonymized *obesus* with *ater*, and since then most, but not all, literature has followed Hollingsworth in referring to this species as *Sauromalus ater*.

*Most important indicators.

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zebra-tailed lizard (*Callisaurus draconoides*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (individuals/ha) (see footnote 2)	<0.5/ha	0.5–1.9/ha	2–10/ha	>10/ha	Pianka and Parker (1972), Tanner and Krogh (1975)	Pianka and Parker (1972) estimated 0.020–1.750 individuals/ha (mean = 0.518/ha) on 9 study areas in NV, CA, and AZ, 3 of these in 2 years (thus *n* = 12). On 1 study area there was a 6-fold density change between years. Tanner and Krogh (1975), using more rigorous methods for estimating density, found 15.5/ha on 1 study area in s. NV, but this dropped to 12.5/ha in the following year.[2]
habitat	plant association[3]	other	somewhat dense desert shrubs and trees	scattered desert shrubs and trees	scattered, low, desert shrubs	various sources including Tanner and Krogh (1975), Baltosser and Best (1990)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	perennial vegetative cover (presumably tall shrubs and trees)[3]	>15% (0%)	12.5–15% (22.2%)	10–12.5% (33.3%)	<10% (44.4%)	Pianka and Parker (1972)	Pianka and Parker (1972) reported that mean perennial vegetative cover on 9 study areas in NV, CA, and AZ ranged 6.0–14.8% (mean of these means = 10.4%). However, they did not find a correlation between plant cover and abundance of *C. draconoides* on their study areas.[4] Numbers in parentheses are the percentages of Pianka and Parker's (1972) 9 study areas with the indicated mean % perennial vegetative cover. (Compare with indicator below.)
habitat	vegetative cover (all)[3,4]	>40%	—	—	<40%	Baltosser and Best (1990)	Baltosser and Best (1990) reported mean total vegetative cover for 2 study areas in extreme sw. New Mexico, where *C. draconoides* was the most abundant of 11 lizard species, as 29.7% and 36.6%. (Compare with indicator above.)
habitat	substrate	very rocky	some rock	gravel	sand	various sources including Degenhardt et al. (1999), Stebbins (1954, 2003), Smith et al. (1987), Clarke (1965)	
habitat	physiography*	hilly, steep, rugged	—	dissected by arroyos	flat or rolling	various sources including Clarke (1965)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal biology	elevation*	>6,000 ft	—	5,000–6,000 ft	<5,000 ft	La Rivers (19442), Stebbins (2003)	La Rivers (1942) reported this species in s. Nevada from 5,600 and 6,000 ft elevation. These 2 elevations apparently are the highest known, and there are probably very few places where it occurs so high. Stebbins (2003) stated the elevational range as: "From below sea level in desert sinks to around 5,000 ft. (1,520 m)."
thermal biology	summer daytime air temperatures (see Comments)	<28 °C or >45 ° C	28–33 °C or 43–45 °C	34–38 °C or 42 °C	39–41 °C	Clarke (1965), Pianka and Parker (1972), Tanner and Krogh (1975), Smith et al. (1987)	"Ratings" are based on body temperatures of active lizards and experimental tests of preferred body temperatures. Actual air temperatures can be slightly (~2.4 °C) lower (see Smith et al. 1987).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	long-term mean annual precipitation[4,*]	<9.0 cm or >21.0 cm (0%)	20.1–21.0 cm (8.3%)	16.3–20.0 cm (33.3%)	9.0–16.2 cm (58.3%)	Pianka and Parker (1972)	Pianka and Parker (1972) reported that long-term mean annual precipitation for 12 study areas throughout the range of this species (NV, CA, AZ, and Sonora) ranged 9.3–20.9 cm (mean of these means = 14.5 cm). Presumably there is a lower limit (i.e., long-term annual precipitation must average >0 cm) and an upper limit. It is here assumed that the range reported by Pianka and Parker (1972) closely approximates these limits. Numbers in parentheses are the percentages of Pianka and Parker's (1972) 12 study areas with the indicated long-term mean annual preciptiation.[4]

[1]This species occurs in the Mojave and Sonoran deserts and in western parts of the Great Basin, from nw. Nevada to s. Baja California Sur and s. Sinaloa. Its ecology in the southernmost part of its range in Sinaloa may differ from that in more northern areas. This table is intended for use mainly in America, its applicability in some areas inhabited by *C. draconoides* in México being uncertain.

[2]Pianka and Parker (1972) commented: "*Callisaurus* is usually a fairly uncommon desert lizard; our study areas are no exception, and on many of them it was rare." Despite the observations of Pianka and Parker (1972) on many study areas over a large geographic area, *C. draconoides* in some places is *not* uncommon. Baltosser and Best (1990) found it to be by far the most commonly encountered of 11 species of lizards on their 2 study sites in extreme sw. New Mexico, greatly outnumbering every other lizard species including the second most abundant of the 11. Although they based their sampling method on that devised by Pianka and Parker (1972) to obtain estimates of population densities, Baltosser and Best (1990) unfortunately did not calculate and report densities, which presumably would have been very much higher than the highest density estimated by Pianka and Parker (1972). Also, at a locality in extreme sw. Utah, the density of *C. draconoides* is many individuals per hectare (Oliver, personal observations), certainly far exceeding the highest density (1.75/ha) reported by Pianka and Parker (1972). The densities reported by Tanner and Krogh (1975) are representative of "very good" populations, and those reported by Pianka and Parker (1972), despite their broad geographic sample, are likely only "fair" at best.

[3]Habitats of this species have been characterized as those where "plant growth is scant" (Stebbins 2003) and "areas with little or no vegetative cover" (Degenhardt et al. 1999), and all authors have noted its preference for "open" areas. However, for various reasons including the fact that plants are the primary producers upon which all animal life ultimately depends, there likely is a lower limit of requisite vegetative cover that is >0% (e.g., for the "very good" ratings).

[4]Although Pianka and Parker (1972) did not find correlations between either plant cover or annual precipitation and the *abundance* of *C. draconoides* on their study areas and concluded that these environmental factors do not regulate abundance in this species, it is apparent that both plant cover and annual precipitation are very important in the ecology of this species and do affect its presence (occurrence) or absence. However, these environmental effects may involve "thresholds" or limits, and thus the ratings, except for "poor" (i.e., the limits), may not be truly meaningful.

*Most important indicators.

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desert night lizard (*Xantusia vigilis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of individuals	«1/acre	1–2/acre	3–10/acre	11–25+/acre	Miller (1951), Zweifel and Lowe (1966)	Densities reported in ideal habitat in the core of the range are not to be expected at the limits of the range (e.g., in Utah), where viable, healthy population densities may be much lower.
plant association	arborescent yuccas, giant cacti, rosettiform yuccas, agaves, sotol, beargrass, or juniper	absent	scarce	common	abundant	Miller (1951), Zweifel and Lowe (1966), and other sources	
microhabitat	availability of suitable cover (e.g., decaying yucca, juniper, or other logs; or rock crevices)	absent	scarce	common	abundant	Miller (1951), Zweifel and Lowe (1966)	
microhabitat	characteristics of (and beneath) decaying yucca or other logs	deteriorated, lacking bark or leaves, or small, or unshaded, or poor seal with ground, dry	lacking shade or bark and leaves but good seal with ground and large enough to provide some insulation	large, with bark and leafy covering, partially shaded, good seal with ground, moist	large, with bark and leafy covering, partially shaded, good seal with ground, moist, and with woodrat (*Neotoma* sp.) nest	Zweifel and Lowe (1966), Miller (1951)	Zweifel and Lowe (1966) provided photographs of examples of the quality range of arborescent yucca habitats.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
microhabitat	maximum summer temperature in retreats (e.g., beneath logs)	>44 °C	38–44 °C	35–38 °C	<35 °C	Miller (1951), Kour and Hutchinson (1970), Cowles and Burleson (1944)	
microhabitat	average summer temperature in retreats (e.g., beneath logs)	<20 °C or >37 °C	20–23 °C or 33–37 °C	23–29 °C or 30–33 °C	29–30 °C	Brattstrom (1965), Cowles and Burleson (1944), Cowles and Bogert (1944)	
microhabitat	minimum winter temperature in retreats (e.g., beneath logs)	< –5.86 °C	–5.86–4.3 °C	4.3–10 °C	>10 °C	Kour and Hutchinson (1970), Zweifel and Lowe (1966), Cowles and Burleson (1944), Lowe et al. (1971)	
climate	elevation	very high (>9,000 ft)	high (6,000–9,000 ft)	low (below sea level to 2,000 ft)	moderate 2,000–6,000 ft)	Zweifel and Lowe (1966) and other sources	Inhabited extreme elevations are known only where climatic extremes are mitigated by maritime conditions. In Utah conditions above 6,500 ft are probably unsuitable.
climate	winter precipitation	low	moderate	fairly high	high	Zweifel and Lowe (1966)	The qualitative indicator ratings should be understood in the context of a very arid (i.e., desert) climate.
climate	maximum summer ambient (air) temperatures	very high (>43 °C)	high	moderate	relatively "low" (≤43 °C)	Miller (1951)	The qualitative indicator ratings should be understood in the context of a very hot (i.e., desert) climate.

[1]The distribution of the desert night lizard is discontinuous and patchy in many areas and especially so in Utah. Thus, even though the ecological requirements of this species may be met and may be in the "very good" range at a particular location within the overall geographic distribution of the species, the species may not occur at the site. Also, the species inhabits two general habitat types, Joshua tree (or other arborescent yucca or giant cactus) desert and juniper (or piñon-juniper) woodland. It is more continuously distributed and thus of more predictable occurrence in Joshua tree desert than it is in arid juniper woodland, occurring

only patchily and highly unpredictably in the latter habitat. Populations within this species also show divergent microhabitat preferences: rock crevices and plants (e.g., decaying yucca or juniper logs). Furthermore, a few populations (e.g., in certain coastal and montane settings in California) show habitat affinities that are exceptional and atypical of the species. Such atypical habitats are not represented in this table, which is intended for use in Utah and within desert areas of the main range of the species.

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Gila monster (*Heloderma suspectum*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density	≤3/mi^2	4–6/mi^2	7–9/mi^2	≥10/mi^2	Beck (1985), Beck (1990, 2005), Beck and Jennings (2003), Coombs (1977)	Densities of 20–25/mi^2 (Coombs 1977, Beck 2005) have been estimated in areas near St. George, Utah, in the past (late 1970s and early 1980s), but such densities are probably exceptional anywhere and probably no longer exist in Utah (McLuckie et al. 2004, Beck 2005). Beck (2005) considered even 10/mi^2 possibly to be exceptionally high density.
habitat	area of suitable habitat	<150 ha	150–750 ha	750–1,500 ha	>1,500 ha		Individual home ranges vary in size from ~6 to ~147 ha (Beck 2005).
habitat	biotic community*	evergreen woodland (juniper, oak, piñon)	desert-scrub	semidesert grassland	tropical thorn-scrub (including Arizona upland)	Beck (2005)	Although this species does occur in the Sonoran Desert and in parts of the Mojave and Chihuahuan deserts, true desert situations are **not** preferred (Beck 2005).
habitat	physiography*	uniformly flat and rockless areas	little dissection of landscape, little slope, few rocks	some slope, some drainage channels, some rocks	rocky slopes, washes, sandy valleys at bases of sandstone cliffs	Beck (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
available retreats or shelters (protection from environmental extremes and predation, mating sites)	available shelter type	none	woodrat nests	mammal and tortoise burrows	cavities or crevices (≥5 cm) in rocks on rocky slopes or among boulders	Beck (2005)	Situations with higher densities of potential shelters, especially rocky shelters on S- or E-facing slopes, are preferred (Beck and Jennings 2003) (see indicators below).
availability of retreats or shelters (protection from environmental extremes and predation, mating sites)	density of potential shelters (see Comments)	<10/ha	10–85/ha	85–175/ha	>175/ha	Beck and Jennings (2003), Beck (2005)	A potential shelter is a stable hole or crevice ≥5 cm in diameter and ≥20 cm deep, these being the dimensions of the smallest shelter observed by Beck and Jennings (2003) to be used by this species.
humidity and temperature (protection from desiccation and from extreme temperatures)	depth of available shelters (≥5 cm opening)	≤30 cm	30–50 cm	50–70 cm	>70 cm	Beck (1990, 2005), Beck and Jennings (2003)	Beck and Jennings (2003) found that shelters used in winter were deepest (mean = 128.0 cm) and those used in spring were the shallowest (mean = 49.4 cm).
humidity (protection from desiccation)	vapor pressure deficit (drying capacity of air) in available shelters during activity season (April–June)	>0.30 kPa	0.25–0.30 kPa	≤0.25 kPa	«0.25 kPa	Beck and Jennings (2003), Beck (2005)	
thermal biology	aspect of shelter entrances and of slope where entrance is situated	NW, N, NE	W	SW	S, E, SE	Beck (1985, 1990, 2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, food (tortoise eggs)	desert tortoise (*Gopherus agassizii*) (see Comments)	absent	rare	fairly common	abundant (e.g., ≥150/mi^2)	Beck (2005)	The tortoise and the Gila monster commonly co-occur. Because the tortoise is much (~10X) more common and is much more easily detected than is the lizard, presence of the tortoise is a useful indicator of conditions suitable for the lizard in many, but not all, places. **Caution**: The tortoise should be used as an indicator only within areas of known sympatry (e.g., UT, NV, w. AZ, and Sonora, but **not** CA, e. AZ, or NM; use range maps in field guides for a particular site). The tortoise is more of a true desert dweller, occurring in some true desert situations uninhabited by the lizard and absent from some semidesert situations where the lizard thrives.
habitat (general)	creosote bush (*Larrea tridentata*) (see Comments)	absent (see Comments)	rare (see Comments)	fairly common (see Comments)	abundant (see Comments)	Beck (2005)	**Caution**: Creosote bush is present in many places where Gila monsters occur, but there are **many exceptions**—the plant may be present and the lizard absent and vice versa.
winter survival (microhabitat)	minimum temperature in winter retreats	< –3.89 °C	–3.89–0 °C	0–9 °C	>9 °C	Lowe et al. (1971), Beck (2005), Beck and Jennings (2003)	
summer survival (microhabitat)	maximum temperature in summer retreats	>44 °C	37–44 °C	30–37 °C	<30 °C	Beck (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
summer activity	summer temperatures	very hot or cool	hot	very warm	warm but somewhat mild	Beck (2005)	
winter survival	winter temperatures	cold (regularly well below freezing, < –5 °C)	cold (regularly freezes, but ≥ –5 °C)	cool (occasionally freezes, but > –5 °C)	mild (seldom if ever freezes)		Ratings are estimates based on Beck (1985, 2005), Lowe et al. (1971), and others
dehydration (survival of juveniles and eggs)	summer rainfall as % of total annual precipitation*	<25%	25–50%	50–70%	≥70%	Bogert and Martín del Campo (1956), Beck (2005)	
dehydration (survival of juveniles and eggs)	season of greatest precipitation*	winter	other (e.g., spring, fall)	summer and winter (bimodal)	summer	Beck (2005)	
dehydration (survival of juveniles and eggs)	total annual precipitation	<2½ in. (or >20 in.)	2½–8 in.	8–12 in.	12–20 in.	Beck (2005)	
juvenile activity (foraging)	summer nighttime temperatures	cool (<20 °C)	somewhat cool (20–25 °C)	fairly warm (25–30 °C)	warm (>30 °C)		Warm nights may be important for foraging in summer, especially for juveniles (Beck 2005). Ratings are estimates.
food resources	abundant presence of prey species (i.e., their eggs and young)	tree-nesting birds, live-bearing snakes and lizards, large mammals	woodrats, egg-laying snakes and lizards	ground squirrels, tortoises	cottontails, quails, doves (and probably ground-nesting passerines)	Beck (2005) and others	Foods are **almost exclusively eggs and young of small vertebrates**; i.e., young of small mammals (especially altricial species), eggs and (altricial) nestlings of ground-nesting (or low-nesting) birds, and eggs of tortoises, lizards, and snakes.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, climate	elevation	>6,000 ft	5,000–6,000 ft	4,000–5,000 ft	0–4,000 ft		Although this species occurs at 5,700 ft in Arizona and has been reported from as high as 6,000 ft near the Arizona–Sonora boundary (Beck 2005), it does not inhabit such high elevations in northern parts of its range (e.g., Utah and Nevada), where it occurs only below ~3,500 or 3,600 ft.
destruction and fragmentation of habitat; direct mortality (e.g., from human persecution, domestic dogs and cats, vehicular traffic)	urban and other development	existing or planned and expanding	—	—	none	McLuckie et al. (2004), Beck (2005) Crowther (1993)	
direct mortality (from vehicular traffic), fragmentation of habitat and barriers to dispersal and other movements	roads (especially paved)	large, multi-laned or very many in vicinity (within 1 mi)	many and/or larger and/or high-use in vicinity (e.g., within 1 mi)	few, small, low-use in vicinity (e.g., within 1 mi)	none in vicinity (e.g., within 1 mi)		"Apart from losses owing to large-scale habitat conversion, road kill is probably the largest source of human-caused mortality throughout most of the range of . . . Gila Monsters . . . " (Beck 2005). Juveniles may be particularly vulnerable, being found more often on roads on warm nights than by any other means or in any other situations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population reduction (removal of animals from the wild, i.e., "ecological death" even if animals are not killed)	illegal collection (poaching)	known to take place	probably occurs regularly	probably very seldom occurs	none (adequate enforcement of and compliance with laws believed to exist)	McLuckie et al. (2004), Coombs (1977), Beck (2005)	Indicator may be difficult to use since law-breakers are unlikely to admit crimes; however, some places are well-known sources for the illegal take of this species, which is "one of the most commercially valuable reptiles in the world" (typically $1,600–$2,000 each for the race that occurs in UT, NV, CA, & w. AZ; reportedly as much as $4,000 each in Japan [Beck 2005]). It is "among the most common black-market reptiles" (Beck 2005), and "illegal commerce is a significant threat" (McLuckie et al. 2004, Beck 2005).
habitat alteration, fire	invasive alien grasses (e.g., *Bromus rubens*, *Pennisetum ciliare*)	abundantly present	present and somewhat common but not dominant	present but very rare	absent	Beck (2005)	A fire control plan should exist, and a program to control or eradicate invasive nonnative grasses should be considered.
habitat degradation, direct mortality, collapse of shelter and nest burrows, persecution	off-road vehicle use	heavy and uncontrolled	moderate, with some restrictions	low, restricted to established routes within certain areas	none	Beck (2005)	OHV use should be prohibited or, if allowed, should be restricted to trails, and signs should warn that it is illegal to capture or to kill Gila monsters.
habitat degradation, trampling of shelter and nest burrows	grazing	high-density or year-round	low-density and occasional or seasonal (e.g., only in winter)	none	none	Beck (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat loss	agriculture	extensive and surrounding	limited and not surrounding	none	none	Beck (2005)	
habitat degradation, trampling of shelter and nest burrows, persecution	outdoor recreation (e.g., hiking, camping)	heavy	moderate	slight	none	Beck (2005)	If recreational use is allowed, signs and other educational information should be used to warn people that it is illegal to capture or to kill Gila monsters, and dogs should be prohibited.

[1]This species occurs from southern Nevada and southwestern Utah to extreme southern Sonora (and perhaps Sinaloa). However, within this area, even in ideal habitat, populations are patchily distributed (Beck 1985).

*Most important indicators.

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western threadsnake (*Leptotyphlops humilis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	life zone or biome	—	—	semidesert	desert	Klauber (1940)	
habitat	general habitat	—	sand dunes, sandy flats, dry lakes, alluvial fans	desert grassland, ocean beaches (above high tide line), irrigated areas and urban lawns and gardens in desert regions	desert foothills, mountain slopes, canyon bottoms, washes	Klauber (1940), Stebbins (1954, 1985), Degenhardt et al. (1999)	Rocky canyons or washes with small streams in desert foothills may be ideal.
surface cover	presence of rocks	—	few or no rocks	moderately rocky	rocky situations (rocks, boulders)	Klauber (1931, 1940), Stebbins (1985), Degenhardt et al. (1999)	
burrowing	soil texture*	hard-packed (e.g., clay, bedrock)	—	somewhat loose (gravelly)	loose (e.g., sand, loam, humus)	Hahn (1979), Stebbins (1954, 1985), Degenhardt et al. (1999)	Loose soil among rocks or boulders may be ideal.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
desiccation	soil moisture	very dry or wet	—	—	damp or moist but not wet (e.g., near permanent or intermittent desert streams, desert springs, ocean beaches)	Klauber (1940), Hahn (1979), Stebbins (1954, 1985)	
habitat, thermal ecology	elevation*	»5,000 ft	—	—	≤5,000 ft	Stebbins (1985), Hahn (1979), Degenhardt et al. (1999)	This species probably does not occur above 3,000 ft at the northern limit of its distribution (Utah).

[1]This species is (or was) also known as the western blind snake and, earlier, the western worm snake. It is a fossorial, subterranean species and eats mostly ants and termites (and their immature stages).

*Most important indicators.

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smooth greensnake (*Opheodrys vernalis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	habitat type	other	—	rocky situations near streams (in west)	prairie, meadow, parkland, marsh, bog, peatland	Grobman (1992)	Suitable habitat may be surrounded by unsuitable habitat (e.g., bogs or meadows within dense forests).
habitat	glacial prehistory	formerly unglaciated areas	—	—	formerly glaciated areas (including former montane glaciers)	Grobman (1941, 1992)	Grobman (1992) noted: "All of the known locality records, other than those in Texas, appear to be sites in glaciated areas. Presumable immature topography, with its ponds, bogs, and meadows, provides suitable habitats for *O. vernalis*."
habitat	vegetation*	other	—	shrubs	dense grasses	Grobman (1941, 1992)	"*O. vernalis* appears to be restricted in its present distribution to relatively moist areas that have a growth of grasses or shrubs" (Grobman 1992).
habitat	moisture*	dry (xeric) situations	—	—	permanently relatively moist (mesic) situations	Grobman (1941, 1992)	See comment immediately above.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	latitude or elevation*	very high or very low: >50° N. Lat. or <38° N. lat. and <5,000 ft elev. (see Comments)	—	—	moderately high: 38–50° N. lat. or 5,000–9,500 ft elev.	Grobman (1941, 1992)	An apparent exception to the "requirement" of moderately high latitude or elevation is the occurrence of this species in Houston, Texas, and vicinity (~30° N. lat., ~100 ft elev.), but Grobman (1992) considered this occurrence to be the result of introduction and perhaps impermanent, "an intermittent population established through the occasional release of snakes from outside the area." This and the following "indicator" are doubtless correlated.
reproductive success (presumably egg development or survival)	average May temperature*	»64 °F (see Comments)	>64 °F	61–64 °F	<61 °F	Stille (1954)	An apparent exception to the "requirement" of cool average May temperature is the occurrence of this species in Houston, Texas, and vicinity (»64 °F), but Grobman (1992) considered this occurrence to be the result of introduction and perhaps impermanent, "an intermittent population established through the occasional release of snakes from outside the area." This and the preceding "indicator" are doubtless correlated.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
alteration, destruction, and fragmentation of habitat	agriculture	present	—	—	none	Grobman (1992)	
alteration, destruction, and fragmentation of habitat	livestock grazing and other impacts to riparian areas (in the west)	severe	moderate	minimal	none	Hammerson (1999)	"Human activities that eliminate shrubby/grassy riparian vegetation are likely detrimental" to this species (Hammerson 1999), especially in the west.
alteration, destruction, and fragmentation of habitat	impoundments	existing or planned	—	—	none	Hammerson (1999)	"Impoundments have flooded some areas of suitable habitat and pose a potential threat in several others" (Hammerson 1999).
alteration, destruction, and fragmentation of habitat	roads	many, large, and with heavy use	many, larger, or with heavier use	few, small, and with low use	none	Hammerson (1999)	"Paved and dirt roads traverse green snake habitat; local populations of this snake therefore may be reduced through mortality caused by automobiles" (Hammerson 1999).

[1]The "core" or continuous distribution of this species is northeastern and north-central America and extreme southeastern and south-central Canada (in meadows, marshes, grassy fields, prairies, bogs). South and west of this area its distribution is discontinuous. West of the Great Plains it occurs in mountains and foothills (usually in meadows along streams and in parklands) in the southern Rocky Mountain region (Wyoming, Utah, Colorado, New Mexico, and Chihuahua).

*Most important indicators.

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cornsnake (*Elaphe guttata*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
diurnal shelter and hibernation	retreats*	—	rocks, boards, logs, debris, other surface cover, rodent burrows	deserted houses, old wells, cisterns, barns, outbuildings, foundations of old buildings	caves (especially entrances and twilight zones), cracks, fissures, boulder piles	Degenhardt et al. (1996), Hammerson (1999), Stebbins (1954, 2003)	
habitat	surface water in vicinity*	none	ponds, lakes, stock tanks	intermittent streams	perennial watercourses (rivers, streams), seeps, springs	Stebbins (1954, 2003), Degenhardt et al. (1996), Hammerson (1999)	
habitat	physiography or landform*	rockless areas	areas with few rocks (outcrops)	rocky outcrops, hills, mountains	canyon bottoms, river valleys, rocky slopes	Degenhardt et al. (1996), Stebbins (1954, 2003), Hammerson (1999)	
habitat	plant association*	desert scrubland, dense forest, sagebrush steppe	farmland	grassland, shrubland, woodland (e.g., piñon–juniper, oak, open coniferous)	riparian shrubland and woodland	Degenhardt et al. (1996), Stebbins (1954, 2003), Hammerson (1999)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
climate and habitat	elevation*	>7,250 ft	6,000–7,250 ft	<3,500 ft	3,500–6,000 ft	Stebbins (1954, 2003), Hammerson (1999), Degenhardt et al. (1996)	The highest reported elevation is "about 2200 m" (7,218 ft) in northern New Mexico (Degenhardt et al. 1996).
prey	small rodents, bats, small birds and bird eggs, lizards	very scarce	uncommon	common	abundant	Stebbins (1954, 2003), Degenhardt et al. (1996), Hammerson (1999)	
mortality	fire	controlled burns take place as part of ongoing management	controlled burns carried out only during winter (November–February or early March)	prevention plan lacking but no intentional burns (e.g., controlled burns)	none; fire prevention and control plans existing and implemented	Heinrich and Kaufman (1985)	11 individuals were killed in April in a controlled burn of prairie in Kansas (Heinrich and Kaufman 1985).

[1]Taxonomy of this species has been unstable. Several recent studies have discussed the possibility that it is actually more than a single species. The most recent of these studies, using molecular techniques, demonstrated that 3 clades exist in what has been called *Elaphe guttata* and proposed elevation of each of these clades to full specific status. Although there currently is great disagreement about species concepts in zoology and it may be a long time before any consensus concerning the species concept is approximated, adherents to some of the newer species concepts (e.g., the various "phylogenetic" species concepts) currently regard the clades of *Elaphe guttata* (*sensu lato*) as 3 species. Under this arrangement, all populations west of eastern Texas are treated as *Elaphe emoryi*, the Great Plains ratsnake. However, other herpetologists do not accept this split, which elevates *emoryi* from subspecific to specific status. Regardless of the taxonomic position of *emoryi*, it is convenient for the purposes of this table to regard *emoryi* as distinct, at least ecologically, from the 2 other clades, which inhabit mesic lowland habitats of eastern North America. Furthermore, populations in eastern Utah and western Colorado are geographically disjunct from others and in the past have been considered a distinct subspecies (*Elaphe guttata intermontana*). **This table is intended primarily for use in Utah and western Colorado (i.e., the upper Colorado River drainage)** and secondarily elsewhere in at least western parts of the range of *emoryi* (e.g., New Mexico).

*Most important indicators.

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Mojave rattlesnake (*Crotalus scutulatus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography	steep, rocky	moderately steep	rolling	flat	Price (1982), Lowe et al. (1986), Degenhardt et al. (1999), Stebbins (2003)	"It [*C. scutulatus*] is generally absent from rocky areas" (Degenhardt et al. 1999).
habitat	plant association*	dense woodland, forest	open juniper woodland	barren desert	semi-arid and desert grassland, desert scrub	Pough (1966), Lowe et al. (1986), Mendelson and Jennings (1992), Degenhardt et al. (1999), Stebbins (2003)	"In New Mexico, *C. scutulatus* prefers lowland semi-arid grasslands or open areas of creosotebush and desert grasslands with dense growth of clump-forming grasses, such as *Sporobolus*" (Degenhardt et al. 1999).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
winter survival	minimum temperature in hibernation sites ratings uncertain —see Comments	ν0 °C	<0 °C	0–4 °C	>4 °C	Dammann (1961)	Dammann (1961, Fig. 4) considered the lethal minimum temperature for *C. scutulatus* to be 0.0 °C and indicated death after 10 days at 4.0 °C, but he also commented (p 35) that the lethal minimum appears to be less than 0.0 °C. Better studies of the thermal biology (including supercooling) of other species of desert rattlesnakes suggest that Dammann's latter comment is more accurate and that *C. scutulatus* actually can survive colder temperatures than Dammann considered to be lethal and that are show in the "ratings" here. Nonetheless, it is likely that winter minimum temperatures limit the occurrence of *C. scutulatus*, elevationally and latitudinally.
habitat	elevation (in America and Sonora)[1,*]	>5,500 ft	5,001–5,500 ft	4,000–5,000 ft	<4,000 ft	Stebbins (1954), Pough (1966), Lowe et al. (1986), Price (1982)	This species has been found at 4,000 ft in Nevada. In Utah its highest known elevation is 4,553 ft, but it is mostly found at lower elevations in Utah, all other Utah localities being below 3,650 ft (Utah Natural Heritage Program database, 2007).[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	roads*	many, large, paved, and with heavy vehicular traffic	moderate in number, size, and traffic	few, small, unpaved, and with very little vehicular traffic, especially at night	none	Rosen and Lowe (1994)[2]	78% of *C. scutulatus* found on a paved highway in Arizona during a 4-year study by Rosen and Lowe (1994) had been killed by vehicles. Of the 20 species of snakes that they detected, *C. scutulatus* had the 5th highest rate of highway mortality.[2] When the snakes encounter warm pavement, they remain on it, often flattening their bodies to absorb as much warmth as possible; this behavior makes them especially vulnerable to being killed by vehicles.
mortality (persecution by people)	cities, towns, military bases, outdoor recreation sites (e.g., hiking trials, camping and picnic areas, parks) in vicinity	present	—	—	absent	see Comments	Although human persecution of many kinds of animals in America has diminished in recent decades (e.g., raptors), rattlesnakes are still routinely harassed, tortured, mutilated, and killed by many people. Fortunately, organized "rattlesnake roundups", in which thousands of snakes, including non-venomous species, are killed, do not exist within the range of *C. scutulatus*, but opportunistic killing of this species almost certainly occurs frequently.

[1]This species occurs in the American southwest and much of c. and n. México, mostly in interior areas. In the American part of its range, *C. scutulatus* inhabits desert and semi-desert situations, usually at lower elevations; however, in most of its range in México (except Sonora), it occurs mainly at elevations between 6,000 and 8,000 ft and is scarce below 4,000 ft (Klauber 1952, Stebbins 1954, Price 1982). This table is applicable primarily in the American portion of its range.

[2]In their study in s. Arizona, Rosen and Lowe (1994) estimated that ~1,000 snakes per year were killed on a 44.1-km (27.4-mi) stretch of paved highway, 82% of which was within a national monument, and commented: "Overall, along our 44.1 km transect, the estimated highway mortality amounts to removal of 5 km^2 [500 ha or 1,235 acres or ~2 sections] of snake population over the four years of study [1.25 km^2/year]. It is clear that roadways, especially if paved, substantially damage snake populations. . . . Our computational result indicates that in the United States alone, tens or hundreds of millions of snakes have been killed by automobiles, certainly affecting snake populations over substantial fractions of the continent. . . . As the density of roadway networks increases, we predict that, first, active snakes . . . , and then others will be locally extirpated or become rare."

*Most important indicators.

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speckled rattlesnake (*Crotalus mitchellii*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	substrate*	—	sand	gravel, loam	rocks	Klauber (1936), Stebbins (1954, 2003), Lowe et al. (1986)	
habitat	physiography*	—	dunes	plains and alluvial fans	slopes of buttes and mountains, canyons	Klauber (1936), Stebbins (1954, 2003) and other sources	In Arizona this species inhabits “rocky upland terrain . . . seldom in the open away from rocky retreats” (Lowe et al. 1986).
habitat	plant association	other (e.g., dense woodland, forest)	—	—	sagebrush, creosote bush, desert scrub, chaparral, piñon–juniper woodland	Stebbins (1954, 2003), Campbell and Lamar (2004)	
habitat	elevation*	>8,000 ft	6,000–8,000 ft	4,501–6,000 ft	<4,500 ft	Stebbins (2003) and other sources	This species has been found at 6,000 ft in Nevada, but its highest known elevation in Utah is 4,050 ft (Utah Natural Heritage Program database, 2007). In Arizona it occurs from 600 to 4,300 ft elevation (Lowe et al. 1986).
habitat	minimum temperature in hibernation sites	« –2 °C	< –2 °C	–2 to 0 °C	>0 °C	Brattstrom (1965)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	roads	many, large, paved, and with heavy vehicular traffic	moderate in number, size, and traffic	few, small, unpaved, and with very little vehicular traffic, especially at night	none	see Comments	When rattlesnakes encounter warm pavement, they remain on it, often flattening their bodies to absorb as much warmth as possible; this behavior makes them especially vulnerable to being killed by vehicles.
mortality (persecution by people)	cities, towns, military bases, outdoor recreation sites (e.g., hiking trials, camping and picnic areas, parks) in vicinity	present	—	—	absent	see Comments	Although human persecution of many kinds of animals in America has diminished in recent decades (e.g., raptors), rattlesnakes are still routinely harassed, tortured, mutilated, and killed by many people. Fortunately, organized "rattlesnake roundups", in which thousands of snakes, including non-venomous species, are killed, do not exist within the range of *C. mitchellii*, but opportunistic killing of this species almost certainly occurs frequently.

[1]This species occurs in the Mojave and Sonoran deserts of sw. America and nw. México (mainly the Baja California peninsula). In México (Baja peninsula) it inhabits chaparral, tropical deciduous forest, and even pine–oak forest; the latter 2 habitats are not part of its ecology in America. **This table is intended for use only in the American part of the range of this species.**

*Most important indicators.

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sidewinder (*Crotalus cerastes*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (no. of individuals/ha)	<0.25/ha	0.25–0.50/ha	0.51–1.00/ha	>1.00/ha	Brown (1970), Secor (1994a, 1995)	Secor (1994a, 1995) found 181 *C. cerastes* on a 120-ha study site in 3 y. If all were alive for the entire 3-y period, this implies a density of 1.508/ha (though density was not calculated or reported by Secor 1994a, 1995). Since the number alive at any time within the 3-y period was likely less than the 3-y total, actual density was probably less. Secor (1994b) estimated the density of this population to be ~1/ha. At the same site Brown (1970), based on tracks in the sand, had earlier estimated the population density to be 0.29–0.71/ha. Secor (1994b) did not think that the population had increased since Brown's study but instead that the difference in estimated density was the result of different amounts of effort in the 2 studies.
habitat	biome*	other	—	—	desert	various sources including Klauber (1944), Lowe et al. (1986), Stebbins (2003)	Writing of this species, Miller and Stebbins (1964) observed: "This snake is strictly a desert inhabitant and displays a number of structural and behavioral attributes related to life in dry sand."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	substrate*	—	rock	clay, gravel	sand	Klauber (1944), Lowe et al. (1986), Stebbins (2003)	This species is "usually found in areas of fine windblown sand near rodent burrows (kangaroo rats, etc.). Most common where there are sand hummocks topped with creosote bushes, mesquite, or other desert plants but may also occur on windswept flats, barren dunes, hardpan, and rocky hillsides" (Stebbins 1985, 2003).
habitat	slope	steep	moderate	slight	none	Klauber (1944), Stebbins (2003)	
habitat, thermal biology	elevation*	>6,000 ft	3,901–6,000 ft	2,501–3,900 ft	≤2,500 ft	Klauber (1944), Stebbins (2003), Campbell and Lamar (2004)	"*Crotalus cerastes* occurs from below sea level in desert basins to nearly 1,830 m [6,004 ft] but usually is found below 1,200 m [3,937 ft]" (Campbell and Lamar 2004). In Nevada this species has been found at 4,500 ft, but in Utah its highest known elevation is 3,775 ft (Utah Natural Heritage Program database, 2007). Seemingly it does not occur (or is very rare) above 3,000 ft in Arizona (see Lowe et al. 1986).
winter survival	minimum temperature in hibernation sites (e.g., rodent burrows)	< –5.22 °C	–5.22 to –2 °C	–2 to –0.67 °C	> –0.67 °C	Brattstrom (1965), Lowe et al. (1971)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	agriculture (cultivation, irrigation)*	present	—	—	none	Klauber (1944)	"The sidewinder seems to be driven out by irrigation, being absent in the cultivated sections of the Imperial Valley, where it was plentiful before 1900. The same is true of the area southwest of Yuma. . . . The inability of the sidewinder to survive such an ecological change is in contrast with some other snakes, such as the desert gopher snake, *Pituophis catenifer deserticola*, which is now much commoner in the cultivated than the primitive areas of the desert" (Klauber 1944).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	roads*	many, large, paved, and with heavy vehicular traffic	moderate in number, size, and traffic	few, small, unpaved, and with very little vehicular traffic, especially at night	none	Rosen and Lowe (1994)[2]	56% of *C. cerastes* found on a paved highway in Arizona during a 4-year study by Rosen and Lowe (1994) had been killed by vehicles.[2] Writing of the thermal biology of *C. cerastes*, Klauber (1944) noted "that under some conditions the snakes seek the highways because they have remained warmer than the adjacent sand", and Stebbins (1954) mentioned that one of the best ways to find *C. cerastes* is "by driving at night on dark-paved roads". When the snakes encounter warm pavement, they remain on it, often flattening their bodies to absorb as much warmth as possible; this behavior makes them especially vulnerable to being killed by vehicles.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (persecution by people)	cities, towns, military bases, outdoor recreation sites (e.g., hiking trials, camping and picnic areas, parks) in vicinity	present	—	—	absent	see Comments	Although human persecution of many kinds of animals in America has diminished in recent decades (e.g., raptors), rattlesnakes are still routinely harassed, tortured, mutilated, and killed by many people. Fortunately, organized "rattlesnake roundups", in which thousands of snakes, including non-venomous species, are killed, do not exist within the range of *C. cerastes*, but opportunistic killing of this species almost certainly occurs frequently.

[1]This species occurs in the Mojave and Sonoran deserts of the American southwest and nw. México. It is one of the most arenicolous of all reptiles in North America. Klauber (1944) summarized the habitat preference of this species, writing that " . . . the ideal territory for the sidewinder comprises desert flats with scattered brush, and where sand hummocks, crowned with mesquite, or sandy washes are prevalent. And they can exist in terrain which is entirely sand, as shown by their presence in the sand hills . . . west of Yuma in Imperial County, where the strip of dunes is fully 5 miles wide."

[2]In their study in s. Arizona, Rosen and Lowe (1994) estimated that ~1,000 snakes per year were killed on a 44.1-km (27.4-mi) stretch of paved highway, 82% of which was within a national monument, and commented: "Overall, along our 44.1 km transect, the estimated highway mortality amounts to removal of 5 km^2 [500 ha or 1,235 acres or ~2 sections] of snake population over the four years of study. It is clear that roadways, especially if paved, substantially damage snake populations. . . . Our computational result indicates that in the United States alone, tens or hundreds of millions of snakes have been killed by automobiles, certainly affecting snake populations over substantial fractions of the continent. . . . As the density of roadway networks increases, we predict that, first, active snakes . . . , and then others will be locally extirpated or become rare."

*Most important indicators.

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American white pelican (*Pelecanus erythrorhynchos*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding habitat	landscape feature*	peninsulas, mainland	isolated islands in rivers	isolated islands in reservoirs	isolated islands in lakes	Evans and Knopf (1993) and other sources	"[American white] [p]elicans occasionally nest on peninsulas, usually unsuccessfully due to predation" (USFWS 1984).
breeding habitat	island size*	<0.1 ha (<0.25 acre)	0.1–0.2 ha (0.25–0.5 acre)	0.3–0.4 ha (0.75–1.0 acre)	>0.4 ha (>1.0 acre)	USFWS (1984), Motschenbacher (1984)	"Where nesting habitat is limited, creation of flat islands of soil or dredged material, at least 0.1 ha in size, well offshore for protection from coyotes and protected from human disturbance, has been proposed . . . [and] [s]uch nesting islands have been successfully created and augmented . . . " (Evans and Knopf 1993). Motschenbacher (1984) reported that sizes of 11 islands (2 of these combining islands within single lakes) supporting nesting colonies ranged 0.3–241.6 ha (0.74–596.8 acres) (mean = 40.13 ha [99.1 acres]).
breeding habitat	nest substrate*	rocky outcrops	gravel	sand	bare soil (including dredged material), sod	USFWS (1984) and other sources	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding habitat	slope*	very steep (>30% slope)	steep (21–30% slope)	gently sloping (11–20% slope)	flat (≤10% slope)	USFWS (1984), Motschenbacher (1984)	Breeding sites in w. America investigated by Motschenbacher (1984) were relatively flat, with ≤30% slope. (Slope percentages for ratings are interpolations [i.e., between 0 and 30%].)
breeding habitat	vegetation	trees (e.g., willows, conifers), *Opuntia* (prickly pear)	—	shrubs	absent or grasses, forbs, bulrush	USFWS (1984)	"Clearing of vegetation, e.g., willows or conifers, may be required if vegetation cover becomes too dense for nesting" (USFWS 1984). However, willows may be of value in preventing erosion of nesting islands. "Nests are often placed near driftwood, boulders, and shrubs" (USFWS 1984).
breeding habitat	erosion (of nesting islands)[2]	occurring	—	—	none	USFWS (1984)[2]	
food for young	distance from breeding habitat (e.g., nesting island) to foraging habitat*	>100 km	81–100 km	50–80 km	<50 km	USFWS (1984)	"[American white] pelicans are capable of commuting long distances between nesting sites and foraging areas, and one-way foraging distances are regularly 50–80 km" (USFWS 1984). It has been suggested that nesting colonies closer to foraging areas experience the greatest reproductive success (Smith et al. 1984 citing another source).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
foraging habitat	type of water body*	other (e.g., hypersaline waters with no fish)	deep waters without shallows	below rapids	shallows of inland marshes, lakes, rivers, canals, ditches, ponds	various sources including Smith et al.(1984), Evans and Knopf (1993)	
foraging habitat	depth of open water (free of emergent vegetation) (ratings uncertain because sources disagree—see Comments)	<0.3 m (1 ft) or >2.5 m (8.2 ft)	0.3–0.65 m (1–2.1 ft) or 2.25–2.5 m (7.4–8.2 ft)	0.65–1 m (2.1–3.3 ft) or 2–2.25 m (6.6–7.4 ft)	1–2 m (3.3–6.6 ft)	USFWS (1984), Anderson (1991), also Evans and Knopf (1993) (but see findings of Motschenbacher [1984] in Comments)	"[A]t foraging wetlands, maintain shallow water, with a depth of 1–2 meters . . . [or] consider drawing down water levels to provide foraging opportunities. Consider installing water control structures to maintain optimum water depths" (USFWS 1984). However, 76% of foraging American white pelicans observed by Motschenbacher (1984) in w. America foraged where average water depth was ≤0.60 m, in areas mostly free of emergent vegetation. In w. Nevada, Anderson (1991) reported: "Preferred foraging habitat . . . consisted of open water 0.3 to 2.5 m deep."
foraging habitat (suitability for fish)	dissolved oxygen*	<5 mg/L	5 mg/L	6–8 mg/L	>8 mg/L	Motschenbacher (1984)	At 10 foraging sites American white pelicans foraged in waters with 5–13 mg/L (mean = 8.5 mg/L) dissolved oxygen, and ≤3 mg/L is considered stressful to most fish (Motschenbacher 1984).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
stability of breeding and foraging habitats (prevention of flooding / inundation and drying / draining)	long-term stability of water level*	very unstable	somewhat unstable	moderately stable	very stable	Evans and Knopf (1993) and other sources	"Permanent flooding or drainage can destroy breeding islands and foraging areas. . . . Nesting and foraging habitat must be protected from widespread permanent flooding or drainage" (Evans and Knopf 1993). High water (flooding) can inundate nests; low water (drying) can create a land bridge connecting island to mainland that allows access by mammalian predators (e.g., coyotes).
food	warm-water fish (e.g., carp, large chubs, suckers) in foraging areas*	scarce or absent	uncommon	common	abundant	USFWS (1984), Smith et al. (1984), Anderson (1991)	"[M]aintain and manage known pelican foraging use areas for prey populations, i.e., nongame fish species. This includes considering such fish species when managing wetlands for purposes which may conflict with maintaining diverse fish communities, e.g., carp control for the purpose of waterfowl management . . . " (USFWS 1984).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest success, mortality	nest predation by coyotes*	occurring	—	—	none	USFWS (1984)	"Fencing has been suggested to reduce coyote predation at selected sites . . . , and was proven effective . . ." (Evans and Knopf 1993). USFWS (1984) suggested maintaining water depth so that nesting islands do not become connected to the mainland, dredging channels >2 m deep between nesting islands and the mainland, cutting channels to disconnect nesting peninsulas from the mainland, fencing peninsular colonies with photovoltaic fences, locating artificial nesting islands as far off shore as possible, and reduction of coyote populations in the vicinity of vulnerable colonies.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
loss of nesting or foraging habitat	draining of water bodies, lowering of water levels (e.g., through diversions) or inundation of nesting sites (e.g., islands) during the breeding season or permanently*	occurring	—	—	none	USFWS (1984), Evans and Knopf (1993)	". . . [L]akes supporting former colonies have been drained, e.g., Tulare Lake, Buena Vista Lake, CA; many former colonies have therefore been abandoned; . . . utilization of wetlands for other purposes, such as irrigation, hydroelectricity, waterfowl production, which can affect existing colonies or their habitat (e.g., by flooding, as at Salton Sea, CA, or by lowering water levels, allowing predator access to nesting sites, etc." (USFWS 1984).
reproductive failure (nest failure, abandonment of nests or entire colonies, avian predation of unguarded nests, exposure of young to thermal stress, trampling of eggs or small young, degradation of nesting habitat)	human intrusion, disturbance of breeding colonies[3,*]	occurring or potentially occurring within ¼ mi (inadequate enforcement or compliance)	none within ¼ mi (adequate enforcement and compliance)	none within ½ mi (adequate enforcement and compliance)	none within 1 mi (adequate enforcement and compliance)	various sources including Motschenbacher (1984), USFWS (1984)[3], Evans and Knopf (1993)	See footnote 3. (Human disturbance of breeding colonies includes scientific research.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	persecution (e.g., shooting)	occurring or believed to occur (inadequate enforcement, education, or compliance)	—	—	none (adequate enforcement, education, and compliance)	USFWS (1984)	Education efforts (e.g., directed to anglers) have been recommended (USFWS 1984). "Shooting is the greatest single source of mortality reported from band returns . . . " (Evans and Knopf 1993, citing other sources).
mortality, impairment of reproduction	use of pesticides (e.g., endrin and DDT) in foraging areas, which can be up to 100 km from nesting areas	occurring	—	—	none	USFWS (1984)	"Recently lethal levels of endrin were found in pelicans in the Klamath Basin, and DDE residues were sufficient to induce eggshell thinning of 10% in Utah, and 10–15% in the Klamath Basin" (USFWS 1984). It is believed that use of organochlorine pesticides is now much less a threat than formerly.
mortality, injury	power lines (in vicinity of nesting or foraging areas)	present	—	—	none	USFWS (1984)	
reproductive failure (abandonment, predation, thermal stress)	height of aircraft flights over breeding colonies	<2,000 ft	2,000 ft	>2,000 ft	o2,000 ft	USFWS (1984)	"[R]equire aircraft to maintain at least 610 m. (2,000 ft.) when flying over colonies, especially early in the breeding season (through June 30). Regional base commanders should be reminded yearly, and highly visible, colorful posters, or at least 'notices to airmen' should be designed and posted in nearby airports" (USFWS 1984).

[1]This species breeds mainly in Canada and America, with some very limited breeding occurring in n. México. There is little mixing between the populations east and west of the continental divide. This table is intended for use during the breeding season and mainly west of the continental divide.

[2]"Where necessary, erosion of nesting islands may be controlled either structurally or, in some instances, by protecting the vegetation from trampling by the pelicans. Implementation of the structural alternatives e.g., rip-rap, porous cement pads ('Fabriform'), should include both an ecological and an engineering analysis. Protection of vegetation (e.g., willows) will entail fencing. Colony location may also be shifted in desired directions somewhat by placement of physical masses, e.g., driftwood, since pelicans show a tendency to place nests alongside irregularities of substrate" (USFWS 1984). Smith et al. (1984) mentioned the planting of sprigs of *Scirpus*, *Carex*, *Phragmites*, and *Typha* along shorelines of 2 nesting islands in an attempt to halt erosion that had caused severe reduction of the land mass of the islands and that might have resulted in complete loss of the islands within 10 years. "The vegetation acts as a wave breaker and sediment trap with resulting accretion of sediment and a net increase in the size of the island or advancement of the shoreline" (Smith et al. 1984). However, dense, tall vegetation is not good nesting habitat and such planting should be done only when necessary to control erosion.

[3]"[C]lose islands to trespass without a permit at least during the breeding season, March 15 through August 31, but preferably year-round to prevent the formation of public use habits and to prevent the destruction and trampling of nesting substrate (vegetation, soils). A buffer zone of 400 m. (1/4 mi.) to 800 m. (1/2 mi.) . . . should also be closed to human activity—boating (especially power-boating), fishing, water skiing, discharge of firearms, etc. . . . Patrol by law enforcement personnel will be necessary, especially early in the nesting cycle" (USFWS 1984). Motschenbacher (1984) found that 6 breeding colonies in w America were 720–5,400 m (0.45–3.36 mi) (mean = 2,088.8 m [1.30 mi]) from the nearest human disturbances.

*Most important indicators.

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California condor (*Gymnogyps californianus*)
Ecological Integrity Table[1, 2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites	geological or other physical features*	other	crevices among boulder piles on cliffs or steep slopes (6); overhung ledges on cliffs (6); cavities (caused by fire) in giant sequoias (2)	crevices or cracks in cliffs (21)	potholes in cliffs (37)	Snyder et al. (1986)	Numbers in parentheses after ratings are the numbers of such nest sites (Σ = 72) examined by Snyder et al. (1986). However, it is important to note that these numbers and the ratings do not consider (1) nest success (i.e., whether young were successfully fledged from such nests), and (2) differential availability of the different site types (e.g., a site type may be preferred but rare or not preferred but abundant).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites	elevation*	<460 m or >2,500 m	460–600 m or 1,800–2,500 m	600–800 m or 1,000–1,800 m	800–1,000 m	Koford (1953), Snyder et al. (1986), and unpublished sources	Only 1 of 15 nests examined by Koford (1953) was above 1,370 m (at ~1,800 m), and the highest of 72 nests examined by Snyder et al. (1986) was 1,830 m. Most nests of naturally occurring birds have been between 600 and 1,000 m elevation, and nearly all have been between 600 and 1,800 m. However, recent nesting by captive-bred birds released in n. Arizona has been as high as 2,500 m, and nearly all of the area inhabited by these released birds is above 1,200 m. Snyder et al. (1986) warned that "[s]ites above about 1,500 m are subject to snows during the incubation period in late winter and spring . . . ."
nest sites	aspect (compass orientation of nest site entrance) of low-elevation nests (below 948 m)	—	—	other	N	Snyder et al. (1986)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.
nest sites	aspect (compass orientation of nest site entrance) of high-elevation nests (above 948 m)	—	other	SW or SE	S	Snyder et al. (1986)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites	entrance height	<30 cm	—	>200 cm	30–200 cm	Snyder et al. (1986)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.
nest sites	entrance width	<20 cm	20–25 cm	>175 cm	25–175 cm	Snyder et al. (1986)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.
nest sites	ceiling height (at egg position)	<38 cm or >229 cm	200–229 cm	125–200 cm	38–125 cm	Snyder et a. (1986)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.
nest sites	nest depth (entrance to farthest point in cave or recess)	<0.5 m	0.5–1 m	1–1.5 m	>1.5 m	Snyder et al. (1996)	Snyder et al. (1986) warned that availability distributions of potential nest sites were not known.
nest sites (visibility of egg to predators, especially ravens)	entrance to egg distance	<0.5 m	—	—	>0.5 m	Snyder et al. (1996)	Oviposition sites were ". . . as far back in the caves as there was suitable level substrate and an adequate high ceiling" (i.e., ≥38 cm high). Snyder et al. (1986) warned that availability distributions of potential nest sites were not known. Among remedial actions taken by Snyder et al. (1996), "internal baffles have been provided for certain . . . sites to obscure their nest chambers from view from the outside."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites (prevention of the rolling of egg(s) or young out of nest)	slope of floor (at egg position)	»5°	>5°	0–5°	0°	Snyder et al. (1996)	From a nest having >5° floor slope "an egg accidentally rolled out the entrance and over the cliff edge", and "[f]rom another, an Andean Condor (*Vultur gryphus*) nestling rolled out the entrance and over the cliff edge during an unsuccessful fostering experiment" (Snyder et al. 1996). Snyder et al. (1996) took the remedial action of "deepening and leveling of the site from which an egg rolled out".
nest sites	loose substrate of floor	none	very little loose substrate	some loose substrate but <1 cm deep	loose substrate ≥1 cm deep	Snyder et al. (1996)	"Nest substrates averaged about 8 cm in depth and ranged from about 1 to 20 cm deep" (Snyder et al. 1996). As a remedial action at one nest site, Snyder et al. (1996) "leveled the floor and added substrate." Snyder et al. (1996) considered gravel to be important but concluded that condors will bring gravel into a nest site if it is absent.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites (pre-fledging exercise preparing young for flight and landing point for parents)	external "porch"	lacking both internal and external space for unimpeded wing-flapping	—	substantial porch lacking, but enough internal space to allow full wing exercise internally	well-developed external porch allowing enough space for nestlings to stretch and flap wings comfortably and safely	Snyder et al. (1996)	". . . [T]he use of small potholes lacking external porches poses considerable risks to chick survival, especially if the sites are located high above the bases of nest cliffs. The frequent use of relatively low cliffs by condors may in part be a reflection of such dangers" (Snyder et al. 1996). A remedial action taken by Snyder et al. (1996) was "provision of a new entrance and porch for an awkwardly entranced site used by a pair . . . ."
roosts	physical features of landscape*	—	—	—	cliffs, tall conifers, dead snags	Kiff et al. (1996)	"California condors apparently will tolerate more disturbance at a roost than at a nest." However, "[r]oosting sites and nesting sites are susceptible to similar disturbance threats, and their preservation requires isolation from human intrusion" (Kiff et al. 1996).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
water; suitability of nest sites	available, accessible drinking water	none in vicinity of nest site	distant from nest site or difficult or dangerous to access or intermittent availability during nesting season (spring–summer)	—	permanently present near nest site, easy and safe to access	Snyder et al. (1996)	Although Snyder et al. (1996) were unable to quantify their observations concerning proximity of water, they wrote: ". . . [W]e emphasize that the presence of accessible nearby drinking water could be an important feature in nest-site selection, since we have frequently observed condors drinking from water sources near nests." In thick brush or in narrow or rocky canyon bottoms, water can be inaccessible or may make condors vulnerable to predators.
disturbance of nest sites	distance to lightly used dirt roads	<0.8 km	0.8–1.0 km	1.0–1.3 km	>1.3 km	Sibley (1969)	Sibley (1969) reported a minimum distance, unshielded by topography, of 1.3 km from nest sites to lightly used dirt roads. However, Wilbur et al. (1978) mentioned a successful nest only 0.8 km from such a road. Also, 19.4% of nest sites found by Snyder et al. (1996) were closer than 1.3 km to such dirt roads, and 36.1% were visible from such roads.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
disturbance of nest sites	distance to regularly used dirt roads	<0.6 km	0.6–1.1 km	1.1–1.9 km	>1.9 km	Sibley (1969)	Sibley (1969) reported a minimum unshielded distance of 1.9 km from nest sites to regularly used dirt roads. However, Wilbur (1978) noted a successful nest only 1.3 km from such a road, and 5.6% of nest sites found by Snyder et al. (1996) were closer than 1.9 km to such dirt roads, the closest being 0.6 km, but topographic features shielded these from view from the roads.
disturbance of nest sites	distance to paved roads	<1.6 km	1.6–2.4 km	2.4–3.5 km	>3.5 km	Sibley (1969), Wilbur (1978)	Sibley (1969) reported a minimum distance of 3.5 km from nest sites to paved roads. However, 16.7% of nest sites found by Snyder et al. (1996) were closer than 3.5 km to paved roads, the closest being 1.6 km, but topographic features shielded most of these from view from the roads.
disturbance of nest sites	distance to oil wells	<2 km	2–3 km	3–3.7 km	>3.7 km	Sibley (1969)	Sibley (1969) reported a minimum distance of 3.7 km for nests within view of the well, but 2 km was tolerated when the nest was shielded from sight and most sound from the well.
disturbance of nest sites	distance to areas of human activity or potential activity	<500 yards	500 yards to 1 mi	1–1.5 mi	>1.5 mi	Koford (1953), Sibley 1969, Snyder et al. (1986), Kiff et al. (1996)	Snyder and Schmitt (2002) questioned the negative affects of human presence or activity.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food	carcasses or carrion*	other (formerly, marine species such as whales and sea lions may have been important foods in coastal areas)	domestic sheep, horses, ground squirrels	cattle (especially calves)	mule deer	Koford (1953), Kiff et al. (1996)	Wilbur et al. (1974) concluded that supplemental feeding once a week (using carcasses of road-killed mule deer) increased nesting success. They noted that spring and summer may be the most important seasons but recommended year-round feeding, varying sites to reduce mammalian carnivore depredations and to avoid regular congregations of condors at a site. Released captive-raised condors have been provided still-born dairy calves (Kiff et al. 1996). Advantages include reduction of lead poisoning, strategic location of sites to influence condor movements, and reintroduction in areas where natural food resources are too variable to support condors.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality from egg predation	common ravens	abundant	common	rare	absent	Snyder et al. (1996) and others	The "poor" rating can be expected throughout suitable California condor habitats, and the common raven is considered the "primary threat to condor nesting in recent decades, being involved in most cases of nesting failure studied closely in the 1980s" (Snyder and Schmitt 2002). However, Snyder et al. (1996) mentioned that ". . . very promising results have been achieved in reducing egg predation of corvids by taste-aversion conditioning . . ., and it is possible that this technique may prove applicable to the condor situation."
mortality from attacks	golden eagles	abundant	common	rare	absent	Snyder and Schmitt (2002) and unpublished sources	Birds released in n. Arizona and their offspring have often been attacked and killed by golden eagles. Immature and inexperienced young adult condors are particularly vulnerable to attacks by golden eagles.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality from shooting	education and patrol and enforcement	none	some	some	intensive	Kiff et al. (1996)	"Although publicity associated with the condor recovery program has doubtless reduced the likelihood of condors being shot, one person was arrested as recently as July 1992 for shooting at a California condor that was part of a reintroduction program, thus indicating the need for continued public education and an enforcement presence to protect the species from wanton shooting" (Kiff et al. 1996). In October 2005 a reintroduced California condor was shot in the head but did not die from the injury. This recent shooting demonstrates the continuing need for education and enforcement.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality from lead poisoning (from bullet fragments in carrion)	hunting, especially within 50–70 km (31–44 mi) of nest sites*	ongoing and legally permissible	very little, but legally permissible	none except illegal	none	Kiff et al. (1996), Snyder and Schmitt (12002)	Lead poisoning is "likely the most important cause of the recent decline of the species . . . . [U]nless truly effective solutions to the lead-contamination problem are implemented, there can be no realistic chances of achieving viable wild populations" (Snyder and Schmitt 2002). Kiff et al. (1996) advised: ". . . [T]he supplemental feeding program should continue to reduce the likelihood of deaths of condors from lead or other poisoning . . .", but Snyder and Schmitt (2002) pointed out the inadequacy of this approach. Free (or exchange) ammunition programs providing non-lead rifle ammunition to hunters may help reduce mortality from lead poisoning.
mortality from poisoned carcasses	predator (e.g., coyote) control using poisoned carcasses	occurring in the vicinity	—	—	none	Snyder and Schmitt (2002) and other sources	Historically the poisoning of carcasses to control predators is believed (at least by some authors) to have contributed to the decline of the California condor, and, to the extent that such methods continue to be used for predator control, they are a serious threat to the bird.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality from man-made structures, particularly power lines	power lines, especially within 50–70 km (31–44 mi) of nest sites	many	some	few	none	Kiff et al. (1996)	Because of deaths from collisions with power lines, Kiff et al. (1996) recommended that "future condor releases should be conducted in areas remote from human settlements with their attendant condor hazards." Kiff et al. (1996) also mentioned wind turbines as a potential mortality factor.
mortality from and disturbance by aircraft	low-flying military and civilian aircraft and sonic booms from higher flying craft	many	some	few	none	Wilbur (1978), Kiff et al. (1996)	Repeated interruption of courtship by overhead airplane traffic was observed by Sibley (1969). Sonic booms have disturbed feeding birds, causing them to fly (Wilbur 1978). ". . . [A] condor sleeping in a pothole virtually 'exploded' from the cave when a sonic boom occurred, and it appeared visibly agitated for the next hour. Sibley . . . on two occasions was inside small nest-type caves when sonic booms occurred. He found the experience very unpleasant, and experienced considerable ringing in his ears" (Wilbur 1978). Such disturbances could cause egg loss through chilling and inadequate feeding of young (Koford 1969, Wilbur 1978).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
disturbance of roosts	petroleum extraction (especially oil wells)	≤1 km	1–2 km	>2 km	»2 km	Wilbur (1978)	In addition to distance, topographic barriers are important in minimizing disturbance effects.

[1]This table is intended for use in the American southwest, within areas of the historically known range of the species and within areas of its prehistoric range where the species has been reintroduced. However, it is not intended for use *throughout* the prehistoric range of the species, which extended east to Florida and New York (with prehistoric breeding confirmed as far east as Texas) (e.g., Snyder and Schmitt 2002).

[2]As noted in comments in the table, **lead poisoning from bullets in animal carcasses is the most critical factor in the conservation of this species**. Because of lead poisoning, "Overall mortality rates of the [captive-bred California condor] releases in Arizona and s. California now closely approximate the unsustainable mortality rates of the historic wild population of the 1980s (about 25% annual mortality) and have been increasing rapidly, as predicted . . . . It appears that unless truly effective solutions to the lead-contamination problem are implemented, there can be no realistic chances of achieving viable wild populations" (Snyder and Schmitt 2002).

*Most important indicators.

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bald eagle (*Haliaeetus leucocephalus*)
Ecological Integrity Table[1, 2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey availability	presence of ospreys or seabird colonies	none	few	some	many	Steenhof (1988), Livingston et al. (1990)	Ospreys or seabirds (e.g., alcids) are indicators of abundant fish prey.
prey availability	large fish species (i.e., known prey species)	0 or 1 warmwater sp. or few diadromous spp.	2 warmwater spp. or few diadromous spp.	3 or 4 warmwater spp. or many diadromous spp.	≥5 warmwater spp. or many diadromous spp.	Livingston et al. (1990)	Examples of warmwater fish prey include large species of pickerels, catfishes, suckers, carp, perch, and bass. Diadromous fish prey include large alewives, herrings, salmon, and eels. **N.B.:** Although fish are, overall, the most important prey, in some places (mostly in interior continental areas), other prey such as birds, especially aquaphilic birds, are more important in the diet than fish. Mammals and carrion are also important foods in some areas.
prey availability	magnitude of water body	higher than 4th order streams or <20 ha open water	4th order streams or 20–40 ha open water	3rd order streams or 40–1,000 ha open water	1st or 2nd order streams or >1,000 ha open water (Peterson 1986?)]	Wright (1986), Peterson and Johnston (1980), Livingston et al. (1990), Wright and Escano (1986)	
prey availability	area of open water and adjacent wetlands (see Comments)	<3.3 km^2	3.3–6.7 km^2	6.7–10 km^2	>10 km^2	Peterson (1986)	**N.B.**: Use only for lacustrine and estuarine situations (and perhaps only north of 37° N latitude).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey availability	aquatic morpho-edaphic index (= total dissolved solids [ppm]/ mean water depth [ft]) (see Comments)	0–12.5	12.5–20	20–100	>100	Peterson (1986)	**N.B.**: Use only for lacustrine and estuarine situations (and perhaps only north of 37° N latitude).[3]
prey availability	distance to major water body (e.g., ocean, lake, river)*	>1,600 m	600–1,600 m	250–600 m	<250 m	Suring (1985), McEwan and Hirth (1979), Livingston et al. (1990), Taylor and Therres (1981), Shea (1980)	
prey availability	intertidal zone and low tide areas <6 ft deep	small	moderate	large	very large	Livingston et al. (1990)	
prey availability	deep pools, riffles, and broad shallows of rivers	none or small	few	many	abundant, large	Haywood and Ohmart (1986)	Haywood and Ohmart (1986) reported pool depths of ≥3 m.
prey toxicity (from pollutants or contaminants)	wet weight concentration of DDE in prey (e.g., fish) tissue*	>3 ppm	0.5–3 ppm	0.1–0.5 ppm	<0.1 ppm	Peterson (1986)	
nesting	available substrate	ground (in treeless areas)	cliffs (in treeless areas)	smaller trees	large, mature, dominant, old-growth trees	Buehler (2000), Peterson (1986)	
nesting; hunting perches	super-dominant trees (especially dead or with dead tops)	none	few	some	many	Livingston et al. (1990) and other authors	
habitat	type of water body*	small river, stream, small lake, or none	large river or reservoir	lake	ocean or estuary	various authors (e.g., Peterson 1986)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	size of forested area	<4 ha	4–8 ha	>8 ha	»8 ha	Taylor and Therres (1981), Whitfield and Jones (1984)	
habitat	% of potential nesting area (within 1.5 km of shore) covered by mature timber (see Comments)	<25	25–50	50–75	75–100	Peterson (1986)	**N.B.:** Although this indicator may have broader applicability, it was presented in a model (Peterson 1986) for use only in lacustrine and estuarine situations north of 37° N latitude.
breeding (and food availability)	elevation (see Comments)	>2,300 m	1,900–2,300 m	1,500–1,900 m	<1,500 m		This indicator should be used with careful consideration of the location. Elevational ranges in the ratings are based on California models (Peterson and Johnston 1980, Jacobsen 1986). Since elevation is believed to affect nesting of this species only through its relationship to temperatures (Lehman 1978, Shea 1980) (see Indicator immediately below this one), suitable elevational ranges might be expected to be lower in areas farther north and perhaps also in inland areas, although Wright and Escano (1986) reported maximum and minimum nesting elevations in their Montana study as 6,960 ft (2,121 m) and 2,100 ft (640 m), which is consistent with the California models.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding (and food availability)	mean April temperature*	< –7 °C	–7–1.5 °C	1.5–10 °C	>10 °C	Peterson (1986), Leighton et al. (1979)	
breeding (and food availability)	mean annual snowfall	>300 in.	200–300 in.	100–200 in. or <50 in.	50–100 in.	Wright and Escano (1986)	Indicator is from a Montana study and was considered "a measure of the effective length of the nesting season." (It may also be correlated with average April temperature [see above].) Applicability of this indicator in other places is unknown.
disturbance of nesting and foraging[4]	distance to human development or disturbance (e.g., buildings, roads, railroads, heavy boat traffic)	<100 m	100–500 m	500–1,200 m	>1,200 m	Buehler (2000), Taylor and Therres (1981), Livingston et al. (1990), Grier et al. (1983)	See footnote 4.
disturbance of nesting and foraging[4]	no. of buildings or campsites/km^2	>20	10–20	5–10	0–5	Peterson (1986)	See footnote 4.
disturbance of nesting and foraging[4]	no. of permanent structures within 1 mi.	>9	3–9	1 or 2	none	Wright and Escano (1986)	See footnote 4.
disturbance of nesting and foraging[4]	% shoreline development within 1 mi.	≥5	1–5	0–1	0	Wright and Escano (1986)	See footnote 4.
habitat degradation	timber harvest	extensive, frequent	limited and infrequent	very limited in the past or selective logging and only in fall and winter	none (past, present, future)	Livingston et al. (1990), Peterson (1986)	

[1]This table is intended for use during the breeding season and within the breeding range of the species, especially in interior western North America. Bald eagles use 2 rather different habitats: expansive open-water situations (lacustrine, estuarine, and marine) and linear aquatic situations (riverine). In interior continental

(inland) settings, there are of course no estuarine or marine situations. Peterson's (1986) habitat suitability index model is applicable only to estuarine and lacustrine situations and only north of 37° north latitude and thus has limited applicability in much of interior western North America. Riverine situations are the main breeding habitat in many parts of interior western North America, particularly where lacustrine situations are lacking, and marine systems are the main breeding habitat in many coastal areas. Livingston et al. (1990) provided models for all bald eagle nesting habitats (river, lake, marine mainland, marine island) in Maine. Many of the indicators used in this table apply only to some of the aquatic habitat types used by bald eagles; comments about applicability in such cases have not been added when such limitations are implicit.

[2]Many authors have considered prey availability to be the most important factor affecting habitat suitability for this species. Various indicators of prey availability have been used, and such indicators include presence of actual prey species (e.g., fishes), various characteristics of aquatic habitats, and presence of other piscivorous birds with similar foraging behavior and prey requirements. Several of these diverse indicators of prey availability are incorporated in this table, their applicability being dependent upon the site that is to be evaluated.

[3]The "morphoedaphic index" of aquatic productivity (MEI) has been used as an index of food availability in habitat suitability models for this species in lacustrine and estuarine situations, but this approach has not been applied to riverine or marine systems, for which morphoedaphic index data are lacking (Peterson 1986). Also, comparisons between lacustrine and estuarine systems are not appropriate because of differences in salinity, which affects total dissolved solids (TDS). Also, Peterson (1986) presented 2 formulae, using different variables and different units, for the MEI. Although Peterson (1986) implied that the MEI that he used was the one that is presented in this table, he was not explicit about this; thus, which formula yields the values presented here is not completely certain.

[4]Although many authors have considered human activities to be the most important factor affecting habitat suitability for this species (see Steenhof 1988, McGarigal et al. 1991), McEwan and Hirth (1979) found no significant effects from either habitat alteration or road use on nest productivity in Florida, as have several other authors (see Peterson 1986).

*Most important indicators.

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ferruginous hawk (*Buteo regalis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
area used per pair	suitable habitat	<7.1 km^2	7.1–97.5 km^2	97.5–4,261 km^2	»4,261 km^2	Olendorff (1993)	
home range per pair	suitable habitat	<3.4 km^2	3.4–5.9 km^2	5.9–9.0 km^2	>9.0 km^2	Olendorff (1993), Smith and Murphy (1973)	
population	breeding density (nests/100 km^2)	<0.05	0.05–1.5	1.5–11.6	>11.6	Bechard and Schmutz (1995)	
prey types	abundant prey species*	insects, amphibians, reptiles, small birds	kangaroo rats, other small mammals	pocket gophers	lagomorphs, ground squirrels, prairie dogs	Olendorff (1993), Howard and Wolfe (1976), and others	
abundance of main prey species	jackrabbit density*	<10/km^2	10–30/km^2	30–50/km^2	>50/km^2	Howard and Wolfe (1976)	Estimates for rating categories are based on 2 densities reported by Howard and Wolfe (1976).
prey accessibility	average height of herb and shrub vegetation	<5 cm or >100 cm	5–10 cm or 80–100 cm	10–15 cm or 60–80 cm	15–60 cm	Jasikoff (1982)	Jasikoff (1982) considered percent canopy cover together with average herb and shrub height (i.e., a bivariate rather than a univariate model).
prey accessibility	herb and shrub canopy cover	«60%	60–100%	60–100%	100% (at av. veg. ht. 15 cm); 60% (at av. veg. ht. 60 cm)	Jasikoff (1982)	Jasikoff (1982) considered percent canopy cover together with average herb and shrub height (i.e., a bivariate rather than a univariate model).
reproduction	available nesting substrates	haystacks, buildings	utility structures, outcrops, ground	cliffs	trees, large shrubs	Jasikoff (1982), Olendorff (1993)	
nesting	distance to tree or large shrub (≥1 m tall)*	≥4.8 km (3 mi)	3.2–4.8 km (2–3 mi)	1.6–3.2 km (1–2 mi)	≤1.6 km (1.0 mi)	Jasikoff (1982)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting sites	topographic relief*	steep (>22.5° slope) and rugged (i.e., mountainous)	flat (e.g., plains) with no breaks in topography	rolling (with some elevated sites)	rolling (with many hills, knolls, rims, cliffs)	modified from Jasikoff (1982), Olendorff (1993)	
habitat	elevation	>1,700 m	≤1,700 m	≤1,700 m	≤1,700 m	Smith and Murphy (1973)	
protection from human disturbance	roads, oil well pads, railroads, etc.	present	absent	absent	absent	Jasikoff (1982)	
protection from human disturbance	distance to primary road(s) (paved roads and interstate highways)	<0.1 km	0.1–4.0 km	4.0–12.8 km	>12.8 km	Bechard et al. (1990)	
protection from human disturbance	distance to secondary road(s) (unpaved access roads)	<0.1 km	0.1–1.6 km	1.6–6.0 km	>6.0 km	Bechard et al. (1990)	
protection from human disturbance	distance to building or other structure	<1.2 km	1.2–4.8 km	4.8–19.2 km	>19.2 km	Bechard et al. (1990)	
habitat suitability	cultivation (within 3 km)	>30%	10–30%	6.7–10%	<6.7%	Schmutz (1987), Bechard et al. (1990), Olendorff (1993)	
habitat suitability	size of contiguous cropland	≥16 ha	<16 ha	«16 ha	none	Jasikoff (1982)	
habitat degradation (especially that of trees—potential nest sites)	grazing (i.e., livestock)	present in large numbers	present in moderate numbers	present in small numbers	absent	Olendorff (1993)	

[1]This table is intended for use within the breeding range of the ferruginous hawk (especially Utah) and during the breeding season for this species.

*Most important indicators.

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northern goshawk (*Accipiter gentilis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (nesting pairs)	<3.5 pairs/100 km^2	3.5–5 pairs/100 km^2	5–7 pairs/100 km^2	>7 pairs/100 km^2	data summarized by Squires and Reynolds (1997)	"In North America, most western populations at midlatitudes have approximately 3.6–10.7 pairs/100 km^2" (Squires and Reynolds 1997).
nesting habitat	forest type*	small clumps of quaking aspen intermixed with sagebrush; juniper	various other combinations of conifers and quaking aspen or other conifer species	white fir, subalpine fir, lodgepole pine, Douglas-fir, Engelmann spruce–lodgepole pine	ponderosa pine, Engelmann spruce, quaking aspen, lodgepole pine–quaking aspen	Squires and Reynolds (1997), Graham et al. (1999), Hennessey (1978)	The species nests in most forest types found throughout its range (Squires and Reynolds 1997). Ratings are for interior western (exclusive of Alaska) and southwestern America.
nesting habitat	vegetative structural condition*	young, dense forest, mid-aged forest	—	2nd-growth stands with large trees	mature (18–24 in. dbh) to old-growth (≥24 in. dbh) forests composed primarily of large trees	Reynolds et al. (1992) and others	Reynolds (1983) found in Oregon that goshawks nested in "150+ year-old conifer stands".

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat (nest microclimate—protection from overheating and desiccation)	canopy cover*	<60%	60–72%	72–79%	>79%	Crocker-Bedford and Chaney (1988)	Ratings are for ponderosa pine and mixed conifer sites (Crocker-Bedford and Chaney 1988). Both method of measurement of canopy cover and proximity to water may affect canopy cover observed at nests (see Crocker-Bedford and Chaney 1988 for discussion). Ratings can be reduced by "about 10% if permanent water is available within 300 m of the nest" (Crocker-Bedford and Chaney 1988). Reynolds et al. (1992) considered "50–70+" % (i.e., ≥ 50%) to be the desired condition.
nesting habitat	density of living trees >20 in. dbh	<25/ha	25–44/ha	44–61/ha	>61/ha	Crocker-Bedford and Chaney (1988)	Ratings are for ponderosa pine and mixed conifer sites (Crocker-Bedford and Chaney 1988).
nesting areas	un-disturbed nesting stand (see other indicators for characteristics)	<8 ha	8 ha	>8 ha	»8 ha	Reynolds et al. (1982), Reynolds (1983), Crocker-Bedford and Chaney (1988)	Reynolds et al. (1992) recommended 6 (3 suitable and 3 replacement) nesting stands of 30 acres (~12 ha) each per home range (i.e., per nesting pair) for a total of 180 acres per pair.
nesting habitat	alternate, potential nesting stands <1 km from each other	0	1	2	≥3	Crocker-Bedford and Chaney (1988), Reynolds (1983)	
nesting habitat	ground cover	>50%	35–50%	20–35%	0–20%	Graham et al. (1999), Reynolds et al. (1982)	Ratings should be considered approximate and may vary with location.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	understory	—	—	—	open	Graham et al. (1999)	
post-fledging family areas	mixture of forest seral stages (see below)	<420 acres	—	—	≥420 acres	Reynolds et al. (1992)	
post-fledging family areas and foraging areas	mixture of forest seral stages	—	—	—	10% grass-forb-shrub (0–1 in. dbh), 10% seedling-sapling (1–5 in. dbh); 20% young forest (5–12 in. dbh); 20% mid-aged forest (12 – 18 in. dbh); 20% mature forest (18–24 in. dbh); 20% old forest (≥24 in. dbh)	Reynolds et al. (1992)	
foraging areas	mixture of forest seral stages (see above)	<5,400 acres	—	—	≥5,400 acres	Reynolds et al. (1992)	
post-fledging family areas and foraging areas	canopy cover	—	—	—	≥70%	Reynolds et al. (1992)	Desirable canopy cover varies with forest type (ponderosa pine, mixed species, spruce-fir) and use type (family vs. foraging); for some forest and use types canopy cover as low as 40% is adequate (see Reynolds et al. 1992, Table 1).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
post-fledging family areas and foraging areas	maximum size of forest openings	—	—	—	1 acre	Reynolds et al. (1992)	Maximum size of forest openings varies with forest type (ponderosa pine, mixed species, spruce-fir) and use type (family vs. foraging); for some forest and use types openings as large as 4 acres are acceptable (see Reynolds et al. 1992, Table 1).
post-fledging family areas and foraging areas	maximum width of forest openings	—	—	—	125 ft	Reynolds et al. (1992)	Maximum width of forest openings varies with forest type (ponderosa pine, mixed species, spruce-fir) and use type (family vs. foraging); for some forest and use types openings as wide as 200 ft are acceptable (see Reynolds et al. 1992, Table 1).
suitable habitat for prey in post-fledging family areas and foraging areas	no. of large snags (≥18 in. dbh, ≥30 ft tall)	—	—	—	2 or 3/acre	Reynolds et al. (1992)	Desirable number of snags per acre varies with forest type: for ponderosa pine, 2/acre; for mixed species and for spruce-fir, 3/acre (Reynolds et al. 1992).
suitable habitat for prey in post-fledging family areas and foraging areas	no. of large downed logs (≥12 in. diameter at midpoint, ≥8 ft long)	—	—	—	3–5/acre	Reynolds et al. (1992)	Desirable number of downed logs per acre varies with forest type: for ponderosa pine, 3/acre; for mixed species and for spruce-fir, 5/acre (Reynolds et al. 1992).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
suitable habitat for prey in post-fledging family areas and foraging areas	amount of woody debris (>3 in. diameter) and downed logs	—	—	—	5–15 tons/acre	Reynolds et al. (1992)	Desirable amount of woody debris varies with forest type: for ponderosa pine, 5–7 tons/acre; for mixed species and for spruce-fir, 10–15 tons/acre (Reynolds et al. 1992).
habitat and nesting	timber harvest*	—	—	—	none	sources reviewed by Graham et al. (1999)	"Timber harvest is a primary threat to nesting populations" (Squires and Reynolds 1997). However, see Reynolds et al. (1992) for discussion of timber harvest compatible with goshawk management. Hennessey (1978) reported that 2 of 32 nests (6.3%) were destroyed by logging.
habitat	livestock grazing	—	—	—	none	Graham et al. (1999)	
disturbance of nesting	human activity (distance from nest)	≤100 m	100–250 m	>250 m	»250 m	Squires and Reynolds (1997), Hennessey (1978)	Logging activities and recreational activities (camping) have caused nest abandonment and nesting failure (Squires and Reynolds 1997). Hennessey (1978) reported that 3 of 32 nests (9.4%) failed as a result of human disturbance (roads, logging, camping, etc.).

[1]The English common name "northern goshawk" is the standardized common name (e.g., American Ornithologists' Union and others) for the (full) species, *Accipiter gentilis*, comprising 10 weakly differentiated subspecies, of questionable validity, throughout its Holarctic range, including 3 nominal subspecies in North America. However, some publications (e.g., Reynolds et al. 1992, Graham et al. 1999) use the name "northern goshawk" inconsistently to refer either to the full species, *Accipiter gentilis*, or to 1 of 3 North American putative subspecies, *Accipiter gentilis atricapillus*, which might be appropriately called the "black-capped race of the northern goshawk", assuming that any races are justified.

[2]This species ranges and breeds widely in boreal and temperate forests throughout the Holarctic (Eurasia and North America). In North America it breeds from the Atlantic to the Pacific coasts and from Alaska to southwestern México. Over this enormous range it breeds in a variety of habitat types, being "a forest habitat generalist, occurring in all major forest types (coniferous, deciduous, and mixed)" (Reynolds et al. 1992). **This table is intended for use primarily in interior areas of the American west (exclusive of Alaska) and southwest.** It may have limited applicability to breeding populations elsewhere (e.g., Eurasia, México, Canada, eastern America, and coastal areas and temperate rainforest of western North America).

*Most important indicators.

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greater sage-grouse (*Centrocercus urophasianus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population maintenance (survival of young)	no. of juveniles/ hen in the fall	<2.19	2.19–2.25	2.25–2.96	>2.96	Connelly et al. (2000) and sources cited therein	"Among western states, long-term ratios have varied from 1.40 to 2.96 juveniles/hen in the fall; since 1985 these ratios have ranged from 1.21 to 2.19 . . . . Available data suggest that a ratio ≥2.25 juveniles/hen in the fall should result in stable to increasing sage grouse populations . . . " (Connelly et al. 2000).
general habitat (food, cover)	cover type	cultivated fields (e.g., alfalfa, wheat, crested wheatgrass)	scrub-willow; sagebrush savannas with juniper, ponderosa pine, or quaking aspen	small sagebrush (e.g., low, black); forb-rich mosaics of low and tall sagebrush; riparian meadows; steppe dominated by native grasses and forbs	large, woody, tall sagebrush (e.g., big, silver, and three-tip)	Schroeder et al. (1999), Connelly et al. (2000, 2004)	
lek sites	topography	—	—	benches, broad ridge tops	valley bottoms, draws	Rogers (1964), Schroeder et al. (1999)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
lek sites	cover type or other landscape feature	roads, landing strips	cropland, burned areas, dry lakebeds, gravel pits	low sage brush flats or ridge tops	open areas surrounded by sagebrush, grassy swales	Connelly et al. (2000), Schroeder et al. (1999), Rogers (1964)	"Leks . . . typically occur in open areas surrounded by sagebrush . . . ; these sites include, but are not limited to, landing strips, old lakebeds, low sagebrush flats and ridge tops, roads, cropland, and burned areas . . . . Sage grouse males appear to form leks opportunistically at sites within or adjacent to potential nesting habitat" (Connelly et al. 2000), and "[t]he most important characteristic for leks may be their proximity and configuration with nesting habitat for females" (Connelly et al. 2004). "No evidence that lek habitat is limiting" (Schroeder et al. 1999). **See indicator at bottom of table concerning lek disturbance.**
lek sites	slope	≥10%	—	—	<10%	Nisbet et al. (1983), Rogers (1964)	
lek sites	aspect	E	—	—	S	Rogers (1964)	The importance of this indicator is uncertain.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites (protective cover)	nest cover	non-shrubs	other shrubs (non-sagebrush) Note: “. . . [N]esting success for non-sagebrush nests (42%) was higher than sagebrush nests (31%) in California . . .” (Connelly et al. 2004).	other sagebrush	mountain big sagebrush	Connelly et al. (2000, 2004) and sources cited therein	“Most sage grouse nests occur under sagebrush . . . , but sage grouse will nest under other plant species . . . . However, grouse nesting under sagebrush experience greater nest success (53%) than those nesting under other plant species (22% . . .). . . . The greatest nest success occurred in a mountain big sagebrush (*A. t. tridentata vaseyana*) cover type where shrubs 40–80 cm in height had greater canopy cover at the site of successful nests than at unsuccessful nests . . . . These observations were consistent with the results of an artificial nest study showing greater coverage of medium-height shrubs improved success of artificial nests . . .” (Connelly et al. 2000).
nest sites (protective cover)	mean height of nest-cover sagebrush*	<29 cm or >80 cm	29–46 cm	46–63 cm	63–80 cm	Connelly et al. (2000) and sources cited therein	“Mean height of sagebrush most commonly used by nesting [sage] grouse ranges from 29 to 80 cm . . . , and nests tend to be under the tallest sagebrush within a stand . . . . In general, sage grouse nests are placed under shrubs having larger canopies and more ground and lateral cover . . . ” (Connelly et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites (protective cover)	mean canopy coverage of sagebrush surrounding nest*	<15% or >38%	15–23%	23–30%	30–38%	Connelly et al. (2000) and sources cited therein	"In general, sage grouse nests are . . . in stands with more shrub canopy cover than at random sites . . . . Sagebrush cover near the nest site was greater around successful nests than unsuccessful nests in Montana . . . . [A]lso . . . successful nests were in sagebrush stands with greater average canopy coverage (27%) than those of unsuccessful nests (20%)" (Connelly et al. 2000).
nest sites (protective cover—"may provide scent, visual, and physical barriers to potential predators")	mean grass (and forb) height at nest site* (measured as "droop height", the highest naturally growing portion of the plant)	<14 cm or >34 cm	14–21 cm	21–27 cm	27–34 cm	Connelly et al. (2000) and sources cited therein	"Grass height at nests under non-sagebrush plants was greater (*P*<0.01) than that associated with nests under sagebrush, ... Grass >18 cm in height occurring in stands of sagebrush 40–80 cm tall resulted in lesser nest predation rates than in stands with lesser grass heights . . . . [T]he herbaceous height requirement may not be possible in habitats dominated by grasses that are relatively short when mature. . . . If average sagebrush height is >75 cm, herbaceous [i.e., grass and forb] cover may need to be substantially greater than 18 cm" in height and >25% cover (grasses and forbs combined) to provide lateral concealment from predators" (C. et al.).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites (protective cover)	mean canopy coverage of grass (and forbs) surrounding nest*	<3% or >51%	3–19%	19–35%	35–51%	Connelly et al. (2000) and sources cited therein	"Some cover estimates may include both grasses and forbs" (Connelly et al. 2000). Upper limit for grasses only (i.e., no forbs) may be 30 or 32%, but this has not been checked against original sources. However, it may be that separating grasses and forbs is not biologically meaningful—i.e., that they are of equal cover value to nesting sage-grouse. "If average sagebrush height is >75 cm, herbaceous [i.e., grass and forb] cover may need to be substantially greater than 18 cm" in height and >25% cover (grasses and forbs combined) to provide lateral concealment from predators. . . . [I]n Oregon, grass cover was greater at successful nests than at unsuccessful nests . . ." (C. et al.)
nesting habitat (food and protective cover)	spring forb cover	<7%	7–13%	13–15%	>15%	Connelly et al. (2004) and sources cited therein	
nesting habitat (food)	food forb cover	<0.5%	0.5–2%	2–3%	>3%	Connelly et al. (2004) and sources cited therein	
nesting habitat (protective cover)	grass cover >18 cm tall	<0.5%	0.5–5%	5–10%	>10%	Connelly et al. (2004) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
early brood-rearing habitat	cover type	—	—	—	upland sagebrush, sagebrush-grassland	Connelly et al. (2000, 2004) and sources cited therein	
early brood-rearing habitat	mean sagebrush height*	<30 cm or >80 cm	—	—	30–80 cm	Connelly et al. (2000)	
early brood-rearing habitat	sagebrush canopy cover*	<15% or >25%	—	—	15–25%	Connelly et al. (2000)	
early brood-rearing habitat	mean grass and forb height* measured as "droop height", the highest naturally growing portion of the plant	<18 cm	—	—	>18 cm	Connelly et al. (2000)	". . . [T]he herbaceous height requirement may not be possible in habitats dominated by grasses that are relatively short when mature" (Connelly et al. (2000).
early brood-rearing habitat	perennial grass cover*	<15%	15–20%	20–25%	>25%	Connelly et al. (2000)	". . . [S]ome Wyoming sagebrush and low sagebrush breeding habitats may not support 25% herbaceous cover. In these areas, total herbaceous cover should be ≥15% . . ." (Connelly et al. (2000).
early brood-rearing habitat	forb cover*	<10%	—	—	>10%	Connelly et al. (2000)	". . . [S]ome Wyoming sagebrush and low sagebrush breeding habitats may not support 25% herbaceous cover. In these areas, total herbaceous cover should be ≥15% . . ." (Connelly et al. (2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
early brood-rearing habitat	portion of indicated habitat type with suitable conditions for the above 5 indicators*	<80%	—	—	>80%	Connelly et al. (2000)	
summer—late brood-rearing habitat	cover type	other	farmland and other irrigated areas near sagebrush	small burned areas within sagebrush	sagebrush	Connelly et al. (2000) and sources cited therein	
summer–late brood-rearing habitat	mean sagebrush height*	<40 cm or >80 cm	—	—	40–80 cm	Connelly et al. (2000)	
summer–late brood-rearing habitat	sagebrush canopy cover*	<10% or >20%	—	—	10–20%	Connelly et al. (2000)	
summer–late brood-rearing habitat	total shrub cover*	>25%	—	—	≤25%	Connelly et al. (2000)	
summer–late brood-rearing habitat	mean grass and forb height*	<15 cm	—	—	>15 cm	Connelly et al. (2000)	
summer–late brood-rearing habitat	portion of indicated habitat type with suitable conditions for the above 4 indicators*	≤40%	—	—	>40%	Connelly et al. (2000)	
winter habitat	portion of indicated habitat type with suitable conditions for the 2 indicators below*	≤80%	—	—	>80%	Connelly et al. (2000)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
winter habitat	mean canopy coverage of sagebrush above snow*	<12% or >43%	12–22%	22–33%	33–43%	Connelly et al. (2000) and sources cited therein	"Sagebrush is the essential component of winter habitat. Sage grouse select winter-use sites based on snow depth and topography, and snowfall can affect the amount and height of sagebrush available to grouse . . . . Thus, on a landscape scale, sage grouse winter habitats should allow grouse access to sagebrush under all snow conditions . . ." Connelly et al. (2000).
winter habitat	mean height of sagebrush above snow*	<20 cm or >46 cm	20–29 cm	29–37 cm	37–46 cm	Connelly et al. (2000) and sources cited therein	"Sagebrush is the essential component of winter habitat. Sage grouse select winter-use sites based on snow depth and topography, and snowfall can affect the amount and height of sagebrush available to grouse . . . . Thus, on a landscape scale, sage grouse winter habitats should allow grouse access to sagebrush under all snow conditions . . ." Connelly et al. (2000).
winter habitat	mean height of sagebrush (total height of plant, no snow)	<41 cm or >56 cm	41–46 cm	46–51 cm	51–56 cm	Connelly et al. (2000) and sources cited therein	Data are from only 2 sources and may not be representative of the full range of suitable conditions.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat alteration, predation	nonnative predators (cats, dogs) and native predators favored by human alterations of habitat (red foxes, common ravens)	abundant	common	few	none	Connelly et al. (2000)	"Constructing ranches, farms, and housing developments has resulted in the addition of nonnative predators to sage grouse habitats" (Connelly et al. 2000). "In Oregon, removal of Common Ravens resulted in 35% rate of nest success compared with 3% rate of nest success in a non-removal area . . . . However, predator removals have not been shown to improve long-term size and stability of Sage Grouse populations over large regions . . ." (Schroeder et al. 1999).
habitat degradation	grazing	—	—	—	none	Connelly et al. (2000)	Grazing can reduce sagebrush cover as well as grass height and cover and forb diversity and abundance, all of which are of critical importance to sage-grouse. "Avoid developing springs for livestock water, but if water from a spring will be used in a pipeline or trough, design the project to maintain free water and wet meadows at the spring. Capturing water from springs using pipelines and troughs may adversely affect wet meadows used by grouse for foraging" (Connelly et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation (e.g., elimination of sagebrush)	herbicide treatments	—	—	—	none	Rogers (1964), Connelly et al. (2000) and sources cited therein	
habitat degradation (e.g., elimination of sagebrush and native grasses and forbs, invasion by exotic annual grasses such as cheatgrass)	burning	—	—	—	none	Rogers (1964), Connelly et al. (2000) and sources cited therein	"Generally, fire should not be used [as a management treatment] in breeding habitats dominated by Wyoming big sagebrush. Fire can be difficult to control and tends to burn the best remaining nesting and early brood-rearing habitats (i.e., those with the best understory), while leaving areas with poor understory. Further, we recommend against using fire in habitats dominated by xeric mountain big sagebrush (*A. t. xericensis*) because annual grasses commonly invade these habitats . . . . Suppress wildfires in all breeding habitats. . . . Do not use fire in sage grouse habitats prone to invasion by cheatgrass and other invasive weed species . . . ."
habitat degradation (e.g., elimination or reduction of sagebrush)	mechanical treatments	—	—	—	none	Connelly et al. (2000) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	invasive junipers and other conifers	present, abundant, and encroaching sagebrush	present, but few or not encroaching	few and not encroaching	absent	Connelly et al. (2000)	Remove or control by using methods that are least disruptive to sagebrush.
habitat restoration (reseeding)	seed mix	non-sagebrush, nonnative species	"species that are functional equivalents and provide habitat character-istics similar to those of native species" of sagebrush, forbs, and grasses	—	native sagebrush, native forbs (especially legumes), native grasses (especially bunch-grasses)	Connelly et al. (2000)	"All wildfires and prescribed burns should be evaluated as soon as possible to determine whether reseeding is necessary to achieve habitat management objectives" (Connelly et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	fences, utility lines and poles	many	—	—	none	Connelly et al. (2000)	"Increase the visibility of fences and other structures occurring within 1 km of seasonal ranges by flagging or similar means if these structures appear hazardous to flying grouse (e.g., birds have been observed hitting or narrowly missing these structures or grouse remains have been found nest to these structures). . . . Avoid building powerlines and other tall structures that provide perch sites for raptors within 3 km of seasonal habitats. If these structures must be built, or presently exist, the lines should be buried or poles modified to prevent their use as raptor perch sites" (Connelly et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
lek and nesting disturbance	energy resource extraction (e.g., natural gas, oil, or coal development) and mining, especially during breeding and nesting season	energy development (well pads, surface mining, or roads) ≤3 km from lek or light traffic (1–12 vehicles/day)	—	—	no well pads, surface mining, roads, or traffic in vicinity	Lyon and Anderson (2003), Braun (1986), Connelly et al. (2000)	From disturbed (vs. undisturbed) leks, hens moved greater distances to nest (12.4 km vs. 2.1 km) and fewer hens (65% vs. 89%) initiated nests. Only 26% of hens from disturbed leks nested ≤3 km from the lek vs. 91% from undisturbed leks, and the probability of a successful hatch appeared to be associated with distances traveled from lek to nest (Lyon and Anderson 2003). Upgrade of coal-hauling roads and increase in traffic caused abandonment of a lek (50 m from a road) and 83% reduction of strutting males on another lek (500 m from a road) within 3 years of the upgrade (Braun 1986). ≥ 6 leks in Alberta were disturbed by energy development and 4 were abandoned.

[1]Concerning this species, Connelly et al. (2000) pointed out: "Populations may have 1) distinct winter, breeding, and summer areas; 2) distinct summer areas and integrated winter and breeding areas; 3) distinct winter areas and integrated breeding and summer areas; or 4) well-integrated seasonal habitats (nonmigratory populations). Seasonal movements between distinct seasonal ranges may exceed 75 km . . . , which complicates attempts to define populations. Thus, [it has been] suggested that sage grouse populations be defined on a temporal and geographic basis. Because of differences in seasonal movements among populations . . . , 3 types of sage grouse populations can be defined: 1) nonmigratory, grouse do not make long-distance movements (i.e., >10 km one way) between or among seasonal ranges; 2) one-stage migratory, grouse move between 2 distinct seasonal ranges; and 3) 2-stage migratory, grouse move among 3 distinct seasonal ranges. Within a given geographic area, especially summer range, there may be birds that belong to more than one of these types of populations. On an annual basis, migratory sage grouse populations may occupy areas that exceed 2,700 km^2 . . . . During winter, . . . migratory sage grouse in southeastern Idaho . . . occupied an area ≥140 km^2. For a nonmigratory population in Montana, . . . winter home range size ranged from 11 to 31 km^2. During summer, migratory sage grouse in Idaho occupied home ranges of 3 to 7 km^2 . . . . Despite large annual movements, sage grouse have high fidelity to seasonal ranges . . . . Females return to the same area to nest each year . . . and may nest within 200 m of their previous year's nest . . . . Although the lek may be an

approximate center of annual ranges for nonmigratory populations . . . , this may not be the case for migratory populations . . . . Average distances between nests and nearest leks vary from 1.1 to 6.2 km, but distance from lek of female capture to nest may be >20 km . . . . Nests are placed independent of lek location . . . ." For migratory populations, suitable migratory corridors are presumed to be of importance for movements between 2 or 3 seasonal ranges. Migratory routes are traditional, and sage-grouse do not readily change established routes, which may be 80–160 km in length. "Unfortunately, the distribution, configuration, and characteristics of these migratory corridors is largely unknown in most portions of the sage-grouse distribution" (Connelly et al. 2004). Thus, the characteristics of suitable migratory corridors cannot be addressed using "indicators" (i.e., rows) in this table. However, it does seem reasonable to assume, despite the lack of knowledge concerning migratory corridors, that healthy sagebrush habitats should connect different seasonal use areas.

*Most important indicators.

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Gunnison sage-grouse (*Centrocercus minimus*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population viability	no. of individuals	<50	50–250	250–500	>500	Miller (2004), GSRSC (2005)	Population viability assessments involve estimates, assumptions, and best guesses.
spring–fall habitats	distance to nearest active lek	>4 mi	4 mi	<4 mi	«4 mi	GSRSC (2005)	85.2% of females nest within 4 mi of lek of capture, and 81.3% of all seasonal habitat locations are within 4 mi of lek of capture (GSRSC 2005).
winter habitat	distance to nearest active lek	>6 mi	6 mi	<6 mi	«6 mi	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	plant community*	—	—	—	sagebrush	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	sagebrush canopy cover (arid)*	<15% or >25%	—	—	15 –25%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	sagebrush canopy cover (mesic)*	<10% or >20%	—	—	10 –20%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	non-sagebrush canopy cover (arid or mesic)[3]	<5% or >15%	—	—	5–15%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	total shrub canopy cover (arid)	<20% or >40%	—	—	20–40%	GSRSC (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding habitat (lek, nesting, early brood-rearing)	total shrub canopy cover (mesic)	<15% or >35%	—	—	15–35%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	sagebrush height (arid)*	<25 cm or >50 cm	—	—	25–50 cm	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	sagebrush height (mesic)*	<30 cm or >50 cm	—	—	30–50 cm	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	grass cover (arid)	<10% or >30%	—	—	10–30%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	grass cover (mesic)	<20% or >40%	—	—	20–40%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	forb cover (arid)*	<5% or >15%	—	—	5–15%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	forb cover (mesic)*	<20% or >40%	—	—	20–40%	GSRSC (2005)	
breeding habitat (lek, nesting, early brood-rearing)	grass height (arid or mesic)	<10 cm or >15 cm	—	—	10–15 cm	GSRSC (2005)	Indicator is measured as “droop height”, the highest naturally growing portion of the plant.
breeding habitat (lek, nesting, early brood-rearing)	forb height (arid)	<5 cm or >10 cm	—	—	5–10 cm	GSRSC (2005)	Indicator is measured as “droop height”, the highest naturally growing portion of the plant.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
breeding habitat (lek, nesting, early brood-rearing)	forb height (mesic)	<5 cm or >15 cm	—	—	5–15 cm	GSRSC (2005)	Indicator is measured as "droop height", the highest naturally growing portion of the plant.
summer–fall habitat[4]	plant communities*	—	agricultural fields	grassland	sagebrush, riparian, wet meadows	GSRSC (2005), Lupis (2005)	
summer–fall sagebrush habitat	sagebrush canopy cover (arid)	<5% or >15%	—	—	5–15%	GSRSC (2005)	
summer–fall sagebrush habitat	sagebrush canopy cover (mesic)	<5% or >20%	—	—	5–20%	GSRSC (2005)	
summer–fall sagebrush habitat	non-sagebrush canopy cover (arid or mesic)[3]	<5% or >15%	—	—	5–15%	GSRSC (2005)	
summer–fall sagebrush habitat	total shrub canopy (arid)	<10% or >30%	—	—	10–30%	GSRSC (2005)	
summer–fall sagebrush habitat	total shrub canopy (mesic)	<10% or >35%	—	—	10–35%	GSRSC (2005)	
summer–fall sagebrush habitat	sagebrush height (arid)	<20 cm or >40 cm	—	—	20–40 cm	GSRSC (2005)	
summer–fall sagebrush habitat	sagebrush height (mesic)	<25 cm or >50 cm	—	—	25–50 cm	GSRSC (2005)	
summer–fall sagebrush habitat	grass cover (arid)	<10% or >25%	—	—	10–25%	GSRSC (2005)	
summer–fall sagebrush habitat	grass cover (mesic)	<10% or >35%	—	—	10–35%	GSRSC (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
summer–fall sagebrush habitat	forb cover (arid)	<5% or >15%	—	—	5–15%	GSRSC (2005)	
summer–fall sagebrush habitat	forb cover (mesic)	<15% or >35%	—	—	15–35%	GSRSC (2005)	
summer–fall sagebrush habitat	grass height (arid or mesic)	<10 cm or >15 cm	—	—	10–15 cm	GSRSC (2005)	Indicator is measured as "droop height", the highest naturally growing portion of the plant.
summer–fall sagebrush habitat	forb height (arid)	<3 cm or >10 cm	—	—	3–10 cm	GSRSC (2005)	Indicator is measured as "droop height", the highest naturally growing portion of the plant.
summer–fall sagebrush habitat	forb height (mesic)	<5 cm or >10 cm	—	—	5–10 cm	GSRSC (2005)	Indicator is measured as "droop height", the highest naturally growing portion of the plant.
winter habitat	plant community	—	—	—	sagebrush (not completely covered by snow during average winters)	GSRSC (2005)	". . . [M]ost [Gunnison sage-grouse] feeding activity during the winter occurred in drainages and on slopes with south or west aspects in the Gunnison Basin. In years with severe winters resulting in heavy accumulations of snow, the amount of sagebrush exposed above the snow can be severely limiting. . . . [D]uring a severe winter in the Gunnison Basin . . ., . . . <10% of the sagebrush was exposed above the snow and available to [Gunnison] sage-grouse. In these conditions, the tall and vigorous sagebrush typical in drainages were an especially important food source for [Gunnison sage-grouse]" (GSRSC 2005).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
winter sagebrush habitat	sagebrush canopy cover (arid)	<30% or >40%	—	—	30–40%	GSRSC (2005)	Indicator is "[m]easured from ground level to the tallest stem (excluding inflorescence)" (GSRSC 2005) and is not merely the above-snow portion of the plant.
winter sagebrush habitat	sagebrush height (arid)*	<40 cm or >55 cm	—	—	40–55 cm	GSRSC (2005)	Indicator is "[m]easured from ground level to the tallest stem (excluding inflorescence)" (GSRSC 2005) and is not merely the above-snow portion of the plant.
disturbance (of courtship, breeding, nesting, brood-rearing, etc.)	fences, utility lines, communication towers, wind power turbines, roads, housing developments, oil & gas exploration and production	<0.6 mi of active lek	0.6–4.0 mi from active lek	>4.0 mi from active lek	none in vicinity (»4.0 mi from active lek)	GSRSC (2005)	New construction should be avoided, and retrofitting of existing structures should be carried out as applicable (e.g., to increase visibility of fences, utility wires, turbines; to make towers unsuitable for raptor perches; burying utility lines). "Vehicles should not exceed 35 mph . . . on local or unpaved roads" through seasonal habitats or near leks. "All surface-disturbing activities should be prohibited within 0.60 miles of an active lek" and "any equipment should have minimal noise" and "should be equipped with effective mufflers . . . reducing noise levels to 10 dBA or less . . ." (GSRSC 2005).
habitat loss or degradation	sagebrush removal or treatment	<0.6 mi of active lek	0.6–4.0 mi from active lek	4.0–6.0 mi from active lek	none in vicinity (>6.0 mi from active lek)	GSRSC (2005)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, reduced reproductive output	disease (especially West Nile virus; also coccidiosis, tularemia, avian malaria, & diseases of domestic fowl)	present locally	present in the region	believed to be rare in the region	believed to be absent in the region	GSRSC (2005)	West Nile virus poses the most serious disease threat. Use BTI (*Bacillus thuringiensis israelensis*) to control mosquito larvae rather than chemical insecticides (larvicides or adulticides), e.g., at oil and gas drilling water containment pits or other potential mosquito breeding waters.

[1]This species was not recognized as distinct from the greater sage-grouse (*Centrocercus urophasianus*) until the 1990s and was not formally described and named until 2000. It currently survives in southwestern Colorado and southeastern Utah and is believed historically to have occurred also in north-central New Mexico and northeastern Arizona. Some authors have suggested that it may have occurred as far east as western Kansas and Oklahoma, but others have dismissed this as unlikely.

[2]Most of the information in this table has been extracted from the "Gunnison sage-grouse rangewide conservation plan" (GSRSC 2005) and much of it from Appendix H of the plan, "GUSG [Gunnison sage-grouse] structural habitat guidelines". Those guidelines were based on 5 studies that reported vegetational structure of habitats of Gunnison sage-grouse and were tested using data from a 6th study. "Most of the data reported were in the form of means and standard errors. . . . The means were bounded by the standard errors to create a variable 'distribution range' and a guideline was developed using the distribution range. Numerical maximum and minimum data points were not included. . . . The vegetation structure guidelines . . . should be interpreted as minimum standards, and managers should strive to meet the full potential of any given site" (GSRSC 2005). **N.B.**: Thus, it may be that for some or many factors ("indicators" in this table), ideal conditions ("very good" in this table) may actually be beyond the ranges shown. For example, in breeding habitat, sagebrush canopy cover of >20 or 25% and sagebrush height of >50 cm may be very good rather than poor, despite what has been recommended in the rangewide conservation plan. (See also footnote 4.)

[3]"In more arid locations, the non-sagebrush shrubs included, but are not limited to, horsebrush, rabbitbrush, bitterbrush, snakeweed, greasewood, and winterfat. In mesic locations the aforementioned shrub species can occur, but the shrub community may also include Gambel's oak, snowberry, serviceberry, and chokecherry" (GSRSC 2005).

[4]"No specific habitat guidelines have been included for riparian or wet meadow habitat used by [Gunnison sage-grouse] during [the summer–fall] period" (GSRSC 2005).

*Most important indicators.

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sharp-tailed grouse (*Tympanuchus phasianellus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (general)	cover type	other	—	—	undisturbed native shrub-steppe, grass-shrubland, climax bunch-grass lands	Hart et al. (1950), Marks (1986), Klott and Lindzey (1990) and other sources	**N.B.**: Areas with tall shrubs or small trees, such as in riparian areas, are required in winter.
habitat (general)	topography (see Comments)	other (e.g., extremely steep or rough)	—	plains	rolling: hills, knolls, ridge tops, benches	Hart et al. (1950), Giesen and Connelly (1993) and sources cited therein	"It is probable that topography has little effect upon the distribution and activities of sharp-tails except as it influences vegetation, snow depth, cultivation by man, and selection of dancing grounds. It seems that these birds will use nearly any topography that offers them the necessities of food and shelter. Generally the rolling lands unsuited to crop land are all that is left for the birds" (Hart et al. 1950).
spring, summer, and fall habitats	shrub cover*	<10% or >40%	10–20%	30–40%	20–30%	McArdle (1977) and other sources	
summer habitat	slope	>50%	40–50%	30–40%	≤30%	Hart et al. (1950), Marks (1986), Giesen and Connelly (1993), and other sources	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
summer habitat	aspect	S, W	—	—	N	Marks (1986)	Tendency for selection of N slopes may be the result of N slopes being wetter and to have more lush vegetation and thus more food and cover.
summer habitat	proximity to habitat edges	>45 m	30–45 m	15–30 m	0–15 m	McArdle (1977) and other sources	
lek sites	cover type	other	—	—	grassland, grass–shrub, shrubland	Parker (1970)	
lek sites	slope	>5%	3.5–5%	2–3.5%	0–2%	Ward (1984)	
lek sites (predator avoidance)	average shrub height	<18 cm or >70 cm	55–70 cm	18–25 cm or 40–55 cm	25–40 cm	Ward (1984), Klott and Lindzey (1989), Giesen and Connelly (1993) and sources cited therein	
lek sites (predator avoidance)	shrub cover	<2% or >40%	2–6% or 30–40%	6–10% or 20–30%	10–20%	Ward (1984), Klott and Lindzey (1989), and other sources	
lek sites (predator avoidance vs. mating success)	horizontal visibility 15.2 cm above ground*	<55% or >95%	55–62.5% or 87.5–95%	62.5–70% or 80–87.5%	70–80%	Ward (1984), Klott and Lindzey (1989), Giesen and Connelly (1993) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	distance from nearest active lek	>3 km	2.0–3 km	1.6 –2.0 km	<1.6 km	Giesen (1997), Giesen and Connelly (1993) and sources cited therein	Habitat that is generally suitable for this species (e.g., shrub-steppe, mountain shrub) should connect nesting habitat with the lek site. Large open areas such as shrub removal treatments ≥30 m wide should not separate nesting habitat from the lek site (Klott and Lindzey 1990).
nesting habitat	topography	other	hilltops	valleys	hillsides	Marks and Marks (1987)	
nesting habitat	slope	»25%	—	—	<25%	Marks and Marks (1987)	
nesting habitat	cover type	agricultural fields	other shrub communities	sagebrush	mountain shrub	Giesen (1997), Marks and Marks (1987), other sources	
nesting habitat	shrub density[2,*] (see Comments)	<5,000/ha	5,000–10,000/ha	10,000–15,000/ha	>15,000/ha	Meints (1991), Giesen (1997) and sources cited therein	Ratings are based on reports of 11,000/ha in Idaho, 17,800/ha in Wyoming, and 32,500/ha in Colorado. Such differences could be the result of differences in climate or even different methods for determining shrub densities (Giesen 1997). Whether there is an upper limit to suitable shrub density in nesting habitat is not known. (Shrub densities can also be determined as shrubs/m^2 by dividing the ratings by 10,000.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	shrub species[2]	—	other shrubs	—	snowberry, sagebrush, saskatoon serviceberry, bitterbrush	Giesen (1997), Marks and Marks (1987), Meints (1991)	
nest sites	vegetative cover 20– 30 cm above ground[2]	<35%	35–45%	45–55%	>55%	Meints (1991)	
nest sites	vegetative cover at 45° angle[2,*]	<55%	55–65%	65–75%	>75%	Meints (1991)	
nest sites	cover at ground level[2]	<70%	70–80%	80–90%	>90%	Meints (1991)	
nest sites	density of shrubs ≥20 cm tall[2,*]	0.5/m^2	0.5–0.7/m^2	0.7–0.9/m^2	>0.9/m^2	Meints (1991)	(Densities can be converted to shrub/ha by multiplying ratings by 10,000.)
nest sites	mean grass height*	<15 cm	—	15–20 cm	>20 cm	Meints (1991)	For nests in non-shrub situations, mean grass height is even greater (~40 cm).
brood habitat	distance from nearest active lek	>2.5 km	1.6–2.5 km	1.1–1.6 km	<1.1 km	Giesen and Connelly (1993) and sources cited therein	
brood habitat	plant association	other	sagebrush–grass; aspen groves; agricultural fields	sagebrush–bitterbrush; meadows	mountain shrub; sagebrush–snowberry; grass–forb openings	Klott and Lindzey (1990), Meints (1991)	
brood habitat	total shrub cover (see Comments)	<13% or >43%	13–18% or 38–43%	18–23% or 33–38%	23–33%	Klott and Lindzey (1990)	Observed conditions for this indicator vary greatly. Suitable conditions of ≥70% (Giesen 1987) and ~0% (Parker 1970) shrub cover have been reported, but most reports suggest that ~28–30% is optimal.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
brood habitat	snowberry cover	<1% or >16%	1–3% or 13 –16%	3–6% or 10–13%	6–10%	Klott and Lindzey (1990)	
brood habitat	shrub species	—	—	serviceberry, chokecherry, sagebrush, bitterbrush	snowberry	Klott and Lindzey (1990)	Klott (1987) reported that in his Wyoming study, "[Columbian] sharp-tailed grouse broods were never found in habitat sites that did not support snowberry." Oedekoven (1985) and other authors have also noted the importance of this shrub in defining the brood habitat (and other habitats) of the Columbian sharp-tailed grouse.
brood habitat	45° screening cover (at 1.5 m)	<70% or >90%	70–73% or 87–90%	73–76% or 84–87%	76–84%	Klott and Lindzey (1990)	
brood habitat	vertical vegetation cover 30–40 cm above ground	<25%	25–35%	35–60%	>60%	Meints (1991)	
brood habitat	grass height	<20 cm	20–30 cm	30–45 cm	>35 cm	Meints (1991)	
brood habitat	bare ground*	>35%	20–35%	10–20%	<10%	Marks and Marks (1987), Meints (1991)	
brood habitat	forbs and grasses	absent	present but few species and not abundant	present but few species or not abundant	present, diverse species, and abundant	Hart et al. (1950), McArdle (1977)	
winter habitat	distance from nearest active lek	>4.5 km	3.6–4.5 km	2.6–3.6 km	<2.6 km	Giesen and Connelly (1993), Marks and Marks (1987), and other sources	"Columbian sharp-tailed grouse seem to move farther to wintering habitats in regions lacking a broad distribution of winter food resources" (Giesen and Connelly 1993).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
winter habitat (food and escape cover)	cover type*	other	seep	big sagebrush	mountain shrub; riparian	Marks and Marks (1987, 1988), Meints (1991)	"The availability of suitable winter habitat is probably the most critical component in determining the ability of an area to support [Columbian] sharptails" (Marks and Marks 1987). Seeps are used only when snow is crusty (rather than powdery), preventing burrowing (for "roosting" after feeding) (Marks and Marks 1988). Plantings of riparian shrubs and trees (e.g., chokecherry, snowberry, serviceberry, hawthorn) can enhance winter habitat.
winter habitat (food and escape cover)	shrub cover	≤40%	—	—	>40%	McArdle (1977)	There may be an upper limit to suitable shrub cover in winter habitat, but, if so, it is not known.
winter habitat (food)	slope	none	slight	moderate	moderate	McArdle (1977)	Snow accumulation is less on slopes, allowing greater access to foods.
winter habitat (food)	aspect	N	—	—	S	McArdle (1977)	Snow accumulation is less on S-facing slopes, allowing greater access to foods.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
removal of nesting and brood-rearing cover; destruction of deciduous trees and shrubs (foraging areas and escape cover) through trampling, browsing, and rubbing; interference with courtship and breeding on leks	excessive grazing[2]	present	—	—	none	Giesen and Connelly (1993) and other sources (e.g., Marks 1986)	"Excessive livestock grazing is 1 factor responsible for the decline of Columbian sharp-tailed grouse . . . . Loss of deciduous cover is especially severe near riparian areas that attract livestock in summer because of water and shade; this cover provides critical foraging areas and escape cover for Columbian sharp-tailed grouse throughout the year" (Giesen and Connelly 1993). Oedekoven (1985) recommended that grazing should be minimized within at least a 1.0 km radius of leks and in riparian areas. However, some authors have suggested that limited, carefully controlled grazing may benefit the habitat of this bird.
immediate loss of nesting, brood, and winter cover	herbicide spraying (e.g., 2,4-D)[2]	ongoing or planned	—	—	none	Giesen and Connelly (1993)	"Herbicide spraying . . . of Columbian sharp-tailed grouse habitat has a negative effect on the species because of detrimental impacts to deciduous shrubs, especially snowberry, serviceberry, chokecherry, and hawthorn . . ." (Giesen and Connelly 1993).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat destruction, lek abandonment	burning[2] (see Comments)	past, present, or future	—	—	none	Giesen and Connelly (1993) and sources cited therein	Various authors have reported negative effects on Columbian sharp-tailed grouse from burning, but in some situations prescribed burning may be effective in maintaining suitable habitat (Giesen and Connelly 1993). "Burning of range land should be discouraged except when it is plainly necessary or highly desirable, and should not be done during or shortly after the nesting season [of the Columbian sharp-tailed grouse, April to early July]" (Hart et al. 1950).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat alteration	mechanical treatments to improve habitat for this species[2] (see Comments)	—	—	chaining	—	McArdle (1977), Giesen and Connelly (1993)	". . . [C]haining was the most beneficial habitat treatment for [Columbian] sharp-tailed grouse in the Curlew Valley of Idaho. Grouse responded almost immediately, and although mechanical treatments cost more than chemical treatments or fire, it was possible to control the amount of brush removed, shape of the treated area, and time of treatment. Livestock grazing on chained areas apparently limited dominance of grass and resulted in recovery of shrubs. No data are available concerning the effects of plowing or rotomowing on Columbian sharp-tailed grouse habitat, although both could be detrimental if they caused shrub and forb cover to decline."
connectivity of habitats and use areas	shrub removal treatments[2]	present and ≥30 m wide	present but <30 m wide	—	none	Klott and Lindzey (1990)	Columbian sharp-tailed grouse (especially hens and broods) will not cross treated areas ≥30 m wide.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	utility lines (e.g., power and telephone lines) and fence wires	many and new	few and new or many and old	few and old	none in vicinity	Hart et al. (1950)	"Sharp-tailed grouse . . . are known to fly into telephone, high tension, or fence wires . . . . This is especially true until the birds become aware that these obstructions exist. Twenty of 24 locations of [Columbian] sharp-tail remains were within 100 yards of the newly erected telephone line" (Hart et al. 1950); 57% of the population inhabiting a 640- acre study area was found dead.

[1]The ecology of this species varies greatly geographically, various of its 7 subspecies (1 extinct) inhabiting very different plant associations. **This table is applicable to only the Columbian race, *Tympanuchus phasianellus columbianus***, which occurs in "sagebrush (*Artemisia* spp.)-grassland and mountain shrub habitats from interior central and s. British Columbia south to Utah and sw. Colorado (formerly west to ne. California)" (Connelly et al. 1998). Its populations and distribution are now very much reduced, highly fragmented, and discontinuous through this region, and it has been extirpated from Oregon, Nevada, and California (Giesen and Connelly 1993). This subspecies currently occupies <10% of its historical range. Hart et al. (1950) stated: "The principal factors which have been responsible for the decrease of the Columbian sharp-tailed grouse in Utah are those resulting from the activities of man. The sharp-tail does not readily adapt itself to living in an area of intensive agricultural use. . . . Overgrazing apparently has been an important factor in causing the decline in numbers of sharp-tailed grouse in Utah, and in preventing their increase . . . ." Marks (1986) cautioned: "One major difficulty in assessing habitat selection [by Columbian sharp-tailed grouse] is that most present day habitats have been modified by humans or their livestock, and optimal sharptail habitat may no longer exist in western Idaho . . . . Thus, even the best available habitats may not contain all of the habitat requirements of a healthy population of sharptails." Much of the information in this table is from studies of currently inhabited conditions, which, though tolerated by Columbian sharp-tailed grouse, may be far from optimal for this bird, as Marks (1986) noted.

[2]Indicator applies to the immediate area of the nest, not necessarily the surrounding landscape. Thus, only suitable patches, rather than vast areas, are required for this indicator.

[3]Critical (e.g., nesting, brood-rearing) and seasonal (e.g., winter) habitats used by Columbian sharp-tailed grouse are typically within relatively close distances (e.g., <5 km radius) of leks. Thus, if the location of an active lek is known, local management of this bird is greatly facilitated, for protection of all habitats in the surrounding area should ensure availability of critical and seasonal habitats. As Giesen and Connelly (1993) have pointed out: "Lek densities provide an index to [Columbian] sharp-tailed grouse populations . . . and indirectly reflect changes in habitat quality. Leks are also more easily located and mapped than nesting, brood rearing, or winter habitats. . . . The breeding complex (lek and nesting areas) includes all lands within a 2-km radius of lek sites, because most nesting occurs within this area. Because of the importance of these areas for nesting and brood rearing and the relative scarcity of Columbian sharp-tailed grouse, vegetation manipulation within this area should be avoided. . . . If disturbance to the breeding complex is unavoidable, disturbance activities should be restricted

as follows: 1. Prohibit physical, mechanical, and audible disturbances within the breeding complex during the breeding season (Mar–Jun) . . . . 2. Avoid manipulation or alteration of vegetation within the breeding complex during the nesting period (May–Jun). Management practices should not reduce height, canopy cover, or density of chokeberry, snowberry, sagebrush, serviceberry, or other shrub species locally important for nesting. In bunchgrass-prairie communities, adequate height-density . . . of residual grasses should be maintained for nesting." In occupied Columbian sharp-tailed grouse habitat (not necessarily the "breeding complex"), they recommended: "1. No vegetation manipulation or disturbance that results in loss of deciduous tree or shrub height, canopy cover, and density should occur within 100 m of streams, including seasonally dry and intermittent secondary drainages. Cottonwood (*Populus* spp.), willows, and deciduous shrubs in riparian areas should be protected and maintained. Livestock use of riparian areas should be managed or eliminated to minimize destruction of associated shrubs and trees. 2. Manipulation or disturbance of vegetation, including herbicide application, burning, or mechanical destruction that results in long-term (i.e., >5 yr) or permanent reduction of height, canopy cover, or density of mountain shrub habitats within occupied ranges should be avoided if shrubs comprise <10% of the cover within occupied areas. Management practices to rejuvenate or increase mountain shrub communities within breeding complexes or winter ranges should be restricted to ≤25% of this cover type annually."

*Most important indicators.

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mountain plover (*Charadrius montanus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	total breeding population (total no. of adults)	≤6	7–18	18–29	≥30	Day (1994), Manning and White (2001a), Ellison (2002, Table 8)	Nesting by this species is philopatric and trends to be clustered and somewhat colonial. This has been observed in breeding studies in Utah (Day 1994, Manning and White 2001a).
abundance of potential prey (food for chicks and adults)	no. of arthropods found in 40 min of searching (by 1 collector?) within ~200 m of nest site see Comments	<3	3–9	10–16	>16	Manning and White (2001b)	Manning and White (2001b) unfortunately did not state details of their sampling method such as how many collectors of arthropods were involved in each search and time of day when searches were conducted. Young of this species are precocial. The adults do not feed the young. Upon hatching, the young must be able to find prey and to feed themselves.
nesting habitat	general plant association (Utah) see Comments	—	—	low-growing salt desert shrub	low-growing salt desert shrub	Day (1994), Manning and White (2001b)	Typical habitat in most of this species' range is short-grass prairie. Nesting habitat in Utah probably is marginal, and what is ranked here as "good" and "very good" is probably only "fair" or "poor" relative to habitats utilized in most other places.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	elevation (Utah) see Comments	?	?	?	1,500–1,920 m	Day (1994), Manning and White (2001b)	Whether this species is restricted, in Utah, to the narrow elevational range that has been reported, and that is presented here, is uncertain. Elsewhere within its breeding distribution, the species has been reported at elevations ranging 640 to 2,580 m (though not necessarily breeding) (Knopf 1996).
nesting habitat	total vegetation cover	<1% or >75%	1–6% or 53.2–75%	6–17.8% or 41.4–53.2%	17.8–41.4%	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, $p = 0.1541$ (Manning and White 2001b).
nesting habitat	shrub cover (as % of total vegetative cover)	—	—	0–24.7% or 85.1–100%	24.7–85.1%	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, $p = 0.1427$ (Manning and White 2001b).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	forb cover (as % of total vegetative cover)	>95%	60.6–95%	37.1–60.6%	0–37.1%	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, p = 0.8202 (Manning and White 2001b). Though actual numbers were not reported, number of species of forbs was 3rd in importance of 14 variables using stepwise discriminant analysis, but not statistically significant, p = 0.1319 (Manning and White 2001b).
nesting habitat	grass cover (as % of total vegetative cover)	—	82–100%	0–6.1% or 56.7–82%	6.1–56.7%	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, p = 0.0795 (Manning and White 2001b).
nesting habitat	maximum height of vegetation*	<3 cm or >60 cm	44.3–60 cm	3–12.5 cm or 44.3 cm	12.5–33.7 cm	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically to be very highly significant, p = 0.0021 (Manning and White 2001b).
nesting habitat	average height of vegetation	<3 cm or >35 cm	22.1–35 cm	3–6.2 cm or 16.8–22.1 cm	6.2–16.8 cm	Manning and White (2001b)	The difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, p = 0.2226 (Manning and White 2001b).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	total rock cover*	<15% or >99%	15–27% or 96.2–99%	27–96.2%	44.3–78.9%	Manning and White (2001b)	Using Wilcoxon 2-sample tests, the difference of nest sites and random sites for this variable ("indicator") was found statistically to be very highly significant, p = 0.0027, and, using stepwise discriminant analysis, this variable was 1st in importance of 14 variables and was very highly significant, p = 0.0007 (Manning and White 2001b).
nesting habitat	presence of prairie dogs*	no	no	yes	yes	Manning and White (2001b)	Although Manning and White (2001b) found nests in places where prairie dogs were present and in places where they were absent, prairie dogs were twice as frequent near nests as at random sites. Using Wilcoxon 2-sample tests, the difference of nest sites and random sites for this variable ("indicator") was found statistically not to be significant, p = 0.1111, but in stepwise discriminant analysis this variable was 2nd in importance of 14 variables and was highly significant, p = 0.0081 (Manning and White 2001b).
nesting habitat	distance to nearest prairie dog mound	>100 m	15–100 m	8.5–15 m	3–8.5 m	Manning and White (2001b)	Presumably "mounds" (Manning and White 2001b) included burrows, whether or not actual mounds existed.
nesting habitat	topography	—	—	flat	top or base of slope	Manning and White (2001b)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat	distance to nearest road or oil well pad see Comments	<44.75 m	44.75–92.5 m	92.5–137.25 m	>137.25 m	Manning and White (2001b)	Manning and White's (2001b, Table 1) data were divided into quartiles to produce the indicator "ratings". The average distance that they found was 68.6 m, the range 3–182 m. Roads are considered a threat, contributing to mortality of eggs, young, and adults. Different authors disagree concerning the effects and impacts of oil well pads on this species.
nesting habitat	eradication or persecution of prairie dogs*	occurring	—	—	none	USFWS (1999), Manning and White (2001b)	Prairie dogs (several species) are "keystone" species that are important in maintaining habitat suitable for this species. Known nesting of *C. montanus* in Utah is in association with the white-tailed prairie dog (*Cynomys leucurus*).

[1]Historically the breeding distribution of this species extended from extreme s. Canada to n. México along the high plains, mostly east of the Rocky Mountains—i.e., the western edge of the Great Plains. Most nesting now is confined to plains in Montana, Wyoming, and Colorado. Some limited breeding also occurs in Nebraska, Kansas, Oklahoma, and perhaps New Mexico; very limited breeding also has been reported in recent years Utah, Arizona, Texas, and Nuevo Leon. Typical habitat of the mountain plover is short-grass prairie (Knopf 1996) such as exists in the rain shadow immediately east of the Rocky Mountains. However, Day (1994) and Manning and White (2001a, 2001b) reported that its known breeding habitat in Utah, which they described as shrub-steppe, differs noticeably from that in the main breeding range of the species on the Great Plains (e.g., Montana, Wyoming, Colorado). See Day (1994) and Manning and White (2001b) for discussion of differences between known breeding habitat in Utah and typical breeding habitat elsewhere. **Known breeding habitat in Utah may be marginal and, at best, is probably only "fair" relative to breeding habitats utilized in the main parts of the species' range. This table is intended for use only in Utah and only during the breeding season.**

*Most important indicators.

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long-billed curlew (*Numenius americanus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	area of suitable habitat (also see footnote 4)	<42 ha (possibly insufficient for 1 nesting pair)	42–249 ha	250–500 ha	>500 ha	Bicak et al. (1982), Jenni et al. (1982, p 100), Dechant et al. (2002) and source cited therein, Ohanjanian (2004)	"Habitat areas need to be ≥3 times as large as a Long-billed Curlew territory, which averages about 14 ha, in order for curlews to use them, because of an unoccupied buffer strip of 300–500 m wide around the edge of suitable habitat . . ." (Dechant et al. 2002 citing another source). However, Ohanjanian (2004) recommended "[t]ypically between 250 and 500 ha but will depend on the number of pairs and area of suitable habitat. Larger contiguous openings will support more curlews (denser numbers) than smaller areas . . . ." (Also see footnote 4.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of territorial males or nests per 100 ha (1 km^2) (see Comments and footnote 2)	<0.5 % or nest/100 ha	0.5–2.9 %% or nests/100 ha	3–5 %% or nests/100 ha	>5 %% or nests/100 ha	Redmond et al. (1981), Jenni et al. (1982), Redmond and Jenni (1986), Pampush and Anthony (1993)	In n.-c. Oregon, Pampush and Anthony (1993) found 0–22.5 nests/100 ha, but only in 1 habitat type (cheatgrass) (of 5 studied) did they find >7.5 nests/100 ha, and in that habitat type they found 5–22.5 nests/100 ha. Using a different, but comparable, measure of breeding density, Redmond and Jenni (1986) found ~5–7 territorial males/100 ha (with standard deviations ranging ~3.5–9) in w. Idaho. "The modified Finnish line-transect method can be used to estimate densities of territorial male Long-billed Curlews only. Females are less detectable before hatching of their eggs, and consequently their density cannot be estimated reliably" (Redmond and Jenni 1986).
breeding habitat	general habitat type*,[3]	areas with high density of shrubs or trees or with tall, dense grass, forbs, or cultivated crops (e.g., forest, woodland, shrub steppe, tall-grass prairie)	agricultural fields: low-profile cropland, fallow fields, stubble	mixed-grass prairie, low-profile forb lands	short-grass prairie also: hayfields, irrigated pastures[3]	various sources including Dugger and Dugger (2002), Hartman and Oring (2005)[3]	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	topography*	very steep	steep	—	flat to moderately rolling	Dugger and Dugger (2002), Ohanjanian (2004)	
elevated nest sites (visibility of predators, dry nests, nest success)	hummocks, mounds, or "bumpiness" of terrain	absent	—	—	present	Cochran and Anderson (1987)	In many places this species prefers to nest on hummocks or other elevated landscape features, and this may be especially important in relatively flat terrain and in wet areas. "Where the ground had not been leveled (native fields), nests were found on sites significantly higher than mean level ground. Average height at nest sites was 6.1 cm above the ground in a radius of 1–5 m around the nest", and nest site heights ranged 2.5 to >20 cm (Cochran and Anderson (1987). Leveling of the landscape (e.g., pastures or fields) degrades nesting habitat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	dominant cover type examples from n.-c. Oregon (see Comments)	shrubs e.g., bitterbrush (1.25 nests/100 ha)	shrubs e.g., open low shrub (2.5 nests/100 ha)	grass, forbs e.g., bunchgrass (3.5 nests/100 ha) dense forb (3.25 nests/100 ha)	grass e.g., cheatgrass (9 nests/100 ha)	Pampush and Anthony (1993)	**N.B.**: This indicator is based on work in n.-c. Oregon, and the examples have limited geographic applicability, for *N. americanus* inhabits other plant communities elsewhere. However, these local examples support the generalization that shrubby habitats ("poor" and "fair") are much less suitable than forbs ("good") and that grassy habitats ("good" and "very good") are strongly preferred. Numbers in parentheses are average numbers of nests per 100 ha found by Pampush and Anthony (1993) in n.-c. Oregon.
nesting habitat (visibility of predators, intraspecific communication)	grass height*	>10 cm	—	—	≤10 cm	Bicak et al. (1982), Jenni et al. (1982), Ohanjanian (2004)	"Provide low profile vegetation (<10 cm) for nesting in April" (Ohanjanian 2004).
nesting habitat (visibility of predators, intraspecific communication)	vertical vegetation coverage (density)	≥55%	33–54%	23–32%	≤22%	Bicak et al. (1982, Figure 3), also Dugger and Dugger (2002), citing others	Indicator (percent vertical vegetation coverage) is measured 30 cm above the ground (the approximate height of l.-b. curlew eyes) using a vertical vision board viewed horizontally. "Ratings" are approximations based on 2 years of data in 1 area in a single study (i.e., Bicak et al. 1982, Figure 3).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
brood-rearing habitat (foraging, locomotion, shade)	grass height*	>30 cm or <20 cm	26–30 cm	20–24 cm	~25 cm	Cochran and Anderson (1987), Ohanjanian (2004)	"Provide vegetation that is approximately 25 cm in height for brood rearing in May. . . . Maintain native bunchgrass in brood-rearing areas" (Ohanjanian 2004).
habitat suitability (openness of habitat, visibility of predators, ease of foraging)	tall, dense residual (i.e., previous year's) vegetation (e.g., following a high-precipitation year)	present	—	—	absent	Dechant et al. (2002) and sources cited therein	"Tall, dense residual vegetation should be removed before the pre-[egg-]laying period (March to April) so that adults do not have to leave their territories to forage . . . . Removal of residual vegetation is especially important after years of above-normal precipitation. Haying and grazing can be used to provide the short vegetation and reduced vertical plant diversity preferred by nesting curlews, but should be timed so that short vegetation is available early in the season . . ." (Dechant et al. 2002 citing other sources). (Also see footnote 2.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
openness of habitat, visibility of predators, ease of foraging	shrub cover*	high	medium	low	none	Dechant et al. (2002) and sources cited therein	"Burn areas where fire will improve habitat by reducing shrub coverage and increasing habitat openness (Redmond and Jenni 1986, Pampush and Anthony 1993). During the breeding season following a fall range fire in western Idaho, the estimated [long-billed] curlew breeding density increased 30% (Redmond and Jenni 1986)" (Dechant et al. 2002). "[P]ostburn plant succession can be rapid, so grazing or mowing must also be used to maintain burned areas as attractive habitat . . ." (Dugger and Dugger 2002, citing others). "Do not use fire in nesting areas during egg-laying or brood-rearing times" (Ohanjanian 2004).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation of habitat	recreation, agriculture, residential expansion, deposition of refuse[4]	occurring	—	—	none	Jenni et al. (1982)[4], Dugger and Dugger (2002)	Dugger and Dugger (2002) considered degradation of habitat to be the "single greatest threat to [this] species". "In Idaho . . . deposition of refuse . . . alone resulted in loss of 750 ha of suitable breeding habitat in one area (Jenni et al. 1981 [1982])" (Dugger and Dugger 2002). "Older plantings of crested wheatgrass (*Agropyron cristatum*), and infestation of knapweeds (*Centaurea* sp.) can severely degrade nesting habitat by creating dense, tall stands of vegetation" (Dugger and Dugger 2002). Jenni et al. (1982, p 181, 183) listed 6 negative effects of littering on this species and recommended removal of trash and prevention of litter.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest abandonment, destruction, or other failure, mortality of chicks	human activities: vehicular use, researcher disturbance, shooting, etc.[4] (see Comments)	occurring	—	—	none	Jenni et al. (1982)[4], Dechant et al. (2002) and sources cited therein, Dugger and Dugger (2002), Ohanjanian (2004)	"Protect breeding habitat of [long-billed] curlews from detrimental human activities, such as vehicular use, researcher disturbance, and shooting . . ." (Dechant et al. 2002, citing others). "Minimize disturbance from humans or livestock during critical times throughout the breeding season (1 April to 15 July). . . . Do not construct roads unless there is no other practicable option. Limit road use during critical times during the breeding season (1 April to 15 July) . . . . Do not establish recreational trails. . . . Prevent or restrict motorized recreational vehicles such as ATVs and dirt bikes . . . particularly between 15 March to 15 July" (Ohanjanian 2004).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
negative: nest disturbance and trampling of eggs or young positive: control of grass height and density to ensure suitable breeding habitat	livestock grazing[5,*] see Comments and footnote 5	occurring during breeding season (March–July)	none (uncertain)	occurring in fall or winter	none during breeding season, occurring in early spring (before nesting), i.e., through March, but ending before 1 April and not resumed before July	various sources including Bicak et al. (1982), Dechant et al. (2002), Ohanjanian (2004)[5]	**N.B.**: Effects of grazing vary greatly geographically and temporally and depend on moisture regimes (precipitation), soil types, and types of vegetative cover and thus must be considered locally and yearly. No simple, generalized prescriptions are fully adequate. "Avoid grazing during the incubation period; in Wyoming, nests in areas that were grazed during incubation had lower hatching success than nests in other areas . . ." (Dechant et al. 2002, citing others). "In Northern Great Plains, highest densities of breeders occurred in lightly grazed grasslands on dry soils and heavily grazed areas on moister soils" (Dugger & D. 2002).
habitat loss	conversion of grasslands to agriculture (cultivation)	occurring	—	—	none	Dechant et al. (2002)	"Prevent conversion of upland prairie to agriculture . . . " (Dechant et al. 2002, citing others). "Anecdotal report suggests [this] species will re-establish on breeding area when agricultural areas are restored to grasslands" (Dugger and Dugger 2002, citing another source).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	forest encroachment	occurring	—	—	none	Dugger and Dugger (2002, citing another source), Ohanjanian (2004)	"Control forest encroachment using logging in combination with burning or other suitable means" (Ohanjanian 2004). "Fire suppression can have a negative effect on breeding habitat by allowing forest encroachment and growth of tall grasses and shrubs . . ." (Dugger and Dugger 2002, citing another source).
mortality, reduced food supply (e.g., grasshoppers)	pesticide use	occurring	—	—	none	Dugger and Dugger (2002), Ohanjanian (2004)	DDE has been found in eggs of this species in Oregon and Alberta, and death of adults in Oregon has been attributed to dieldrin, heptachlor epoxide, and oxychlordane (Dugger and Dugger 2002).
degradation of habitat (encouragement of tall, dense grass)	use of fertilizers	occurring	—	—	none	Cochran and Anderson (1987)	". . . [T]wo land uses were found that predicted nest failure: grazing during incubation, and field fertilization" (Cochran and Anderson 1987).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
degradation of nesting habitat (eliminating camouflage of adults incubating on nests), nest predation	"dragging" to break up livestock manure (see Comments)	occurring during the breeding season	occurring outside of the breeding season	—	none	Cochran and Anderson (1987), Dechant et al. (2002)	In many places (e.g., se. Washington [Allen 1980], w.-c. Wyoming [Cochran and Anderson 1987]), this species prefers to nest near livestock manure (or other objects). "Nests built where cattle had pastured were directly against a manure pile" (Cochran and Anderson 1987). In such places "dragging" to break up and scatter manure reduces suitability of nesting habitat. However, in some places (e.g., Idaho) this species does not show a preference for nesting near manure; in these places "dragging may be acceptable if it occurs after the breeding season when eggs or chicks are no longer vulnerable" (Dechant et al. 2002, citing others).

[1]Historically this species was much more common and occupied a much larger breeding and non-breeding range. It nested in much of the American "upper Midwest", coastal Texas, and Arizona, and it was common during the non-breeding season along the Atlantic coast of America. Hunting, intensive grazing, and loss of habitat (conversion of grasslands to agriculture) during the late 19th and early 20th centuries eliminated it from these areas. It currently breeds in interior central (w. Great Plains) and western North America and winters mainly in interior México and along the Gulf and Pacific coasts of America and México. **This table is intended for use within the existing breeding range of this species (interior w. America, including the w. Great Plains).** Although many generalizations can be made concerning the ecology of this species, it does exhibit important regional and local ecological differences. In some places it prefers wet sites (wet pastures, wet meadows, and/or proximity of water) for nesting, but in many places it avoids wet areas for nesting, selecting the driest available sites. Dominant plant species differ considerably across its breeding range. In many areas the invasive exotic annual, cheatgrass (*Bromus tectorum*), is its preferred cover type for nesting. Ohanjanian (2004, citing others) summarized the design of management areas for breeding long-billed curlews: "The [long-billed curlew habitat area] should include flat to moderately rolling terrain and short grass cover (ideally ≤10 cm tall during the pre-laying period and up to 25 cm during brood-rearing) . . . . Ideally the [managed area] should include as large an area of grassland as possible but should include ~250 ha of brood rearing habitat with scattered clumps of grasses 20–30 cm in height (this may include the nesting territory). The [area] should be at least 250 m wide at its narrowest point but should include a 500 m buffer of similar open habitat . . . to protect against disturbance. The buffer should be managed similar to the core so does not need to be

distinguished but should be considered when designing . . . boundaries." Cochran and Anderson (1987, citing an unpublished source) stated: "Long-billed curlews have four essential habitat requirements in the northwestern United States: (1) short grass (less than 30 cm tall), (2) bare ground components, (3) shade [e.g., bunchgrass clumps to protect young from overheating], and (4) abundant vertebrate prey [*sic*: **in**vertebrate prey such as grasshoppers and beetles] . . . ."

[2]In some places reported breeding densities of <1.5 nests, pairs, or territories/100 ha have been considered by authors to be quite good. For example, Allen (1980) found densities of nesting territories on 3 sites in se. Washington of ≥0.58, ≥ 0.65, and 1.45 per 100 ha and commented that the last of these "supports the highest nesting density of [long-billed] curlews because the habitat there is prime. Such is not the case at the other [2] study sites, and consequently the nesting densities are lower." Nesting densities of ~0.14–0.17 pairs per 100 ha have been estimated in areas of seemingly suitable habitat in Saskatchewan (Sadler and Maher 1976), and nesting densities of 0.64–2.36 breeding males per 100 ha have been found on study areas along the eastern shores of the Great Salt Lake in Utah (Paton and Dalton 1994). All of these would be in the "poor" and "fair" categories as rated here. Paton and Dalton (1994) argued that latitude explained both similarities of breeding densities in some studies at similar latitudes (all but 1) and the very low breeding densities observed at the higher latitudes in Saskatchewan. However, they also noted the 1 exception that "[a]n area with consistently high densities is the shortgrass rangelands of western Idaho" and commented: "The exact reasons for this variation in population densities across the species' range is unclear, yet should be studied further to assess factors regulating their populations. For example, little is known about prey and predator densities in various parts of the curlew range." Although Paton and Dalton (1994) were aware of the work of Redmond and Jenni (1986) in Idaho, they apparently did not know of the work of Pampush and Anthony (1993), which demonstrated similar high breeding densities in Oregon. Furthermore, breeding densities of 3.33–5.00 pairs/100 ha have been found in British Columbia, in contrast with the very low densities reported in Saskatchewan. Thus latitude does not seem to explain variation in breeding densities. On different plots within 1 study area (and in the same year) in Idaho, "male density estimates ranged from 1.74 males/100 ha (suitable) . . . to 8.40 males/100 ha (suitable) . . . " (Jenni et al. 1982). O'Connor et al. (1999) analyzed Breeding Bird Survey (BBS) data and, although they found that abundance increased with increasing longitude and increasing availability of winter wheat and decreased with increasing mean annual precipitation and increasing January mean temperature, such landscape variables accounted for only 11.0% of variation in abundance. Because of the great variability in reported breeding densities of long-billed curlews in different places and incomplete understanding of such variation, the "ratings" of breeding densities in this table should be considered uncertain.

[3]Many authors have considered some agricultural lands such as hayfields and pastures to provide somewhat suitable, though perhaps marginal, breeding habitat for *N. americanus*. However, Hartman and Oring (2005), studying this species in the Ruby Valley of ne. Nevada, found that it breeds in large numbers on irrigated pastures and hayfields where these birds find extremely abundant food (earthworms) and thus are not only able to re-nest but invariably do so if a clutch is destroyed (re-nesting having previously been considered extremely rare or non-existent in this species by most authors). Their work suggests that irrigated pastures and hayfields may, in fact, provide ideal breeding habitat for the long-billed curlew. Their findings in ne. Nevada are further corroborated by surveys by the Utah Division of Wildlife Resources in w.-c. Utah (K. Asmus, unpublished UDWR report, 2005, and personal communication, 2007), which have revealed high densities of long-billed curlews in hayfields and pastures, especially in patches of musk mustard (*Chorispora tenella*) within these areas. In view of these findings, an important consideration concerning the suitability of hayfields as breeding habitat is mowing, which should not occur until after the breeding season (fledging).

[4]Concerning an important breeding area for this species on BLM lands in Idaho (which may contain half of the breeding population west of the continental divide), Jenni et al. (1982, p 184) commented: "The refusal of [long-billed] curlews to establish breeding territories within approximately 0.4 km of areas of heavy human use has significant implications. Curlews don't need little patches of isolated habitat, they need big expanses of short grass rangeland devoid of human disturbance. If the owners of rangeland inholdings start developing them for any purpose, curlews will be unable to use not only those inholdings, but all adjoining rangeland within a radius of at least 0.4 – 0.5 km as well (a single 1 ha conversion would ruin a whole section for the curlews). The BLM should seriously consider consolidating its ownership of the best curlew habitats and all land immediately adjacent to them . . . . Unless the BLM can maintain large expanses of short grass rangeland all other management techniques are futile."

[5]Ohanjanian (2004) provided the following recommendations concerning livestock grazing in long-billed curlew breeding areas: "Control timing and distribution of livestock grazing to avoid disturbances during the breeding season. Plan livestock grazing to maintain grass cover in nesting areas that is on average <10 cm in height when curlews return in spring. Avoid concentrating livestock during the breeding season (1 April to 15 July) particularly during the incubation period. Place salt and water troughs in treed areas wherever possible to prevent livestock concentrations in the open where nests may occur. When it is necessary to move livestock . . . during the incubation period (generally 15 April to 31 May) . . ., use forest or shrub areas or areas immediately adjacent to trees (<20 m) rather than in the middle of openings." Sheep are better than cattle for improving general habitat conditions, but sheep cause more mortality during the nesting period through trampling of nests.

*Most important indicators.

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yellow-billed cuckoo (*Coccyzus americanus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of pairs in local breeding population	<10	10–25	>25	»25	Laymon and Halterman (1989)	
humidity	proximity to water*	>400 m	200–400 m	100–200 m	0–100 m	Gaines (1974), Hanberg (2000), Howe (2000)	
habitat	riparian vegetation (length)*	<300 m	≥300 m	≥300 m	≥300 m	Gaines (1974)	
habitat	dominant tree species*	tamarisk	Russian olive	mixed (tamarisk or Russian olive with willow or cottonwood)	willow and cottonwood	Laymon and Halterman (1989), Hanberg (2000), Howe (2000)	
habitat	riparian vegetation (width)*	<100 m	100–200 m	200–600 m	>600 m	Gaines (1974), Laymon and Halterman (1989)	
habitat	riparian vegetation (area)*	<15 ha	15–40 ha	41–80 ha	>80 ha	Gaines and Laymon (1984), Laymon and Halterman (1987, 1989)	
habitat	closed-canopy, broad-leafed forest (area)	<3 ha	≥3 ha	≥3 ha	≥3 ha	Laymon and Halterman (1987)	
habitat	canopy height*	<5 m	5–10 m	10–20 m	≥20 m	Gaines (1974) and other sources	
habitat	canopy cover*	<50%	50–70%	70–95%	>95%		Rating are derived and modified from Gaines (1974).
habitat	understory vegetation*	sparse or lacking	dense	dense	dense	Gaines (1974)	
habitat	understory cover*	<60%	60–75%	75–90%	>90%		Ratings are derived and modified from Gaines (1974).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	elevation (Utah only)*	>1,800 m	≤1,800 m	≤1,800 m	≤1,800 m	UNHP data	**See footnote 1.**
lack of habitat degradation	livestock	present	absent	absent	absent	implied by various authors	
lack of disturbance	human activity (fishing, camping, picnic and lunch sites)	present	absent	absent	absent	Hanberg (2000)	

[1]**This table is applicable only to the putative subspecies *Coccyzus americanus occidentalis* and only west of the Rocky Mountains**. Most information is from studies in California, supplemented and modified with limited information from Utah. Elevational data are for Utah only and are not applicable elsewhere (e.g., Pacific coastal states and Arizona).

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Mexican spotted owl (*Strix occidentalis lucida*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density	<0.05/km^2	0.05–0.10/km^2	0.10–0.15/km^2	>0.15/km^2	Ward et al. (1995)	
habitat	physiography[2,*]	—	—	mountain slopes (above 2,300 m elevation)	narrow, steep-walled, deep canyons (below 2,300 m elevation)	Ganey and Balda (1989), Ganey and Dick (1995)	Ganey and Balda (1989) found that this subspecies "occurred either in rocky canyons or in any of several forest types, and were most common where unlogged closed canopy (>80%) forests occurred in steep canyons."
habitat	forest type[2,*]	other (e.g., spruce–fir, piñon–juniper, low-elevation riparian)	ponderosa pine, ponderosa pine–Gambel's oak, Arizona cypress	Madrean pine–oak, evergreen oak (encinal), high-elevation riparian	mixed-conifer (Douglas-fir and/or white fir)	Ganey and Balda (1989), Ganey and Dick (1995)	**N.B.**: This indicator is not generally applicable in Utah or Colorado. (In Utah, where this subspecies is a canyon- rather than a forest-dweller, canyon rim habitats are typically piñon–juniper or ponderosa pine, and canyon bottom habitats are usually mixed-conifer or piñon–juniper. [See Howe et al. 1994, Appendix B.])
habitat (**in forests**)	canopy closure[2]	<55%	55–67.5%	67.5–80%	>80%	Ganey and Balda (1989), Seamans and Gutiérrez (1995), studies reviewed by Ganey and Dick (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest site (**in forests**)	dwarf mistletoe (causing "witch's broom")[2]	absent	—	—	present	Seamans and Gutiérrez (1995)	This owl, like most other owls, does not build a nest but uses naturally occurring features such as "witch's broom" as a nest platform as well as old nests of other large raptors.
nest site (**not in forests**)	cliff ledges, potholes, etc.[2]	absent	—	—	present	various authors	
habitat	elevation	<1,000 m or >3,000 m	—	—	1,000–3,000 m	Ganey and Balda (1989)	Ganey and Balda (1989) found this owl at elevations of 1,125–2,930 m in Arizona, and elevations reported by others in America fall within this range (see review by Ganey and Dick 1995). However, the importance of elevation is uncertain. Also, it would be reasonable to expect that the inhabited elevational range (or at least the upper limit) would shift upwards farther south (e.g., in central or southern México).
habitat	timber harvest[2]	previously logged	—	—	none (current or planned)	Ganey and Balda (1989)	
habitat	forest management[2]	managed forests	—	—	unmanaged virgin forests	Ganey and Balda (1994)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
disturbance (≤0.5 mi from nest site)	recreation (biking, hunting, rock climbing, off-road vehicle use, & large-group [>12] camping) and recreation development (trails, picnic areas, camp-grounds)	present	—	—	none	Howe et al. (1994)	Howe et al. (1994) also recommended protection, from various human activities, of larger areas around nest sites for roosting, foraging, and post-fledging use.
disturbance (≤0.5 mi from nest site)	road use, maintenance, development	existing	—	—	none	Howe et al. (1994)	Howe et al. (1994) recommended seasonal closure (during breeding season) of existing roads.

[1]The spotted owl (*Strix occidentalis*) is very closely related to the very similar barred owl (*Strix varia*), one of the most widespread and abundant owls in eastern North America, with which it freely interbreeds. The 2 are sibling or sister species and together can be considered a superspecies.

[2]The ecology of this subspecies is different from that of the 2 other nominal subspecies of the spotted owl (the northern race, *S. o. caurina*, and the California race, *S. o. occidentalis*). The Mexican race, *S. o. lucida*, itself is ecologically bimodal geographically. In the northern, marginal portions of its range (i.e., Utah and Colorado), where it is comparatively rare, the Mexican race is an inhabitant of rocky canyons, often in areas with few or no large trees, and nests exclusively on rock (e.g., on cliff ledges, in potholes, etc.). In central parts of its range (i.e., Arizona and New Mexico), this race is much more abundant and inhabits well-developed forests with dense canopies and large, old trees, in which it nests. Presumably this is also true in southern parts of its range (i.e., México, ~15 states), but the race has not been well studied in México, and its ecology and population biology are still poorly known there. (This table is intended for use mainly in America and mainly within the breeding season, March–September.) Although the ecological extremes are very different, there is overlap in preferred conditions in some places. For example, within forests, narrow canyons may be preferred sites (Ganey and Balda 1989, Ganey and Dick 1995). Elevation also plays a role; in Arizona Ganey and Balda (1989) found that mountain slopes were inhabited at higher elevations while narrow canyons were utilized at lower elevations. The univariate structure of this table obscures these ecological complexities, but simply stated: **This subspecies requires either canyons or forests—or, optimally, both.** Thus the indicators "physiography" and "forest type" can be used together (especially for the higher ratings and south of Utah and Colorado) or may be used in place of each other (particularly when there is a low rating for 1 of the 2); i.e., a high rating for 1 will compensate for a low rating of the other, even though both have been marked (*) as "most important indicators". Although both the full species and this race are considered to be non-migratory, some individuals of the Mexican race do make short-distance seasonal movements and use non-breeding habitats that would be considered unsuitable or marginally suitable during the breeding season (e.g., piñon–juniper woodland) (Ganey and Balda 1989, Ganey and Dick 1995).

*Most important indicators.

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short-eared owl (*Asio flammeus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
territory	minimum extent of suitable habitat*	<50 ha	50–150 ha	151–250 ha	>250 ha	sources cited by Holt and Leasure (1993) (see Comments)	Reported sizes of breeding territories range from <18 ha to 242 ha, but territory size changes greatly in response to prey abundance (see Holt and Leasure 1993). In a study in Scotland, average territory size increased 7.6X in response to a decline in prey (vole) population. In the 4 studies reviewed by Holt and Leasure (1993) in which ranges of territory sizes were reported, minimum territory sizes were 23, 25, 25, and 48 ha. Maintaining large, continuous tracts of habitat for this species and its prey has been recommended (see Holt and Leasure 1993).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	nesting density	<0.4 nest/ 100 ha	0.4–2 nests/ 100 ha	2–4 nests/ 100 ha	>4 nests/ 100 ha	see Comments	"In Montana, 32 nests (30 active simultaneously) within 164 ha, yielding about 1 nest/5.5 ha . . ." (Holt and Leasure 1993, citing another source) or ~18 nests/100 ha. However, this appears to disagree greatly with reported breeding territory sizes (see above), which suggest a maximum density of only ~5.6 nests/100 ha and a "minimum" of 0.4 nests/100 ha (actual minimum is of course 0/100 ha).
habitat	"open-ness" *	woodlands, forests	—	—	old fields, grain stubble fields, hay meadows, pastures, marshes, prairie, grassy plains, tundra, coastal grasslands, heathlands, shrub-steppe, moors, páramo, puna, some cultivated landscapes, desert grasslands	Clark (1975), Holt and Leasure (1993), König et al. (1999)	
prey	available abundant prey*	invertebrates (insects, crustaceans)	birds	other small mammals	voles, lemmings	Clark (1975), Holt (1993), Holt and Leasure (1993)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal biology	elevation	>4,000 m	—	—	<4,000 m	König et al. (1999)	High elevations are inhabited in the Andes (near the equator) but not in most other regions (i.e., at higher latitudes).
mortality	avian (or fowl) cholera, especially in ducks, gulls, and coots	present (e.g., in coots, gulls, or ducks)	historically recurring regularly in area	historically known but believed not to recur in area or only very rarely	historically unknown in area and believed not to be or to have been present	Rosen and Morse (1959)	Rosen and Morse (1959) found 44 individuals of this species that had died of fowl cholera in an epizootic in California. Except for gulls and ducks (e.g., American wigeon), which were the majority of the mortalities, *A. flammeus* mortalities outnumbered those of all other species including geese. Rosen and Morse (1959) suggested that *A. flammeus* contracted cholera from ingesting mice that had become infected from feeding on birds (e.g., ducks or gulls) that had died of cholera.
mortality, paralysis	use of pesticides[2]	occurring	—	—	none	Mendelssohn and Paz (1997), Sheffield (1997), Fimreite et al. (1970)	See footnote 2.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	human persecution (mainly shooting) (see Comments)	regularly and commonly occurring or culturally encouraged or inadequate laws or enforcement	irregularly and uncommonly occurring or culturally accepted or weak laws or uncertain enforcement	occasionally occurring or culturally tolerated or poorly known laws or irregular enforcement	believed to be none, culturally discouraged, adequate laws and enforcement	Clark (1975) and other sources	Because this species often forages during daylight, flying very low over the ground in open, unobstructed country, repeatedly "quartering" fields in search of rodents, it is particularly vulnerable, making an easy target. The shooting of raptors was formerly common practice in America but has decreased greatly in this country in recent decades. However, in some places (e.g., Latin America) shooting of predatory species such as this and other raptors still commonly occurs.
habitat	loss of habitat (especially urbanization and agricultural development)*	occurring (past, present, future)	—	—	none	Marti and Marks (1989), Holt and Leasure (1993)	Holt and Leasure (1993) considered habitat loss to be a "key factor in declines" in populations of this species, noting "conversion of open habitats to agriculture, grazing, recreation, housing, and resort development" as examples. They also mentioned that "[r]eforestation in some areas may also contribute to habitat loss."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest predation	alteration of habitat favoring predators (e.g., skunks, raccoons, foxes, and domestic and feral cats and dogs)	occurring (past, present, future)	—	—	none	Holt and Leasure (1993) and sources cited therein, White (1994)	Because this owl nests on the ground, it is particularly vulnerable to nest predation, including terrestrial predators. White (1994) commented: "Habitat alterations may . . . increase the risk of predation by mammals (e.g., foxes and raccoons which increase as a result of those alterations). . . . Short-eared Owls (*Asio flammeus*) may be especially vulnerable."
interspecific competition	nest box programs to attract barn owls	existing or planned	—	—	none	Holt and Leasure (1993)	Holt and Leasure (1993) reported that "successful nest box programs to attract Barn Owls have coincided with the decline of Short-eared Owls . . .", and they speculated that interspecific competition was the cause.

[1]This is 1 of the most widely distributed of all non-marine vertebrates in the world, and, of the more than 10,000 living species of birds, perhaps only 3 species of birds surpass it in cosmopolitan distribution. It occurs on nearly all continents (except Australia, Antarctica, and most of Africa) and on a various oceanic islands and archipelagos. Despite its very great—nearly worldwide—distribution, this species is a moderate ecological specialist, requiring low, open habitats and feeding mainly on small mammals with cyclic populations, typically voles. It "follows" prey (usually voles) in both space and time, and changes in prey availability often quickly result in changes in local presence and abundance of short-eared owls. This table is intended for use mainly in interior (inland) areas rather than in coastal or island settings, although, except for kinds of available prey, it probably is also applicable in the latter areas (where its main prey may be birds). Holt and Leasure (1993) reviewed studies that have shown indirect benefits for *A. flammeus* from protecting nesting cover for waterfowl, from reclaimed and replanted strip-mines and dikeland, and from burning and maintenance of grasslands for gallinaceous birds and waterfowl.

[2]In an 8-km^2 area of alfalfa fields in Israel that had been sprayed with the organophosphate Azodin (monocrotophos), a rodenticide, to control voles, mass mortality of raptors resulted from their feeding on contaminated prey; 5 *A. flammeus* were found dead and 4 others paralyzed (Mendelssohn and Paz 1997). In the state of Washington 1 *A. flammeus* was found dead from Fenthion (an organophosphate insecticide and avicide) poisoning, and in Utah another individual was found dead from Carbofuran (a carbamate insecticide) poisoning (Sheffield 1997). In the prairie provinces of Canada, Fimreite et al. (1970) found that, of 7 species of raptors,

A. flammeus, 1 of which was found dead, had the highest levels of mercury residues; in the same areas they also found that seed-eating prey species in fields sown with seed dressed with organic mercury compounds contained significantly higher mercury levels than those in fields sown with untreated seed.

*Most important indicators.

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burrowing owl (*Speotyto cunicularia*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	slope*	>40°	11–40°	1–10°	0°	Rich (1986)	Of 80 occupied nest burrows of *S. cunicularia* found by Rich (1985) in se. Idaho, 79% were on sites of ≤10° slope. "Burrows were not randomly placed with respect to slope (. . . $P < 0.001$), with an excess of sites on flat terrain" relative to available, random sites.
nesting habitat	aspect (if any) (see Comments)	—	N	NE	E, SE, S, SW, W, NW	Rich (1986)	Despite the fact that Rich (1986) found statistically significant difference between aspects at occupied vs. randomly chosen sites, this indicator is relatively unimportant since there typically is little or no slope in the habitat of *S. cunicularia* (see indicator above).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	aridity and openness of habitat (short and/or sparse vegetation)* (see 2 indicators below)	other (e.g., tall-grass prairies, wet grasslands, marshes, dense brushlands, chaparral, woodlands, forests, swamps)	golf courses, cemeteries, road allowances within cities, airports, vacant lots in residential areas, university campuses, fairgrounds, some agricultural lands	—	dry, open, short-grass, treeless plains, steppes, deserts, prairies	Haug et al. (1993) and other sources	Quantitative vegetative characteristics of nest sites have been reported in various studies, e.g., % bare ground, which tends to be high, often >40%, and % grass and other vegetative cover, which tends to be low, often <40% for grass cover (see Green 1983, MacCracken et al. 1985, Green and Anthony 1989).[2] However, such characteristics vary with location and plant community, making quantitative generalizations, other than local ones, impossible. Invasion by trees, shrubs, or tall grass may make habitat unsuitable (veg. too tall & dense) for this species. Use of fire and grazing have been suggested for vegetation management (see Green 1983 and Haug et al. 1993).
visibility of predators	vegetation height around nest (<50 m from nest burrow)	>23.25 cm	15.25–23.25 cm	9.5–15.25 cm	<9.5 cm	Uhmann et al. (2001)	The ratings for this indicator are derived from the HSI model of Uhmann et al. (2001).
visibility of prey, suitability of habitat for prey	vegetation height in foraging habitat (around nest, 50–600 m from nest burrow)	<6.4 cm or >58.4 cm	6.4–12.8 cm or 52.7–58.4 cm	12.8–18.8 cm or 46.3–52.7 cm	18.8–46.3 cm	Uhmann et al. (2001)	The ratings for this indicator are derived from the HSI model of Uhmann et al. (2001).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
intraspecific competition and territorial aggression (leading to nest abandonment or failure)	inter-nest distance (nearest neighbor distance)	<25 m	25–50 m	50–75 m	>75 m	Uhmann et al. (2001)	The ratings for this indicator are derived from the HSI model of Uhmann et al. (2001). Several studies have found reduced nest success when the nearest neighbor nest burrow was <100 m or <110 m.
nest sites; shelter, i.e., avoidance of environmental extremes (temperature, desiccation) throughout the year (Coulombe 1971), refuge from predators	presence of burrows (usually those of mammals) and thus the species that make them (especially prairie dogs, ground squirrels, and badgers)* (see Comments and indicator below)	no burrowing mammals or other burrowing species of appropriate size	few burrowing mammals or other burrowing species of appropriate size	moderate numbers of burrowing mammals or other burrowing species of appropriate size	abundant burrowing mammals or other burrowing species of appropriate size (especially prairie dogs; also ground squirrels, badgers, marmots, skunks, armadillos, large species of kangaroo rats, or burrowing tortoises)	Coulombe (1971), Martin (1973), Rich (1986), Haug et al. (1993) and sources cited therein, Sheffield (1997b), and other sources	In Florida and on Caribbean islands, this species digs its own burrows. Although in w. North America this species can dig its own burrows, it rarely does so (e.g., Thomsen 1971), and thus "[p]resence of a nest burrow seems to be the critical requirement for the Western Burrowing Owl" (Haug et al. 1993, citing others). Minimum cross-sectional dimensions of burrows are ~10 X 13 cm (Martin 1973), but they are typically ~20 cm diameter at the entrance and can be 80 cm diameter (Coulombe 1971) or larger. Artificial tunnels and nest boxes placed underground have been suggested as a management practice (see Green 1983 and Haug et al. 1993).
nest sites, shelter	burrow availability (density of suitable burrows)	0–2.6 burrows/ha	2.6–11.1 burrows/ha	11.1–36.5 burrows/ha	>36.5 burrows/ha	Uhmann et al. (2001)	The ratings for this indicator are derived from the HSI model of Uhmann et al. (2001).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal biology	elevation (Utah and Colorado)*	>9,000 ft (0.1%)	7,500–9,000 ft (2%)	5,500–7,500 ft (15%)	<5,500 ft (83%)	Utah Natural Heritage Program data (2007)	Elevation is clearly an important factor in the ecology of *S. cunicularia*. However, the only mention of elevation that has been found in the literature pertaining to this species is that of Andrews and Righter (1992), who indicated that in Colorado this species occurs at ≤5,500 ft and 7,500–9,000 ft. The highest elevation of 686 known locations in Utah is 9,064 ft, but this is the only Utah location (0.1% of total) that is above 8,525 ft. Only 16 locations (2.3%) are above 7,500 ft. 83% are <5,500 ft (UNHP data 2007).
loss of burrows, loss of foraging habitat, creation of suboptimal nesting habitat, increased vulnerability to predation, and possibly reduced likelihood of finding mates (Haug et al. 1993); also exposure to pesticides	intensive agriculture*	existing or planned	—	—	none	Haug et al. (1993) and sources cited therein, Sheffield (1997b)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
loss of suitable nest sites	eradication or "control" of prairie dogs or other burrowing mammals*	occurring	—	—	none	Haug et al. (1993) and sources cited therein, Sheffield (1997b)	Protection of populations of burrowing mammals, such as badgers, has been suggested as a management strategy (see Green 1983 and Haug et al. 1993). "Protection of existing badger populations would ensure future burrow availability, a consideration which would be especially important in areas where burrow longevity is short (sandy soils)" (Green 1983).
mortality	shooting*	occurring (inadequate enforcement or compliance)	—	—	none (adequate enforcement and compliance)	Haug et al. (1993) and sources cited therein	Haug et al. (1993, citing others) mentioned "3 colonies completely destroyed by shooting" and "shooting caused 66% of the known mortality on . . . study sites in Oklahoma."
mortality form direct and indirect (through prey) poisoning, reduction or elimination of prey base, reproductive failure	pesticide use (insecticides such as the carbamate Carbofuran, rodenticides such as strychnine-coated grain)*	occurring in immediate area (<0.5 mi from nest burrows)	occurring very near nest burrows (0.5–1 mi)	occurring in vicinity (1–1.5 mi)	none in vicinity (>1.5 mi)	Haug et al. (1993), Sheffield (1997a,b) and sources cited therein (Ratings are based on reported distances that the adult and young owls have been seen from nest burrows [see Haug et al. 1993].)	"Agriculture Canada has changed Carbofuran insecticide instructions to prohibit Carbofuran within 250 m of occupied [burrowing owl] nest burrows; although many land owners are aware of Burrowing Owls, this labeling program appears to have been ineffective despite extensive promotion" (Haug et al. 1993, citing another source).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	proximity to roads	<0.5 mi	0.5–1 mi	1–1.5 mi	>1.5 mi	Ratings are based on reported distances from nest burrows that the adult and young owls have been observed (see Haug et al. 1993).	"Vehicle collisions [are] a major source of mortality" (Haug et al. 1993). "[T]he owls habitually sit and hunt on roads at night" (Haug et al. 1993, citing others). In 3 studies, 25%, 37%, and 60% of known deaths were from vehicle collisions (see Haug et al. 1993). Also, proximity to roads greatly increases the likelihood of mortality from shooting.

[1]The breeding distribution of this species extends (though discontinuously in many areas) from w.-c. Canada through w. North America to Tierra del Fuego in South America, and disjunct populations occur in Florida and on Caribbean and other islands. **This table is intended for use mainly in interior continental areas, especially in w. North America.** It is not applicable in Florida and the Caribbean islands and perhaps other islands. In Florida, for example, *S. cunicularia* digs its own burrows, is largely benefited by human alterations of habitat, and favors residential and industrial areas, unlike in w. North America. Although population densities have been reported by many authors, because they vary with location and habitat they are not included in this table. (In California, Coulombe [1971] found: "[Burrowing] [o]wl populations were stable at about 20 owls/mi.[2] in optimal habitat; in other areas the number fluctuated seasonally, with the highest densities occurring during the breeding season.") Soil texture and its affect on burrow stability, burrow modification, and drainage have been discussed by some authors (e.g., Green 1983, McCracken et al. 1985, Green and Anthony 1989), but particular substrates or soil textures do not appear to be limiting, and burrows can be even in rock such as sandstone (e.g., 86 of 104 burrows found by Coulombe 1971) and lava (Rich 1986), some even being in natural rock cavities rather than burrows (Rich 1986).

[2]Green (1983), studying this species in the Columbia Basin of n.-c. Oregon, found it nesting in 3 plant communities (snakeweed, cheat grass, and bitterbrush) but not in 2 others (bunchgrass and rabbitbrush) despite the greater availability (i.e., density) of potentially useable burrows in the 2 unused habitats. He found statistically significant differences between actual nest sites and "potential" (unused) nest sites within 2 of the inhabited plant communities. "For the cheatgrass habitat, . . . [b]urrowing owls selected nest sites with higher perches (85.9 cm vs 31.6 cm) (or essentially nests with perches) and less grass cover (28% vs 50%) [and thus more bare ground] than the 'potential' nest sites. . . . Shrub volume [shrub intercept multiplied by mean height of intercepted shrubs] was the only variable important in discriminating the 2 groups in the bitterbrush habitat, with the burrowing owls selecting for less shrub volume (9.3 vs 13.5) [and thus less shrub cover]. . . . Burrowing owls selected nest sites with greater bare ground (54.8% vs 41.3%) and less vertical density 0–10 cm (1.50 vs 1.64) than what was available in the cheatgrass habitat, and less shrub cover (11.4 vs 19.6[%]) in the bitterbrush habitat. . . . Burrowing owls were selecting nest sites in response to differences in horizontal visibility. The fact that Columbia Basin burrowing owls commonly used some habitats for nesting (snakeweed, cheatgrass, and bitterbrush) and avoided others (rabbitbrush and bunchgrass) may be a result of horizontal visibility of [*sic*] differences. For instance, the snakeweed habitat, with its low vegetation (3–4 cm effective height) and constant grazing pressure, would display characteristics very similar to sciurid colonies in which burrowing owls are commonly known to nest elsewhere. The snakeweed habitat displays the components of 'openness and short vegetation' deemed essential to good burrowing owl habitat . . . and therefore provide horizontal visibility. A factor common to all nest sites in both the bitterbrush and cheatgrass habitats was the use of an elevated

perch by nesting pairs. . . . However, owls in the snakeweed community did not utilize perches. . . . The bitterbrush habitat provided a large number of suitable perches; however, high shrub coverage obstructed vision. . . . [B]urrowing owls selected for less than average shrub volumes which may indicate a trade-off between a maximum number of perches and a minimum number of view obstructing shrubs. The dominant plants of the bunchgrass and rabbitbrush habitats appeared to be structurally unsuitable for owl perches. . . . Because the average height of these habitats are [*sic*] great enough to restrict horizontal visibility from the ground level, lack of suitable perches probably precludes the owls' use of these habitats. . . . Burrowing owls readily use artificial structures for perching (fenceposts, stakes, etc.) making the creation of artificial perches a viable management option, especially in cheatgrass habitats where the average height of the surrounding vegetation is greater than 5 cm. Several perches interspersed throughout the nesting area may be required." (Artificial perches, however, should not be very tall. Thomsen (1971) found that stakes ~18 inches tall used to mark burrowing owl nest burrows were used as perches by the owls. High perches are used as hunting perches by larger raptors, many of which known, or are believed, to prey on burrowing owls [see Haug et al. 1993] and produce avoid responses by burrowing owls [Thomsen 1971].) See also MacCracken et al. (1985) and Rich (1986) for vegetative characteristics of burrowing owl habitat.

*Most important indicators.

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black swift (*Cypseloides niger*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of adults (or pairs or nests) in local nesting population	<2 (<1 pair or nest)	2–3 (1 pair or nest)	4–5 (2 pairs or nests)	≥6 (≥3 pairs or nests)	Foerster and Collins (1990)	Foerster and Collins (1990) found 2–14 adults (presumably 1–7 pairs) at 6 inhabited sites in California. Knorr (1961) estimated ≥15 pairs in some nesting colonies in Colorado. He found "27 active breeding colonies consisting of approximately 80 nests", which implies an average of ~2.96 nests (and thus pairs) per colony.
nesting habitat, nest sites	physiographic features	other	—	—	moist, narrow canyons with streams and (usually) waterfalls	Knorr (1961), Foerster and Collins (1990), Marín and Sánchez (1998)	Although inland nest sites are almost invariably associated with waterfalls or cascades, a few exceptions are known (see Michael 1927, Marín and Sánchez 1998).
disturbance, abandonment of nests or nest sites, mortality	recreation, other human disturbance (mid-April to early Sept.)	regularly occurring	irregularly occurring	occurring very seldom	none	Lowther and Collins (2002)	Though waterfalls provide security for the nesting of this species, they also are very attractive to people. Lowther and Collins (2002) commented: "Inland waterfall nesting sites often popular destination of hikers; 1 egg [i.e., entire clutch, since this species lays only 1 egg] destroyed by rock thrown into nest . . . ."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat, nest sites	permanent water* (typically waterfalls)	absent	—	—	present	Knorr (1961), Foerster and Collins (1990)	In Knorr's (1961) work in Colorado, water was present at every nest site, without exception, and varied from a trickle to a torrent, usually the latter. No nests were found on any truly intermittent streams, and even during the driest years water continued to flow at all nesting sites. The distance of nests from water varied from 8 in. to 35 ft. Spray from the more heavily flowing streams permitted more distant nest placement: "The moss of which nests are constructed continues to grow in most cases, emphasizing the role of the spray and damp surroundings" (Knorr 1961).
nesting habitat, nest sites	high relief* (typically waterfalls)	absent	—	—	present	Knorr (1961), Foerster and Collins (1990)	The nest site must "have a commanding position above the surrounding terrain so that birds flying out from the nests on a horizontal course find themselves automatically at feeding altitude above the adjacent valley" (Knorr 1961). Potential nest sites that are located near the valley floor are not utilized (Knorr 1961). However, exceptions to this requirement are known (e.g., Marín and Sánchez 1998).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat, nest sites, avoidance of nest predation	inaccessibility* (typically waterfalls)	accessible to terrestrial animals	—	—	completely inaccessible to terrestrial animals	Knorr (1961), Foerster and Collins (1990)	"No nest was ever found which was accessible to anything without wings" (Knorr 1961).
nesting habitat, nest sites	darkness*	site illuminated during most or all of day	—	mostly shaded, some direct sunlight during part of the day	site always shaded: no direct light at any time of day	Knorr (1961), Hunter and Baldwin (1962), Foerster and Collins (1990)	Knorr (1961) "never found an occupied nest on which the sun shone" and indicated that the darker the site, the more preferred it was by this species, with more illuminated nest sites being marginal in a nesting colony. "The young bird invariably faces away from the light while in the nest except when anticipating the return of an adult" (Knorr 1961). Hunter and Baldwin (1962), however, reported that 4 of 5 active nests of this species in Montana did receive direct sunlight during late afternoon, 1 of them for 1½ h a day .

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat, nest sites	unobstructed flyways*	tree branches or other obstructions present in front of nest site	—	—	"air immediately in front of a nest site . . . free of obstructions"	Knorr (1961), Foerster and Collins (1990)	"[T]he air immediately in front of a nesting site must be free of obstructions." The birds are undaunted by waterfalls, which they fly through, and by narrow, tortuous gorges, but "no [black] swift colony has been found in which it was necessary for the birds to dodge trees on their way to the nests" (Knorr 1961). Foerster and Collins (1990), while accepting and corroborating all 5 of Knorr's (1961) requirements including this 1, noted: "An unobstructed flyway, other than in the immediate vicinity of the nest, appears to be the least important requirement [of the 5]." However, they ignored the fact that Knorr had specified "immediately in front of a nest site".
nesting habitat, nest sites, "protection from weather in the form of precipitation"	cover from above (e.g., overhangs or ledges, caves or cave-like situations)	absent	—	—	present	Knorr (1961)	"The impossibility of seeing the nests from above . . . is another physical factor present in all cases but it is not to be ranked with the others" (Knorr 1961).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nesting habitat, nest sites	roaring water (typically waterfalls) (see Comments)	absent	—	—	present	Knorr (1961)	"An additional factor may be sound, since I have never seen, read about, or heard about a Black Swift nest which was not within the range of the sound of water in motion, usually violent motion" (Knorr 1961). **N.B.**: The importance of this indicator is uncertain.
nesting habitat, nest sites	hydrophilic plants	none	—	—	*Mimulus* (monkey-flower), ferns, mosses	Knorr (1961)	
nesting habitat, nest sites	ledges or shelves	absent	—	—	present	Foerster and Collins (1990)	Foerster and Collins (1990) found that some sites in California met Knorr's (1961) 5 requirements but apparently were not used as nest sites. They commented: "Some clearly lacked a suitable ledge or shelf to support a nest, and this most likely contributed to the absence of nesting at these sites."
loss or degradation of nesting habitat	dewatering of streams above waterfalls (e.g., diversions, impoundments)	occurring or planned	—	—	none		

[1]The breeding range of this species is in w. North America from se. Alaska and n. British Columbia to Costa Rica and on several of the islands of the West Indies. Throughout this extensive range only ~80 nesting locations are known, much of the area within its overall range being uninhabited by the species. The species is highly philopatric, nesting at traditional sites year after year. It is an extreme ecological specialist, but its nesting ecology differs in coastal and inland locations. In coastal areas it nests in sea caves and along ocean cliffs; in inland areas it nests on walls of moist canyons, typically behind or near waterfalls. The clutch consists of a single egg and the incubation and nestling periods are very long. Adults forage on flying insects, often at very high altitudes, and are known to travel very long distances from nests while foraging. **This table is intended for use primarily in interior or inland areas** and pertains only to nesting ecology; it is not

applicable in coastal areas or outside this species' breeding range. Some of the "indicators" used in this table are correlated (e.g., permanent water, roaring water, and hydrophilic plants; cover from above and darkness).

*Most important indicators—the 5 physical requirements that Knorr (1961) found characterized nesting sites in Colorado and corroborated by Foerster and Collins (1990) in California. **N.B.**: Typically all 5 of these requirements must be met, exceptions being almost unknown. Knorr (1961) pointed out: "[S]eemingly suitable locations in which no [black] swifts were present were found to be lacking in one or more of these five requirements." "The unique combination of ecological factors characterizing Black Swift nesting sites does not occur in many places, presumably explaining the wide scattering of colonies" (Knorr 1993).

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Lewis' woodpecker (*Melanerpes lewis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	no. of pairs per 100 ha	0	1–5	6–10	≥11	Thomas et al. (1979)[2]	Thomas et al. (1979, Appendix 21) reported maximum density of 16.6 pairs/100 ha (6.7 pairs/100 acres).[2] "Ratings" are estimates based on this maximum.
habitat	plant association*	other	(1) piñon–juniper woodland, (2) agricultural lands (with trees in fence rows, along roads, or around buildings)	(1) oak woodland, (2) nut and fruit orchards, (3) pine–fir forest	(1) ponderosa pine forest, (2) cottonwood or aspen riparian woodland, (3) logged or burned pine forest	Bock (1970, Table 1), Tobalske (1997), Newlon (2005), Saab and Vierling (2003), Sousa (1983)	The geographic distribution of this species approximately matches that of ponderosa pine, its preferred forest type (Tobalske 1997 and sources cited therein, Saab and Vierling 2003).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	% tree canopy cover (% of ground shaded by vertical projection of canopies of woody vegetation >5 m [16.5 ft] in height)*,[3] (**N.B.**: see Comments and footnote 3)	>63%	52–63%	41–52%	<41%	Sousa (1983)	This species prefers open-canopy forests. Because forests that have experienced burns often have widely spaced trees and fairly dense understory (shrubs), which are ideal conditions for *M. lewis*, it has been called a "burn specialist" by some authors. Although Sousa's (1983) model assumed that ≤30% tree canopy closure provides maximum suitability for this species, it is not logical that 0% is actually part of the optimal range. Despite use of tree-lined fencerows and roadsides by this species in open country, suitability must decline at some point as canopy cover approaches 0%. Also, Newlon (2005) found that there were *more* trees in the vicinity of nests.[3]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
foraging habitat ("for numerous insect prey for ground or brush foraging" [Sousa 1983])	% shrub crown cover (% of ground shaded by vertical projection of canopies of woody vegetation <5 m [16.5 ft] in height) (**N.B.**: shrub or understory cover has been considered by some to be important, but ratings are uncertain —see Comments and footnote 3)	<13%	13–25%	25–37%	>37%	Sousa (1983)	In Sousa's (1983) HSI model, reviewed by an authority on the ecology of this species, "Optimal understory conditions are assumed to exist if shrub crown cover exceeds 50%." (His top quartile, >37%, is here rated "very good".) However, Tobalske (1997) pointed out: "Appropriateness of [Sousa's] model has not been tested. It was noted in burned habitat in Wyoming . . . and California . . . that percentage of shrub canopy in breeding areas was 13–16% rather than the ≥50% recommended in the HSI." (Also see footnote 3.)
food	% crown cover of hard-mast-producing shrubs (% of ground shaded by vertical projection of canopies of woody vegetation <5 m [16.5 ft] in height that produce hard mast such as acorns)	<25%	25–50%	50–75%	>75%	Sousa (1983)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food	% of total tree canopy cover (see 3 rows above) that is hard-mast-producing trees (e.g., acorns, walnuts, almonds, pecans)	<25%	25–50%	50–75%	>75%	Sousa (1983)	
winter food	corn cropland management practice (see Comments)	corn harvested and stubble plowed under in fall	corn harvested in fall, stubble plowed under in spring	—	corn left standing throughout winter	Sousa (1983)	**N.B.**: This indicator applies only in agricultural areas where corn is grown (e.g., se. Colorado). Corn is the only cultivated grain crop that is utilized (Tobalske 1997).
potential mast storage sites	distance to nearest trees, wooden utility poles	>0.88 mi	0.75–0.88 mi	0.63–0.75 mi	<0.63 mi	Sousa (1983)	Trees with rugose or rough bark or utility poles with desiccation cracks are used by this species for storage of mast (acorns, fruit, corn, etc.), for winter use (and for storage of insects at other times). Mast storage trees are significantly taller and of greater girth than other available trees (Vierling 1997).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites	no. of snags ≥30.5 cm (12 in.) dbh and ≥9.1 m (30 ft) tall per 0.4 ha (1 acre)*	<0.25/acre	0.25–0.50/acre	0.50–0.75/acre	>0.75/acre	Sousa (1983)	Thomas et al. (1979, Appendix 22) recommended 249 snags (≥30.5 cm in dbh, ≥9.1 m in height) per 100 ha (or 101 snags per 100 acres), in riparian cottonwood–alder, ponderosa pine, and mixed conifer communities to support maximum densities of this species. Minimum dbh of nest trees (snags) used by this species was actually 38.1 cm (15 in.), but they assumed 30.5 cm (12 in.) to be adequate. "Soft" (i.e., decayed) snags are preferred.
habitat	elevation (varies with latitude—see Comments)	>11,000 ft	9,000–11,000 ft	7,000–9,000 ft	<7,000 ft	various sources including Bock (1970)	Tobalske (1997, citing others) wrote that this species "[m]ay prefer ponderosa pine forests at medium to high elevations (up to 2,800 m [9,186 ft] in Arizona, 900 m [2,953 ft] in British Columbia), and open riparian forests at low elevations . . . ." Andrews and Righter (1992) indicated that in Colorado it occurs primarily below 7,000 ft, secondarily from 7,000 to 8,000 ft, sparingly from 8,000 to 10,000 ft, and exceptionally at 12,000 ft.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, foraging	forest management*	management eliminates snags, brushy understory, and slash or prevents or suppresses crown fires or wildfires (instead prescribing controlled understory fires)	—	—	management leaves snags, brushy understory, and slash and allows crown fires or wildfires	Sousa (1983), Saab and Vierling (2003)	
mortality	use of pesticides (e.g., insecticides and herbicides) (see Comments)	occurring in vicinity	—	—	none	Sorensen (1983), Tobalske (1997)	This indicator is speculative, and its importance is uncertain.
possible competition for food, possible competition for (and possible usurpation of) nest-holes	European starlings (see Comments)	abundant	common	scarce	absent	Sorensen (1983)	Although European starlings are known to have strongly adverse effects on some species of woodpeckers through usurpation of nest cavities, this has not been demonstrated for *M. lewis*, and this indicator should be considered hypothetical.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
disturbance, loss of habitat	mechanical disturbance (e.g., coal mining and other forms of development)	occurring within 100 m of breeding areas	—	—	none	Tobalske (1997) and source cited therein	"During exploration, mine development, and mining phase, buffer zones of at least 100 m should separate active mines from breeding grounds" (Tobalske 1997, based on a cited source).
loss of habitat	urban expansion	occurring in vicinity	—	—	none	Sorensen (1983), Tobalske (1997)	
degradation of riparian cottonwood habitat (little or no recruitment of cottonwoods)	flood control, water diversions, livestock grazing, tamarisk invasion	occurring	—	—	none	Tobalske (1997) and sources cited therein	Newlon (2005) found almost 4 times as many nests in areas grazed by cattle than in those grazed by sheep. Although she could not explain this difference, she speculated that arthropod prey abundance may have been affected differently by the 2 grazers.

[1]During warm months this species feeds on insects, which it often "flycatches" or "hawks" from the air (unlike most other woodpeckers, which typically excavate insects from wood). In winter it consumes mast (e.g., acorns, nuts, corn), which it stores in cracks in trees and utility poles. Its breeding populations often are localized within broad expanses of suitable habitat, and its occurrence can be unpredictable since it is highly opportunistic, responding to local fluctuations in insect populations. Its breeding populations can be extremely concentrated and dense where and when insects such as grasshoppers, crickets, or tent caterpillars are exceptionally abundant ("plagues"), but, when its insect prey are scarce, it may be absent from (or in very low density in) the same places. This table is intended for use mainly within the breeding range of this species.

[2]Tobalske (1997) misstated (e.g., pp 20, 23) many of the data in Thomas et al. (1979, table 16 and appendices 21, 22). Densities of pairs of Lewis' woodpeckers *per hectare* and of snags *per hectare* attributed by Tobalske (1997) to Thomas et al. (1979) are 100 times what Thomas et al. (1979) actually reported, which were densities of pairs and of snags *per 100 ha*. In addition to his hundredfold increase of the densities reported by Thomas et al. (1979), Tobalske (1997) did not reproduce some of the actual numbers correctly; e.g., on p. 20 Tobalske stated maximum density found by Thomas et al. (1979) to be "16.1 nesting pairs/ha" though Thomas et al. (1979, appendix 21) had reported *16.6* pairs per *100* ha (and did not specify nesting).

[3]In aspen riparian woodland in south-central Idaho, Newlon (2005) found fewer woody stems of plants 0.5–1.37 m in height and less bare ground in a 5-m radius around trees used as nest sites than at random sites. She also found more trees, both live and dead, >1.37 m in height and ≥20 cm in diameter in an 11.3-m radius around nest trees than at random sites. Although direct comparison of Newlon's (2005) results with Sousa's (1983) HSI model is not possible since the vegetational categories are defined and measured quite differently by these authors, they appear to disagree strongly.

*Most important indicators.

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American three-toed woodpecker (*Picoides dorsalis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
extent of suitable habitat to support a population	tracts of old-growth forest	<200 km^2	200–600 km^2	600–1,000 km^2	>1,000 km^2	see Comments	Although Goggans et al. (1989) recommended 528 acres of mature or overmature forest for each *P. dorsalis* pair, suitable tracts must be very much larger than this to support a population. The "poor" and "very good" ratings are based on studies of the Eurasian species *P. tridactylus*, with which *P. dorsalis* was formerly considered to be conspecific and which it closely resembles ecologically, and the "fair" and "good" ratings are interpolations. (See Comments for indicator "forest fragmentation" below, near bottom of table.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat (foraging, nesting)	plant association[3,4,*]	other	non-spruce single-species conifer forest, mixed conifer forest lacking spruce or lodgepole pine, aspen forest, mixed hardwood forest	mixed conifer forest containing spruce (e.g., spruce–fir forest) or lodgepole pine (or in some places Douglas-fir[4])	spruce (*Picea* spp.) forest	various sources including Goggans et al. (1989), Leonard (2001) and sources cited therein	In some places (e.g., ne. Oregon, Bull et al. 1986) lodgepole pine, in mixed coniferous forests, provides preferred habitat[3] (perhaps in the absence of suitable stands of spruce), but in other places lodgepole pine appears to be only of secondary or marginal importance. In Colorado, for example, "[s]pruce/fir habitats claim, by far, the largest share of observations, with only a handful of records from ponderosa, lodgepole, and aspen habitats" (Versaw 1998).[4]
habitat	stand age*	young	mixed age	mature	old growth and overmature	various sources including Goggans et al. (1989), Leonard (2001) and sources cited therein	
nesting, roosting, and foraging sites	snags and decadent trees, especially those with heart rot[3,*]	absent or rare	uncommon	common	abundant	various sources including Goggans et al. (1989), Leonard (2001) and sources cited therein	This species nests in, roosts in, and forages on the trunks of snags and decadent trees. In c. Oregon 14 of 20 nest trees were verified to have heart rot, and the remainder were believed also to have heart rot; 15 of the 20 nest trees were dead (Goggans et al. 1989). "In Idaho and Montana, 59 of 61 nests were in snags and 84% were in unlogged study plots" (Leonard 2001, citing another source).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
nest sites	dbh of snags and decadent trees with heart rot	<18 cm	18–22 cm	23–26 cm	>26 cm	data reported by Goggans et al. (1989), Leonard (2001) and sources cited therein	See Comments below.
nest sites	height of snags and decadent trees with heart rot	<13 m	13–17 m	18–21 m	>21 m	data reported by Goggans et al. (1989), Leonard (2001) and sources cited therein	The data used for this indicator are from Oregon (*n* = 20, Goggans et al. 1989) and British Columbia (*n* = 13, Leonard 2001, citing another source) in studies that involved careful searches for nests. Although nests of this species have often been reported in trees (and stubs) much shorter than those indicated in the ratings, such nests have mostly been found fortuitously and involve very small numbers (sample sizes) and thus probably are not typical.
habitat	natural forest disturbance*	—	undisturbed	—	disturbed (e.g., by disease, fire, flooding, insects, wind)	Leonard (2001) and sources cited therein	Summer population densities of this species are known to increase by 2 to ~5 times after forest fires, and winter densities increase as much as 20 times after forest fires (see Leonard 2001). After fires, food resources and foraging habitat remain suitable for up to 3 years (Bull et al. 1986) or 5 years (Versaw 1998).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey	larvae of bark beetles (Scolytidae), 1st instar larvae of long-horned beetles (Cerambycidae)[5,*]	rare or absent	uncommon	common	abundant	Murphy and Lehnhausen (1998), Leonard (2001) and sources cited therein	Scolytid and cerambycid (as well as buprestid and pythid) beetle larvae are the primary foods, though some other foods are consumed in lesser amounts (e.g., other beetles, ants, other insects, spiders, and some plant matter including cambium and sap).
habitat	elevation (Utah and Colorado)[2,6,*]	<8,000 ft (0/41 = 0%)	8,000–8,999 ft (7/41 = 17%)	9,000–9,999 ft (6/41 = 15%)	≥10,000 ft (28/41 = 68%)	Rich (1967)—numbers in parentheses are the numbers of Utah specimens examined by Rich from within each elevational range. In Utah this species occurs "above 8,000 feet, but seemingly more common above 9,000 and 10,000 feet" (Rich 1967).	Utah Natural Heritage Program elevational data (2007) for this species range 7,005–12,848 ft, with 72% of the locations being >9,000 ft, in close agreement with the findings of Rich (1967). In Colorado this species occurs at 8,000–11,500 ft according to Andrews and Righter (1992) or at ~7,000–12,000 ft, but mostly above 9,000 ft, according to Versaw (1998).
habitat	timber harvest*	cutting rotation ν100 years	cutting rotation <100 years	cutting rotation >100 years	none	Leonard (2001) and sources cited therein	"In black spruce-dominated forests of Québec, habitat loss due to timber harvesting may often be permanent as Three-toed Woodpeckers are restricted to forests older than scheduled cutting rotations . . ." (Leonard 2001, citing another source).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	forest fragmentation	already existing, taking place, or likely to occur	—	—	none	Leonard (2001) and sources cited therein	"In Finland, Three-toed Woodpecker [i.e., *P. tridactylus*, with which *P. dorsalis* was until recently considered to be conspecific and to which it is ecologically very similar] density was significantly correlated with the proportion of forest in nature preserves >100 yr old; in large old-growth tracts (about 1,000 km^2) the species had not declined, but in smaller old-growth forests (1–140 km^2), isolated as a result of logging, the species had declined or disappeared . . ." (Leonard 2001, citing other sources).
habitat, food resources	forest management (especially spruce species and lodgepole pine)*	fire suppression, alteration of natural fire intensity, salvage logging (cutting of beetle-infested or dead trees), suppression logging (cutting of susceptible trees), pest control (bark beetle control)	—	—	none	Leonard (2001) and sources cited therein	". . .[A]lteration of natural fire intensity (i.e., from intense stand replacement to 'cool' understory fires) has likely resulted in population declines in this species . . ." (Leonard 2001, citing another source). Goggans et al. (1989) recommended exempting forest areas from commercial and salvage timber harvest and managing those areas to retain mature and overmature condition.

[1]This species was formerly included within a holarctic concept of *Picoides tridactylus*, which, as currently restricted, occurs only in Eurasia. Because this species-level split has occurred only recently, much existing information pertaining to *P. dorsalis* has used the name *P. tridactylus*. *P. dorsalis* occurs in most of Alaska, most of Canada (east to the Atlantic Ocean), and in the Rocky Mountains region south to Arizona and New Mexico.

[2]In western parts of its range, this species occurs in interior areas at moderate to high elevations, but in eastern areas (Canada and New England) it occurs at lower elevations (see footnote 6) and closer to the ocean coast (and possibly is less strongly associated with coniferous forests). It is an ecological specialist that typically prefers bark-beetle-infested, burned, old-growth spruce forests providing trees with heart rot (for nests) and dying and decaying trees (for prey base). *P. dorsalis* is irruptive, responding spatially and numerically to local outbreaks or infestations of bark beetles, often after forest fires. Although population densities have been reported by many authors, such information has not been incorporated in this table because of the irregularity and extreme variability in its populations. Except for the indicator "elevation", which is specific to Utah and Colorado, this table is intended to have rangewide applicability (see also footnote 6).

[3]Most authors have reported a preference for spruce forests (*Picea* spp.). Murphy and Lehnhausen (1998), following a stand-replacement fire in Alaska, found that 93.2% of all *P. dorsalis* foraging (and 100% of females) was on white spruce that typically were slightly burned (base only or <½ of height of trunk) and averaged 27.3 m tall and 130.4 cm in circumference; however, they observed few females and believed that females were foraging mainly in unburned forests nearby. Bull et al. (1986) in ne. Oregon found this species mostly in (mixed) grand fir forest where it foraged exclusively on lodgepole pines that averaged 24 cm dbh and 18 m tall, usually those that had been dead for <3 years, and on flat terrain.

[4]Winkler et al. (1995) stated: "In N America, there is . . . a clear general preference for spruce, but in NW USA, for instance, forests containing fir (*Abies*) or lodgepole pine (*Pinus contorta*) are inhabited as well. Does not occur in stands of Douglas fir (*Pseudotsuga menziesii*) or ponderosa pine (*Pinus ponderosa*)." Although this is generally true, there are exceptions, particularly with regard to Douglas-fir.

[5]"Three-toed Woodpeckers play a significant role in the regulation of timber-damaging beetles. . . . [I]ndividuals are estimated to consume several thousand larvae/day . . ." (Leonard 2001).

[6]Winkler et al. (1995) indicated that *P. dorsalis* occurs "in W USA above 1300m to 2750m [4,265–9,022 ft], and at 360–1250m [1,181–4,101 ft] in the east." In both Utah and Colorado this species occurs mainly above these elevational ranges (Rich 1967, Andrews and Righter 1992, Versaw 1998, Utah Natural Heritage Program data 2007). In c. Oregon, Goggans et al. (1989) found 20 nests of this species at elevations ranging 4,500–5,600 ft, which they considered to be its minimum elevational tolerance in c. Oregon in summer.

*Most important indicators.

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southwestern willow flycatcher (*Empidonax traillii extimus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population (resistance to demographic and environmental stochasticity)	no. of territories/ site[2]	<10	10–15	15–24	≥25	Finch et al. (2002), Marshall (2000)	Ranges in the "fair" and "good" ratings are interpolated from the 10–25 range advocated by Finch et al. (2002) based on a population stability model (but may be impractical[2]).
connectivity of sites	distance between occupied (or suitable) sites	>30 km	15–30 km	2–15 km	<2 km	Finch et al. (2002), Sogge (2000)	Ratings based in part on a model assuming metapopulation stability (Finch et al. 2002) and in part on known dispersal distances (Sogge 2000).
habitat	proximity of surface water (or saturated soil)*	>100 m	50–100 m	25–50 m	0–25 m	Sogge and Marshall (2000), Finch et al. (2002)	Distance to water should be measured early in breeding season and during non-drought conditions. Cited authors did not provide distances or ratings used here. Water is usually lentic or, if lotic, is slow-moving, low-gradient.
habitat	density of riparian vegetation*	sparse	dense	dense	dense	Sogge and Marshall (2000), Finch et al. (2002)	Density of vegetation in the first 3–4 m above ground and in interior of habitat patch is most important (Sogge and Marshall 2000).
habitat	patch size	<0.1 ha	0.1–8.5 ha	8.5–72 ha	>72 ha	Sogge and Marshall (2000), Finch et al. 2002	"Aggregations of occupied patches within a breeding site may create a riparian mosaic as large as 200 ha (494 ac) or more . . . " (Finch et al. (2002). Rating ranges interpolated from Finch et al. (2002).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	patch width	<10 m	≥10 m	>10 m	»10 m	Sogge and Marshall (2000), Finch et al. (2002)	
habitat destruction and long-term alteration of plant community	fire suppression	planned burns; flood control; fire-prone plant species are dominant	fire-prone plant species are dominant but no intentional burning and no flood control	fire-prone plant species are present but not dominant; no intentional burning and no flood control	no intentional burning; natural flood regime (removing fuel load [drift and other dead wood]); absence of salt-cedar and other fire-prone and fire-favored exotics	Marshall and Stoleson (2000), Marshall (2000), Sogge (2000), Finch et al. (2002)	5 (33%) of 15 impacted sites documented by Marshall (2000, Table 2-5) were lost to fire. Six inhabited sites in Arizona were destroyed by fires in 1 yr (Finch et al. 2000). A fire management plan is recommended (see Finch et al. 2000), but fire breaks or fuel breaks, which can degrade habitat and increase predation, parasitism, and disturbance, should be used only with caution.
habitat loss, degradation, and fragmentation; increased predation and brood parasitism	urban development (buildings, reservoirs, water withdrawal, flood control, recreation, native and exotic predators, roads and bridges)	present or planned in immediate vicinity	present or planned nearby but with few local effects	minimal or distant	absent	Marshall and Stoleson (2000), Finch et al. (2002)	Habitat degradation and fragmentation is believed additionally to increase nest predation (Marshall and Stoleson 2000). 2 (13%) of 15 impacted sites documented by Marshall (2000, Table 2-5) were lost to bridge construction.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation, fire, disturbance of nests, attraction of predators (birds and mammals)	recreation (camp-grounds, picnicking, OHV use, boating, fishing, etc.)	present in high intensity	present in moderate intensity	present in low intensity	absent	Marshall and Stoleson (2000), Blakesley and Reese (1988)	Close occupied, potential, & suitable sites to OHV use; use “Area Closed” signs to exclude human access from occupied sites; fence off occupied habitat, do not allow entry during breeding season, & allow only day use during non-breeding season; no campfires at any time; prohibit construction of new trails, roads, campgrounds, & other facilities in or adjacent to occupied, potential, or suitable habitat; if accessible by boats, use closures, speed limits, buoys, signs, etc. to restrict boating use & access; provide adequate trash receptacles & frequent trash pick-up in campgrounds or dispersed campsites near occupied sites (Finch et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
brood parasitism	presence of brown-headed cowbirds (causing nest abandonment and lowered nest success)*	present in large numbers	present in moderate numbers	present in low numbers	absent	Marshall (2000), Marshall and Stoleson (2000), Stoleson et al. (2000), Uyehara et al. (2000), Finch et al. (2002)	3 (20%) of 15 impacted sites documented by Marshall (2000, Table 2-5) were believed to have been affected by high levels of cowbird parasitism. Trapping and other means of removal of cowbirds have been effective in increasing nest success. Reducing cowbird parasitism (e.g., through trapping) may be very important management strategies (Stoleson et al. 2000). Increasing the amount and quality (e.g., density) of riparian habitat and eliminating attractants (e.g., livestock) may be better long-term strategies (Finch et al. 2002).
predation	presence of feral cats and other predators	present in large numbers	present in moderate numbers	present in low numbers	absent	Finch et al. (2000, 2002)	Implement predator control (esp. feral cats); reduce predator intrusion by closing trails; if possible, increase habitat patch size and reduce patch isolation (i.e., increase connectivity), control presence of predator attractants (e.g., trash and food).
habitat degradation or elimination	phreatophyte control (mowing, cutting, root-plowing, herbicides)	present or planned in immediate vicinity	present or planned nearby but with few local effects	minimal or distant	absent	Marshall and Stoleson (2000), Finch et al. (2002)	"Eliminate phreatophyte control at occupied sites and minimize control at suitable and potential sites" (Finch et al. 2000).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation (and destruction of nests), especially at higher elevation sites	presence of wild ungulates (e.g., elk)	present in large numbers	present in moderate numbers and only in winter	present in low numbers and only in winter	absent	Marshall and Stoleson (2000)	Consider exclosure of wild ungulates (Finch et al. 2000).
habitat degradation; attraction of cowbirds; direct destruction of low nests	livestock (grazing)	present in large numbers; or present in late spring and summer	present in moderate numbers; or present in late autumn and winter	present in low numbers and only in late autumn and winter (occasional, short-duration, highly supervised grazing)	absent	Marshall and Stoleson (2000), Finch et al. (2002) and others	Complete exclosure of all livestock is recommended if sw. willow flycatchers are present on a site or if restoration or regeneration of habitat to a stage suitable for sw. willow flycatcher occupancy is desired. Remove trespass livestock from occupied sites by drawing them out using attractants (e.g., hay, mineral blocks) rather than herding, or wait until ≥1 September to drive them out (Finch et al. 2000).
hydrologic alterations (deterioration of riparian habitat — water and plant community, esp. cottonwoods and willows)	dams, diversions, ground-water pumping, channelization, bank stabilization, dredging, levees, flood control, etc.	present or planned in immediate vicinity	present or planned nearby but with few local effects	minimal or distant	absent	Marshall and Stoleson (2000), Finch et al. (2002)	4 (27%) of 15 impacted sites documented by Marshall (2000, Table 2-5) were lost to inundation from impoundment or to flood control. See Finch et al. (2000) for recommended management strategies.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hydrologic regime; vegetation	presence of beavers	beavers damaging habitat by (1) removing willows and other vegetation (e.g., where riparian habitat is linear and habitat patches are small) or (2) permanently inundating habitat by damming (e.g., high elevation sites)	few beavers and negative effects minimal	beavers absent or their effects neutral	beavers improving habitat (e.g., dams create backwaters favorable to sw. willow flycatchers)	Finch et al. (2000)	**N.B.**: Site-specific analysis needed in order to make determination. If beavers are beneficial, they should be left in place and monitored to assess future conditions. If detrimental, actively reduce or remove beaver population. Beaver introduction or reintroduction may be used to enhance a site, creating still water conditions that encourage colonization by flycatchers.
habitat loss, attraction of cowbirds	agricultural expansion	present or planned in immediate vicinity	present or planned nearby but with few local effects	minimal or distant	absent	Marshall and Stoleson (2000), Finch et al. (2002)	2 (13%) of 15 impacted sites documented by Marshall (2000, Table 2-5) were lost to clearing, at least 1 of these being for agriculture.
suitable habitat	elevation	>2,600 m	1,900–2,600 m	1,500–1,900 m	0–1,500 m	Sogge and Marshall (2000), Sogge (2000)	This species has been known to breed at >2,600 m in Arizona and southwestern Colorado; however, there is uncertainty whether birds at higher elevations, especially in the northern part of the presumed range, are the race *E. t. extimus*.

[1]Information in this table applies to breeding birds; migrants use a wider range of conditions, in many cases unsuitable for breeding. Sogge (2000) has cautioned that, because the various subspecies of the willow flycatcher migrate at slightly different times and migrants of the other subspecies may be present (i.e., passing through) when resident *E. t. extimus* are already breeding, "it is only during a short period of the breeding season (approximately 15 June through 20 July) that one can assume that a willow flycatcher seen within *E. t. extimus* range is most likely of that subspecies." The work of others suggests that the period of assumed certainty of identification of breeding race may be even 10 days shorter—20 June to 15 July (Unitt 1987). Because characteristics of breeding habitats of this subspecies are highly diverse and very difficult to generalize, it can be instructive to consider "what is not southwestern willow flycatcher habitat" (see Sogge and Marshall [2000, pp 54–55]). Unsuitable habitats include park-like cottonwood–willow gallery forests devoid of understory; isolated, linear riparian patches <10 m wide (though mosaics of such patches are suitable); high-elevation willow patches devoid of live vegetation in the first 0–2 m above ground; salt-cedar stands <4 m high; and sparse stands of salt-cedar (Sogge and Marshall 2000). Finch et al. (2000, 2002) provided detailed management recommendations for occupied, potential, and suitable southwestern willow flycatcher habitats, including suggestions for habitat restoration; some of these recommendations are summarized in the "comments" column, but managers should refer to the original sources for complete recommendations (including water management, mining, etc.).

[2]Greatest known number is 134 territories/site. Since the global estimated number of all territories is only 549, even 1 occupied territory may be of conservational importance, and the ratings used here may require impractically high numbers (e.g., all 7 *estimated* sites in Utah have «10 territories, there being only 12 *estimated* territories in Utah [Marshall 2000] and only 3 *known* territories in Utah as of 2001 [Finch et al. 2002]). Globally 90.8% of occupied sites have ≤10 estimated territories; only 7.3% of occupied sites have >10 estimated territories, only 2.8% >20, and only 0.9% >30 (data from Marshall [2000, Table 2-2]). Although the ratings used here may be impractical, they are conservationally realistic; in one study that documented extirpations at 25 sites (McCarthey et al. [1998]), 21 (84%) were sites with ≤10 territories.

[*]Most important indicators. Although this subspecies (much like the full species) "breeds only in dense riparian vegetation near surface water or saturated soil[,] . . . [o]ther habitat characteristics such as dominant plant species, size and shape of habitat patch, canopy structure, vegetation height, etc., vary widely among sites[,] . . . [and] [t]here has yet to be developed a comprehensive habitat model for the southwestern willow flycatcher that enables one to determine which breeding habitats, or parts of a single breeding patch, are better than others based on vegetation characteristics alone" (Sogge and Marshall 2000). Unable to identify precise habitat characteristics that can be used to generalize or to predict breeding occurrence of this subspecies, Sogge and Marshall (2000) relied primarily on photographic and narrative examples of 12 breeding sites to illustrate the range of habitat variability (see Sogge and Marshall 2000). They arranged these examples in 3 categories: native-vegetation-dominated (low to mid-elevation sites [<1,900 m] and high elevation sites [>1,900 m]), exotic-vegetation-dominated, and mixed native and exotic vegetation. As the names of these categories indicate, vegetation can be native, exotic, or a mixture of native and exotic, and elevation can be low, middle, or high (although correct assignment to the subspecies *extimus* is questionable at high elevations, especially in Utah and Colorado). Sogge and Marshall (2000) found that "there is no clear evidence that the exotic-dominated habitats in which southwestern willow flycatchers now breed are generally suboptimal" and observed that such habitats (e.g., dominated by salt-cedar, *Tamarix ramosissima* [= *T. chinensis*], or Russian olive, *Elaeagnus angustifolia*) are of considerable importance to the subspecies and that the exotic plant species themselves are frequently used by the flycatchers as the nest substrate. "Russian-olive . . . may provide equivalent or better nesting habitat . . . ," and in many places salt-cedar provides very important nesting habitat and nesting substrate for the subspecies. They did note, however: "Southwestern willow flycatchers do not nest in all exotic species that have invaded and sometimes dominate riparian systems. For example, flycatchers do not use arundo [giant reed] (*Arundo donax*) or tree of heaven (*Ailanthus altissima*) [or Siberian elm (*Ulmus pumilis*)]."

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bobolink (*Dolichonyx oryzivorus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (males/ 100 ha [=1 km^2]) see Comments	<20 %% /100 ha	20–55 %% /100 ha	56–90 %% /100 ha	>90 %% /100 ha	Bollinger and Gavin (1992, Table 2)	Bollinger and Gavin (1992, Table 2) compared densities of males in occupied habits in prairies in the Midwest and in hay fields (i.e., grasses, not alfalfa) in New York. Mean densities of males per 100 ha were 26 in tall-grass prairie, 33 in mixed-grass prairie, 91 in all hay fields, and 120 in hay fields ≥8 years old. (However, standard deviations were very large in all cases.) Whether such densities exist even in the best of habitats available in w. North America is uncertain.
habitat	plant association*	fields of alfalfa (or other legumes), other cultivated fields, heavily grazed pastures, brushy fields, woodlands, forests	—	lightly grazed pastures (i.e., habitats such as those rated "very good", but with light grazing)	grassy meadows, hay fields, prairies, grasslands	various sources including Bollinger and Gavin (1992), Martin and Gavin (1995)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	soil moisture (or proximity to surface water)	xeric (dry, far from water)	hydric (wet)	—	mesic (moist and/or near water)	Wittenberger (1978, 1980)	Both draining of marshes to produce grazing lands and irrigation producing moister soil conditions are known to create breeding habitat for this species in some places (e.g., Oregon) (Wittenberger 1978).
habitat	elevation (Colorado and Utah)*	<4,200 ft or >7,000 ft	—	—	4,200–7,000 ft	Andrews and Righter (1992), Utah Natural Heritage Program data (2007)	The highest known elevation of breeding by this species in Utah is 7,060 ft (Utah Natural Heritage Program database, 2007). In Utah (though not elsewhere) there probably also is a lower limit, the lowest breeding elevation in Utah being 4,214 ft.
habitat	total vegetation cover see Comments	<[35]% or >84%	[35–44]% or 75–84%	[45]–54% or 65–74%	55–64%	Bollinger and Gavin (1992, Fig. 2)	Bollinger and Gavin (1992, Fig. 2) in New York found bobolink abundance to be very high where total vegetative cover was <55% but did not report the minimum % cover that was available, which may not have been very low. Although various authors have reported a preference of *D. oryzivorus* for sparse vegetation, the minimum suitable coverage, though seemingly unreported, must be >0%. Below 55%, the intervals shown (in square brackets) are guesses that mirror those above 55%; the lowest of these is close to that for forb cover (see indicator immediately below).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, nest sites	forb cover see Comments	≤35% or ≥65%	36–40%	41–49%	50–64%	Wittenberger (1978, 1980), also Martin (1971, Table 7)	Although the work of Wittenberger (1978, 1980) in Oregon indicated that higher % forb cover is favorable (statistically significant), being lowest in territories of unmated males and highest in territories of males with more than 1 mate, there was great variability across years and great overlap of categories (18–49% in bachelor % territories, 41–56% in monogamous % territories, and 36–64% in polygamous % territories). The importance of this indicator in other parts of the range of *D. oryzivorus* is uncertain, and the "ratings" are uncertain.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	disturbance regime (where applicable) see Comments	none or grazing or mowing in spring or summer before 8 August at earliest (see below) or burning in spring or summer	—	—	grazing or mowing in fall or winter or after 8 August at earliest (see below) or burning in fall or winter	Martin (1971), Wittenberger (1978)	"Bobolinks depend upon new growth of vegetation, so the continued presence of old vegetation in spring may reduce habitat quality" (Wittenberger 1978). "To benefit bobolinks, we recommend that [lands in land retirement programs such as conservation reserve lands] be hayed every 2–3 years; cutting should not begin before the middle of July. Opening these lands to early hay cropping will negate their potential benefits to grassland birds" (Bollinger et al. 1990). There may be places where disturbance is not required or not even beneficial.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality of embryos (eggs), nestlings, and fledglings (from direct destruction of eggs or young and from increased predation and nest abandonment)	time of mowing (of hay)* (where applicable)	≤5 July	6–22 July	23 July– 8 August	≥9 August	various sources including Bollinger et al. (1990), Martin and Gavin (1995), Wittenberger (1978)	" . . . [H]ay fields are now cut 2–3 wk earlier than they were in 1940s and 1950s, with mowing coinciding with peak nesting period. . . . Fields should be mowed annually to maintain breeding habitat, but mowing should be delayed until early Jul to minimize impacts on fledglings. Even later mowing would allow fledging of birds in renesting situations" (Martin and Gavin 1995). During 1 breeding season in w. New York, "mowing mortality . . . would have been only 7–8% if mowing had occurred 2 weeks later, but 32–44% if mowing had occurred 2 weeks earlier" (Bollinger et al. 1990).
habitat	field type (i.e., grass hay, not alfalfa) (where applicable)	young hay field (<8 yr since planting)	fallow field, old field (abandoned)	lightly grazed pasture	old hay field (≥8 yr since planting, and especially >25 yr)	Bollinger and Gavin (1992, Fig. 3)[2]	See footnote 2. Also see "indicator" "age of hay fields" 5 rows below.
habitat	alfalfa or total legume cover (where applicable)	>50%	31– 50%	11–30%	≤10%	Bollinger and Gavin (1992, Fig. 2)[2]	See footnote 2.
habitat	% grass/ % legume (e.g., alfalfa) (where applicable)	≤0.5	0.6–3.0	3.1–5.0	>5	Bollinger and Gavin (1992, Fig. 2)[2]	See footnote 2.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	litter cover	<5%	—	5–25%	26–50%	Bollinger and Gavin (1992, Fig. 2)[2]	See footnote 2. Bollinger and Gavin (1992) did not indicate litter cover of >50%; whether even greater litter cover would be more suitable for this species apparently is unknown.
habitat	conversion of hay to other crops (e.g., alfalfa) (where applicable)	occurring	—	—	none	Bollinger et al. (1990), Bollinger and Gavin (1992), Martin and Gavin (1995)	"Land-use changes . . . are [the] most important [factors] in affecting overall abundance [of this species] on regional and continental scales" (Martin and Gavin 1995).
habitat	age of hay fields (time since last plowing and reseeding) (where applicable) see Comments	<8 years	8–16 years	17–25 years	>25 years	Bollinger et al. (1990), Bollinger and Gavin (1992, Fig. 4), Martin and Gavin (1995)	Bobolink abundance in hay fields increases with increasing age of fields up to at least 25 years (Bollinger et al. 1990, Fig. 1, Bollinger and Gavin 1992, Fig. 4). However, these unnatural fields must continue to be managed (e.g., mowed or grazed) to remain suitable; otherwise, invasion by shrubs and trees reduces suitability. Possibly the reason for positive correlation of bobolink abundance with increasing field age is the greater tendency for grasses to have been planted in the past and an increasing tendency in recent years to plant legumes (e.g., alfalfa) (see Bollinger and Gavin 1992, p 503 and Fig. 8).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	size of hay field (where applicable)	<1 ha	1–10 ha	11–30 ha	>30 ha	Bollinger et al. (1990), Bollinger and Gavin (1992)[2]	" . . . [L]arge fields have higher densities than small fields; fields ≥ 30 ha support more than twice the number of males per 100 m of transect than fields ≤ 10 ha (Bollinger and Gavin 1992)" (Martin and Gavin (1995). Bobolink abundance in hay fields increases with increasing size of field up to at least 30 ha (Bollinger et al. 1990, Bollinger and Gavin 1992).

[1]This species breeds across much of s. Canada and n. America, with a few isolated breeding populations farther south (e.g., se. Arizona). It winters on the pampas of South America. This table is intended for use within the breeding range of the species and primarily in w. North America. Because most of what is known of the ecology of *D. oryzivorus* pertains to its populations in the east, information about the species in e. North America has been incorporated. Although several of the authors and publications cited in this table have used the terms "mowing" and "hay-cropping" interchangeably (i.e., synonymously), it is likely that the latter term, "hay-cropping" (or perhaps the term "haying"), is the more accurate and is what was intended by these authors; repeated mowing without removal of the hay results in heavy build-up of litter that suppresses new growth until the accumulated hay litter has decayed. Though original wording has in most cases been maintained here, "mowing" should be understood as "hay-cropping" or "haying".

[2]The work of Bollinger et al. (1990) and Bollinger and Gavin (1992) was in unnatural habitats (e.g., hay fields and other artificially created fields) in New York. Whether their findings apply elsewhere in the range of *D. oryzivorus* (e.g., in the Midwest and in the West) is uncertain.

*Most important indicators.

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grasshopper sparrow (*Ammodramus savannarum*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (territories [or pairs or nests]/ha) see Comments	<0.10/ha	0.10–0.19/ha	0.20–0.29/ha	≥0.30/ha	Janes (1983), Collier (1994, Table 5), Vickery (1996)	In OR, at the margin of the range of this species and in patchy habitat, Janes (1983) found 2.8 to 20.3 *individuals*/km^2 (= 0.03–0.20/ha). In s. CA, Collier (1994, Table 5) in 2 yrs found 0.1–1.0 *pairs*/ha (mean = 0.5 *pairs*/ha) on 4 inhabited 10-ha study plots. Vickery (1996) reviewed works that reported 0.24–0.25 *territories*/ha in ND, 0.75/ha in WI, and 0.20–0.41/ha in FL. Vickery et al. (1992) found in ME that on plots with medium densities of territories (0.25–0.35/ha) nest success was higher than on plots with lower or higher densities.
habitat	plant association*	other (e.g., woodland, forest)	shrubland, shrubsteppe	exotic grassland	native grassland	Bock and Bock (1992), Vickery (1996), also Collier (1994)	(See Comment below.)
habitat	grass type	—	—	sod-forming grasses	bunch grasses	various sources including Whitmore (1981), Janes (1983)	"Reclamation of disturbed sites should be with bunch grasses if grasshopper sparrows are to be encouraged; shrub or tree plantings should be avoided" (Whitmore 1981).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	grass canopy cover (%)	<15%	15–32%	33–50%	>50%	Bock and Bock (1987, 1992)[2], Bock and Webb (1984), Collier (1994)	Whitmore (1979) considered the optimum grass cover for this species on reclaimed surface mines in WV to be 27.78%.
habitat	shrub canopy cover (%) see Comments (and see Comment for Indicator 2 rows above)	>12%	—	—	0–12%	Bock and Bock (1987, 1992)[2], Bock and Webb (1987), Collier (1994), Vickery (1996)	Bock and Bock (1992)[2] found significant positive correlation between shrub cover and abundance of this species in AZ; the highest summer counts were on the plot with the greatest shrub cover, 11.73%. Inhabited sites in MT had 0–11% shrub cover; random sites had 0–33% shrub cover (Bock and Bock 1987). In OR, Janes (1983) found 0–5% shrub cover and 0–50% shrub-like forb cover. The upper limit of acceptable shrub cover in GA is 35% (Vickery 1996 citing others). Most other studies have found very low % shrub cover in breeding territories. In WV, Whitmore (1981) found mean shrub cover of 0.7% (SD 2.3%) in occupied territories & 31.1% (SD 17.6%) in non-territories.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	bare ground	>31%	—	—	≤31%	Bock and Bock (1987, 1992)[2], Bock and Webb (1984), Whitmore (1979), Collier (1994)	Whitmore (1979) considered the optimum bare ground for this species on reclaimed surface mines in WV to be 24.09% and commented: "It appears that the territories of Grasshopper Sparrows . . . must have at least 24% bare ground." However, this conclusion has not been corroborated in w. North America.
habitat	aspect see Comments	other (E, SE, S, SW)	—	W, N, NE	NW	Janes (1983)	**N.B.**: The importance of this indicator is questionable. It is uncertain whether aspect is important in other areas and whether preferred aspects are the same as those found in n.-c. Oregon by Janes (1983).
habitat	slope see Comments	>25%	—	—	≤25%	Janes (1983)	**N.B.**: The importance of this indicator is questionable. Janes (1983) reported slopes of inhabited sites as 0–23% (mean = 14%). It is uncertain whether slope is important and whether slopes preferred elsewhere are the same as those found in n.-c. Oregon by Janes (1983).
habitat	elevation (Colorado and Utah)* for Utah, see Comments	>6,000 ft	5,501–6,000 ft	5,000–5,500 ft	<5,000 ft	Andrews and Righter (1992), Utah Natural Heritage Program data	Elevations of breeding by this species in Utah range 4,315–5,246 ft or possibly 5,456 ft (Utah Natural Heritage Program database, 2007).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	livestock grazing	occurring	—	—	none	Bock et al. (1984), Bock and Webb (1984), Saab et al. (1995)	Bock and Webb (1984), in se. Arizona, detected this species on ungrazed study plots but not on comparable grazed plots. "In our study area, grasshopper sparrows were the best indicators [of 4 bird species] of ungrazed rangeland with few shrubs or mesquite. . . . Grasshopper sparrows illustrate the point that bird species do not respond to grazing per se, but to its effects on vegetation" (Bock and Webb 1984). However, in some other places (e.g., east of the Rocky Mountains), grazing is known to benefit this species (see Saab et al. 1995), but in such places "[t]iming of grazing should be delayed until nesting is completed" (Whitmore 1981).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	burning (varies with location and with time since burn—see Comments)	occurring, planned, or having occurred in last 2 years	none in last 2 years	none in last 3 years	none in >3 years	Bock and Bock (1987, 1992), also Collier (1994, Fig. 10 and pp 49, 51, 61)	In e. North America this species is benefited by burning, on the c. Great Plains the effect can be neutral, and in some parts of w. North America the effect is negative (see Vickery 1996). Fire degraded habitats for this species in s.-c. MT (Bock and Bock 1987) and in se. AZ (Bock and Bock 1992), but in e. North America (WV) Whitmore (1981) recommended: "Grasslands that have invading shrubs should be burned during late winter." In s. CA, Collier (1994) found that "grasshopper sparrows . . . had higher reproductive success rates in areas that were 2 to 4 years post-burn versus areas that were greater than 10 years post-burn." Poorest was 1 yr post-burn.

[1]This species breeds in much of e. America, east of the Rocky Mountains, extreme s. Canada, and in scattered locations in w. America, México, Central America, nw. South America, and the West Indies. It winters in s. America, México, and parts of Central America and the West Indies. This species selects somewhat different breeding habitats in different parts of its range (e.g., e. vs. w. North America). Burning, mowing, and grazing all benefit this species in e. North America but degrade its habitat in w. North America. Litter cover, litter depth, and forb cover have been considered to be of importance to this species in e. North America, but whether, and to what extent, litter (i.e., duff) and forbs are important to the ecology of this species in w. North America is uncertain. **This table is intended for use in within the breeding range of *A. savannarum* only in w. America and mainly in interior areas**, but development of the table has been hampered by the fact that little has been reported concerning the ecology of this species in w. North America.

[2]The data for se. Arizona presented by Bock and Bock (1992) are multivariate, involving native vs. exotic grassland, burned vs. unburned tracts, 4 ground cover types, and multiple years. Adaptation of such multivariate data for univariate use, such as that of this table, is problematic and involves uncertainty.

*Most important indicators.

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Preble's shrew (*Sorex preblei*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	elevation	<1,000 ft or >9,100 ft	—	—	1,000–9,100 ft	Kirkland and Findley (1996), Nagorsen et al. (2001)	The "very good" rating is based on the known elevational range of *S. preblei*, but the inhabited elevational range may vary with latitude. The highest known elevation, 2,750 m (9,022 ft) (Kirkland and Findley 1996), is the southernmost Recent locality (c. NM); whether this species occurs at such high elevation in the northern parts of its range is questionable. The lowest known elevations, 343 m (1,125 ft) and 452 m (1,483 ft) (Nagorsen et al. 2001) are the 2 northernmost localities (s. BC)[3]; whether this species occurs at such low elevations in the southern parts of its range also is questionable.
habitat	habitat type (see footnote 2)	other	—	forests, wet meadows, riparian areas, marshes, chaparral	sagebrush steppe, other shrublands, grassland	various sources (see footnote 2) including Cornely et al. (1992)	The "ratings" are questionable. Despite assertions of various authors that arid shrublands (especially sagebrush) and grasslands are preferred and that other habitats such as dense forests and various wet habitats are atypical, such claims have not been supported by more than incidental or anecdotal evidence.[2]

[1]*S. preblei* remains 1 of the most poorly known of American mammals. Its known distribution is mostly (but not entirely, e.g., Montana) west of the Great Plains in interior western North America and includes at least parts of all western American states except Arizona, as well as extreme s. British Columbia. Numerous extensions of its known range have been reported in recent years, and it would not be surprising if more range extensions were added in the future.

[2]Some authors have emphasized the association of *S. preblei* with wet sites (Larrison and Johnson 1981), and others (e.g., Tomasi and Hoffmann 1984, Kirkland and Findley 1996, Kirkland et al. 1997, Nagorsen et al. 2001) have claimed that its occurrence in moist habitats is atypical and that it prefers arid situations such as habitats dominated by or containing sagebrush (especially sagebrush steppe), grasslands, and dry, open forests. The arid or semiarid shrub steppe (sagebrush) and shrub–grassland hypothesis has become especially popular, with a succession of authors reiterating this idea. Such assertions likely are overgeneralizations. Although still poorly known, *S. preblei* appears to be an ecological generalist, inhabiting (at least in particular, scattered locations) diverse, dissimilar ecological situations that comprise many or most habitat types that exist within its geographic range—wet or dry, in various plant associations (from low in vegetative profile and sparse to tall and dense), on various soil types—including riparian areas (Bailey 1936, Ports and George 1990), marshes (Bailey 1936, Tomasi and Hoffmann 1984), wet meadows, dry grasslands (Nagorsen et al. 2001, Hendricks and Roedel 2002), shrub steppes (Hoffmann et al. 1969, Kirkland et al. 1997, Nagorsen et al. 2001), oak chaparral (Long and Hoffmann 1992), mountain shrub, mixed forests, and coniferous forests (both dense and open, of various species composition) (Armstrong 1957, Larrison and Johnson 1981, Kirkland and Findley 1996), and in many cases ecotones between some of these habitat types. Some evidence, however, indicates little breadth in its use of habitats at the local scale. Many authors have listed plant species observed in areas where they found *S. preblei*. Some have further provided estimates of vegetative cover; for example, Nagorsen et al. (2001) listed 30–80% shrub cover at sites where 3 *S. preblei* were captured, and Hendricks and Roedel (2002) reported ~40–60% total vegetative cover where 5 specimens of this species were taken. Despite the attempts of some authors to construct narrow ecological circumscriptions for *S. preblei*, none seems justifiable rangewide or even within some regions within its range, and all such attempts have required distorting, ignoring, dismissing, or discounting evidence that does not support the desired generalizations. Cornely et al. (1992) commented: "The geographic distribution of *S. preblei* . . . appears as several disjunct populations, but this likely is as much a result of unequal sampling effort as a lack of continuity of occupiable habitats." Fragmentary knowledge of the species combined with its apparent ecological breadth (regionally and rangewide, if not locally) makes ecological understanding of this species, and thus construction of a table such as this, problematical.

[3]Although Armstrong (1957) indicated that 1 of 9 specimens captured in the Blue Mountains of Washington was at "[e]l. 500′" (152 m), this was clearly a typographical or printer's error, for elsewhere in the same publication Armstrong stated that the elevations sampled were "5000 ft. to 6000 ft.", and the elevations shown for all of the other 8 specimens ranged 5,100–6,000 ft.

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fringed myotis (*Myotis thysanodes*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
thermal biology	elevation*	>9,350 ft	7,000–9,350 ft	<4,000 ft	4,000–7,000 ft	Barbour and Davis (1969), O'Farrell and Studier (1980), Oliver (2000)	The "fair" rating is an interpolation.
habitat	plant association[3] (see Comments and footnote 3)	other	shrub steppe, grassland (uncertain—perhaps "good" [3])	coniferous forest, mixed forest	oak, piñon, and/or juniper woodland, desert scrub	various sources including Barbour and Davis (1969), O'Farrell and Studier (1980), Oliver (2000)	Most habitats utilized by this species are arid, although wet coastal forests are inhabited in Oregon. O'Farrell and Studier (1980) commented: "All desert and steppe areas within the range of *M. thysanodes* were within an hour flight from forested or riparian areas." Average flight speed in this species has been determined (experimentally) as 8.6 mi (13.8 km) per hour. O'Farrell and Studier (1980) stated that "[o]ak and pinyon woodlands appear to be the most commonly used vegetative associations", and Barbour and Davis (1969) considered it to be a resident of "oak, piñon, and juniper . . . and desert scrub". Many habitats are used; "ratings" uncertain.[3]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
reproduction (maternity), hibernation (uncertain)	loss, alteration, or disturbance of roosts (e.g., abandoned mine closures, removal of large snags and decadent trees [forest management], recreation-al cave and mine exploration)*	occurring	—	—	none	various sources	O'Farrell and Studier (1980) noted, with regard to roosts: "This species seems easily disturbed by human presence."
habitat	loss or degradation of habitat (e.g., large-scale piñon–juniper or sagebrush removal, clear-cutting of forests, "managed" forests, intense grazing or inundation of riparian woodlands)*	existing or planned	—	—	none	various sources	

[1]Recent genetic work has shown greater genetic divergence between some populations of *M. thysanodes* than between this species and *M. evotis* in some places, and some individuals morphologically identifiable as 1 of these species are genetically assignable to the other species. Further work is needed to resolve these paradoxes.

[2]This species occurs in western North America west of the Great Plains, from British Columbia to southernmost México, but its occurrence may be patchy or localized within this great area. Although little concerning its ecology in México has been reported, within its range north of México it is found in nearly all habitats that are ≤9,350 ft elevation. It also utilizes a wide variety of roosts including buildings, mines, caves, rock crevices, trees (snags), and bridges. Thus it may be considered an ecological generalist. **This table is intended for use north of México**.

[3]It has been asserted that oak, piñon, and/or juniper woodlands (O'Farrell and Studier 1980, Barbour and Davis 1969) and desert scrub (Barbour and Davis 1969) are the plant associations most commonly used by *M. thysanodes*. However, it is questionable whether this species actually shows strong habitat preferences. In 2 Utah studies, in which many sites were sampled and large numbers of bats were captured, relatively few *M. thysanodes* were found in piñon–juniper habitat, and the majority (64% and 56%) were captured in desert scrub situations (see Oliver 2000). This species also has often been captured in sagebrush and in a variety of coniferous forests in Utah and elsewhere. Hoffmeister (1986), discussing this species in Arizona, stated: "Fringed myotis are found from chaparral to ponderosa pine, but the preferred habitat is probably the oak woodland, from which they forage out into a variety of other habitats." Nagorsen and Brigham (1993, p 93; also Table 1, p 40) wrote of this species: "The British Columbian population is associated with arid grassland and Ponderosa Pine - Douglas-fir forest." Findley et al. (1975), writing of it in New Mexico, noted that it occurs from grassland and desert situations to yellow (= ponderosa) pine forest. Of 84 individuals of this species that Jones (1965) captured in the Mogollon Mountains area of New Mexico and Arizona, 95.3% were in montane coniferous forest (above 7,000 ft elevation), 4.7% were in piñon–juniper–oak woodland (mostly between 5,000 and 7,000 ft elevation), and none were in desert scrub–grassland (below 6,000 ft elevation). Thus, the assertions of some authors concerning its main or preferred habitats as well as the "ratings" of plant associations in this table are questionable, and this species should be considered a habitat generalist, though patchy in its occurrence.

*Most important indicators.

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western red bat (*Lasiurus blossevillii*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	setting*	other	—	towns and cities	riparian situations	Oliver (2000)	
habitat (roosting and foraging)	plant association*	other	coniferous forest (e.g., pine-fir)	oak woodland, cultivated orchards (fruit and nut trees)	riparian deciduous woodland (e.g., sycamore, cottonwood, walnut)	various sources including Findley et al. (1975), Hoffmeister (1986), Nagorsen and Brigham (1993)	Suitable riparian situations include desert riparian areas.
roosts	habitat features*	other	mines and caves	shrubs, vines	trees	various sources	Preferred roosts are likely higher (e.g., trees), in plants with large leaves (e.g., sycamores, figs, grapes, sunflowers), and within dense foliage. Although this is a foliage-roosting species, caves and mines are occasionally used (see Oliver 2000).
habitat, thermal ecology	elevation (in America)	≥7,000 ft (uncertain)	—	—	<7,000 ft	Oliver (2000)	Although elevation has rarely been reported, apparently the highest in America is 6,760 ft (Oliver 2000). Most known elevations in America are much lower (e.g., Nagorsen and Brigham 1993).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat loss (roosting and foraging)	loss of riparian areas (conversion to agriculture, reservoirs, etc.)*	existing or planned	—	—	none	various sources	This species appears to be more dependent upon riparian areas than are most other bats within its range. Thus the loss of or degradation of riparian situations likely would affect it even more than other bat species.
direct mortality, loss of insect prey	pesticide use (especially in orchards)	existing	—	—	none	various sources	Because this species is known to forage in orchards and in urban residential settings where pesticide use often is especially heavy, it is suspected that pesticides represent even greater danger to it than to other bats.

[1]Not all mammalogists consider this to be a valid species distinct from the "eastern" red bat (i.e., the red bat), *Lasiurus borealis* (see Oliver 2000 for discussion). Despite the questionable validity of this species as distinct from *Lasiurus borealis*, care has been taken in the preparation of this table to separate and use only information specific for *L. blossevillii*.

[2]*Lasiurus blossevillii* has a very broad latitudinal distribution, occurring in temperate and tropical regions of both North America and South America, from British Columbia to Argentina and Chile. **This table is intended for use north of México**.

*Most important indicators.

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Allen's big-eared bat (*Idionycteris phyllotis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	diurnal roosts	—	—	rock crevices in cliff faces	exfoliating bark of large, dead trees ("snags"); abandoned mines; caves, rock shelters	Barbour and Davis (1969) Rabe et al. (1998), Brown and Berry (2005), other authors	
habitat	maternity roosts	—	—	—	abandoned mines, boulder piles in caves	Commissaris (1961), Cockrum and Musgrove (1964)	Few maternity roosts have been found, and knowledge of the acceptable range of conditions is thus very limited.
habitat	elevation*	<2,500 ft or >9,800 ft	2,500–3,500 ft or 8,500–9,800 ft	3,500–5,000 ft or 7,500–8,500 ft	5,000–7,500 ft	Genoways and Jones (1967), Barbour and Davis (1969), Czaplewski (1983), Oliver (2000)	
habitat	plant association*	—	piñon–juniper woodland, mountain brushland, mixed forest, lowland riparian woodland, desert shrub, sagebrush steppe, mesquite grassland	oak–juniper woodland, mixed coniferous forest	ponderosa pine forest	Czaplewski (1983), Oliver (2000), Barbour and Davis (1969), Lewis (2005), Brown and Berry (2005), Jones (1965)	This species has been found, at least occasionally, in most habitats that are present within its limited range, and it is uncertain what constitutes unsuitable habitat within its range. Most mist-net captures have been at ponds in ponderosa pine forest, which is considered to be preferred or optimal habitat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	physiography (perhaps related to roost availability)	—	lava flows	rocky slopes	cliffs, canyons	various authors (e.g., Czaplewski 1983)	
habitat	forest management*	managed (i.e., by thinning and removing "fuel loads")	—	—	unmanaged	Lewis (2005)	
roosting habitat	closure or "reclamation" of abandoned mines	complete closure (e.g., back-filling or dynamiting of entrances)	gating with "bat friendly" gates	none	none	various authors (e.g., Brown and Berry 2005)	
roosting habitat	vandalism and other human disturbance (including scientific investigation) of roosts, such as abandoned mines	recurring	infrequent	isolated instances	none	Barbour and Davis (1969)	

[1]The ecology of this species is not well known; of all the bat species that occur in America, it is one of (if not *the*) most poorly known species. Incomplete knowledge often leads to incorrect generalizations, and it is possible that partial knowledge of Allen's big-eared bat has resulted in distorted beliefs about the ecological requirements of this species. It has often been stated that this species is primarily a dweller of forested mountainous areas (e.g., Barbour and Davis 1969, Czaplewski 1983); however, recent work (e.g., Brown and Berry 2005) suggests that this is too narrow a generalization. Also, like many bat species, Allen's big-eared bat may roost in one habitat and forage very widely in other habitats. Brown and Berry (2005) found that Allen's big-eared bats traveled ~70 km roundtrip nightly from roosts in one habitat to foraging areas in other habitats (at different elevations and in different plant associations). The wintering habits of this species (migration versus hibernation) are unknown (Czaplewski 1983). Its closest relatives hibernate in caves and mines.

*Most important indicators.

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spotted bat (*Euderma maculatum*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	roosts* (see Comments)	—	caves	—	rocky situations (e.g., rock crevices in cliffs)	various authors	Roosts are poorly known and incompletely understood. This species has been found in caves and cave-like situations several times but generally is not considered to be a cave-roosting species. However, the only reported observation of hibernation was in a cave in Utah. Although some of the sources that have claimed that rock crevices are the main roosts drew this conclusion from flawed experimental approaches (e.g., the release of spotted bats during daylight; see discussion in Oliver 2000), roosting in cliff crevices has been confirmed by reliable methods.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, injury	capture, handling, collection (science)* (see Comments)	bats killed for specimens or mist nets not continuously monitored or bats released during daylight	no collecting of specimens and mist nets monitored at all times and bats released only at night	none	none	various authors including Fenton et al. (1983), Oliver (2000) and sources cited therein	*E. maculatum* is an especially delicate bat and appears to be much more subject to injury from capture and handling than are other bat species (see Oliver 2000). Mortality of spotted bats in mist nets that are not *continuously* monitored is very high, as is mortality of spotted bats released during daylight, which very commonly are taken by diurnal birds of prey (see Oliver 2000). Severe injuries and death from mist net capture and handling are very common in this species (see Oliver 2000). Fenton et al. (1983) considered scientific collecting to be the greatest threat to this species, which is among the most coveted of all species by collectors of mammals.
mortality, impairment of reproduction	use of pesticides	occurring in vicinity	—	—	none	Fenton et al. (1983)	

[1]This species occurs throughout most of western North America west of the Great Plains, from British Columbia to central México, and from below sea level to almost 10,000 ft elevation. Within its elevational and geographic range, it inhabits most (perhaps all) habitats from low desert situations and lowland marshes associated with lakes to montane coniferous forests, and it has been found in agricultural areas and occasionally in towns and cities. Some earlier authors suggested that *E. maculatum* is a bat of higher elevations that may move to lower elevations in cooler months. Several later authors have speculated that *E. maculatum* prefers low elevations and only makes seasonal movements to higher elevations when temperatures become unbearable at low elevations in summer. However, the latter hypothesis is unlikely for at least 2 reasons. Most other western North American bats, including all of the closest relatives of this species, are quite tolerant of high ambient temperatures. More importantly, lactating females of this species have been captured at some of the highest known locations for *E. maculatum*, and high elevations must be considered important maternity habitats for it, just as low elevations are known to be. Existing evidence indicates that *E. maculatum* exhibits no elevational preference in most of its distributional range. Although its wintering habits are poorly known, the spotted bat has been found

hibernating in a cave (once) and has been captured in mist nets on several occasions during winter when temperatures were well below freezing (as low as –5 °C) (see Oliver 2000). Because of the elusive nature of this species, many aspects of its biology remain poorly understood relative to other North American bats. Various authors have claimed insights into its ecology, but some of these have been based on unreliable methods (see Oliver 1997, 2000) and most others appear to be of only local rather than general application. Aspects of its ecology reported thus far suggest that, despite its being a difficult species to study, it is an extreme ecological generalist. There may in fact be only 1 other bat species (*Eptesicus fuscus*, the big brown bat) in western North America that is as great an ecological generalist as *E. maculatum*. Other than capture, handling, and collecting for scientific purposes, threats to this species are unknown, but generalizations from knowledge of threats to other bat species could be made.

*Most important indicators.

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Townsend's big-eared bat (*Corynorhinus townsendii*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population density	no. of individuals per hectare	≤0.007/ha	0.008–0.016	0.016–0.024	≥0.025/ha	Pearson et al. (1952), Humphrey and Kunz (1976)	This species "seems to be nowhere abundant" (Barbour and Davis 1969). Humphrey and Kunz (1976) estimated a population density of 1 bat per 40 ha in an area on the Great Plains (Oklahoma and Kansas) (grossly misstated as "one bat per ha" by Kunz and Martin 1982). Pearson et al. (1952) estimated 1 bat per 310 acres (126 ha) and 1 bat per 419 acres (170 ha) in 2 places in California but considered these to be the lower limit of densities and probably underestimates. **N.B.**: "Ratings" should be considered uncertain since they are based on few data and estimates.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
shelter, reproduction, hibernation, thermal ecology	roosts (including maternity colonies[3], day roosts, hibernacula)*	other (e.g., bridges, culverts) (tree hollows and rock crevices are used in some places that lack caves and mines, but such roost sites are not generally preferred)	buildings (e.g., abandoned buildings, attics, cellars)	abandoned mines	caves	Sherwin et al. (2000, 2003) and other sources including Barbour and Davis (1969), Kunz and Martin (1982), Pierson et al. (1999), Oliver (2000)	Although Sherwin et al. (2000) found that "[i]n general, roosts with single low (<1.5 m) entrances were more likely to be occupied than those with multiple or tall entrances . . .[,] maternity colonies tended to be located in large complex sites with multiple openings." They warned: "At the landscape level, predictions can be made regarding likelihood of presence of *C. townsendii*. However, the perception that individual sites within a habitat of choice can be identified as roosts based on easily selected and measured variables is false", and it is ". . . difficult, if not impossible, to quickly assess the value of potential roosts." (See also footnotes 3 and 4)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
hibernation	winter temperatures in roosts used as hibernacula*	>55 °F (>13 °C) or <28.5 °F (<–2 °C)	50–55 °F (10–13 °C)	28.5–33 °F (–2–0.5 °C)	33–50 °F (0.5–10 °C)	Pearson et al. (1952), Barbour and Davis (1969), Kunz and Martin (1982), Nagorsen and Brigham (1993), Pierson et al. (1999) and sources cited therein	Only part(s) of the roost need to satisfy the indicated thermal requirements at any given time, and the bats will move as thermal conditions shift within the roost. Ideal temperatures probably are at or near the low end of the "very good" range. (Survivable minimum temperatures may actually be lower than those indicated, for hibernation has been reported at temperatures as low as –4 °C and –7 °C in British Columbia [Nagorsen and Brigham 1993].)
habitat	summer temperatures in maternity roosts	>30 °C or <19 °C	—	—	19–30 °C	Pierson et al. (1999)	"Recorded temperatures in maternity roosts throughout California vary between 19°C in the cooler regions to 30°C in the warmer southern regions . . ." (Pierson et al. 1999).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, thermal ecology	elevation* (see Comments)	>2,600 m (>8,530 ft)	2,001–2,600 m (6,565–8,530 ft)	1,701–2,000 m (5,581–6,562 ft)	<1,700 m (<5,577 ft)	Sherwin et al. (2000, 2003)	The work of Sherwin et al. (2000) was in n. Utah in an area that "ranged in elevation from 1,350 to 3,600 m [4,429–11,810 ft]". This species has been reported to occur "from near sea level to well above 3,160 m [10, 367 ft]" (Kunz and Martin 1982), which suggests that there are not many places within its range that would be elevationally completely unsuitable. However, this bat is rarely encountered above ~9,000 ft elevation, at least in America (see Barbour and Davis 1969, also Oliver 2000). Of 263 potentially suitable roosts above 2,600 m (8,530 ft), Sherwin et al. (2000) found only 1 that was occupied. (It is possible that higher elevations are inhabited in México.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	plant association (in inter-mountain west, especially n. Utah[4]) (see Comments)	aspen forest, mixed conifer forest	riparian	sagebrush–grass steppe, mountain brush	juniper woodland	Sherwin et al. (2000)[4]	**N. B.**: Ratings for this indicator are for intermountain w. North America, esp. n. Utah, and should not be applied elsewhere (e.g., Canada, México, Pacific coast, Great Plains, eastern North America). The work of Sherwin et al. (2000) was in n. Utah; thus, many plant associations inhabited by this species elsewhere were not available and were not evaluated. This species also occurs in deserts and prairies and in eastern deciduous forest and other forest types. Sherwin et al. (2000) found that presence of *C. townsendii* was associated with lower elevation and with habitat (plant community), and "[n]o other surface variables were associated with occupancy of a site".

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
health	banding (for scientific research)	occurring	—	—	none	Pearson et al. (1952), Humphrey and Kunz (1976), Kunz and Martin (1982), Verts and Carraway (1998)	Wing bands should not be attached to bats of this species, which responds more negatively to bands than do other temperate zone bat species. Banding of this species frequently causes irritation and inflammation of tissues, sometimes resulting in abnormal bone growth or heavy, persistent infection, especially in females (Humphrey and Kunz 1976). Also, banding of pre-volant young has been known to cause their mothers to move all young to a different roost (Pearson et al. 1952).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, abandonment of roosts	human disturbance (e.g., recreation-al caving, scientific studies) and vandalism of roosts*	occurring or potentially occurring (e.g., no bat gates)	—	—	none (e.g., suitably designed, vandal-proof bat gates exist)	various sources including Barbour and Davis (1969), Kunz and Martin (1982), Verts and Carraway (1998), Pierson et al. (1999), Oliver (2000), Sherwin et al. (2000, 2003)	*C. townsendii* is particularly sensitive to disturbance. "[S]imply the presence of people cause[s] this species to desert preferred roosts as well as alternate roosts" (Humphrey and Kunz 1976), and "disturbance at roost sites has contributed substantially to population declines" (Pierson et al. 1999, p 27). Caves and abandoned mines used as roosts should be protected from human entry, including scientific monitoring (Verts and Carraway 1998; see also Pierson et al. 1999, pp 22–23, 25–26), e.g., using "bat gates", signs, and enforcement (Pierson et al. 1999).
poisoning (mortality), reduction in prey base	pesticide use	occurring within 3 mi (5 km)	none within 8 mi (13 km)	none within 20 mi (32 km)	none within 40 mi (64 km)	Pierson et al. (1999)	"Ratings" are estimates based on greatest reported distances moved by this species (32 and 64.4 km) and reported foraging distances (up to 5 and 13 km) (see Kunz and Martin 1982, Pierson et al. 1999, pp 3, 6, 27). However, recent, unpublished work suggests that foraging distances may be much greater than have been reported (>150 km in a single night), so the "ratings" are likely quite conservative.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	toxic material ponds (cyanide used in mining; oil reserve pits)	existing within 3 mi (5 km)	none within 8 mi (13 km)	none within 20 mi (32 km)	none within 40 mi (64 km)	Pierson et al. (1999, p 24)	"Ratings" are estimates based on greatest reported distances moved by this species (32 and 64.4 km) and reported foraging distances (up to 5 and 13 km) (see Kunz and Martin 1982, Pierson et al. 1999, pp 3, 6, 27). However, recent, unpublished work suggests that foraging distances may be much greater than have been reported (>150 km in a single night), so the "ratings" are likely quite conservative. "This problem may be particularly severe in desert areas, where water associated with mining operations may be the only water in an area" (Pierson et al. 1999).
habitat	conversion of natural habitats (e.g., to agriculture)	occurring (past, present, or future)	—	—	none	Pierson et al. (1999)	Some preferred habitats of this species in w. North America—piñon–juniper woodland and sagebrush steppe—are subject to widespread conversion for agriculture and grazing.
loss of foraging habitat and prey base	livestock grazing	occurring	—	—	none	Pierson et al. (1999)	"Livestock grazing practices have been responsible for large-scale conversions of mesic riparian habitats to more xeric . . . habitats across the range of *C. townsendii*" (Pierson et al. 1999).

[1]Although most mammalogists currently assign this species to the genus *Corynorhinus*, some place it in the genus *Plecotus* (see Oliver 2000 for discussion).

[2]This species occurs mainly in western North America, where it ranges from British Columbia to Oaxaca, but a few disjunct populations also occur in eastern America (as far east as West Virginia and Virginia). **This table is intended for use mainly in western America, especially the intermountain west; the indicator "plant association" should be applied *only* in the intermountain west and is recommended only in n. Utah and similar areas.** Most of the other indicators, however, can be used throughout the range of this species.

[3]Pierson et al. (1999) asserted: "*C. townsendii* . . . requires a relatively spacious roost. The majority of the roosts examined in California . . . are at least 30 m in length, with the roosting area located at least 2 m above the ground [i.e., the cave or mine floor]. Maternity clusters are often located in ceiling pockets or along the walls just inside the roost entrance, within the twilight zone."

[4]Sherwin et al. (2003) cautioned: "[M]odels of roost selection [of *C. townsendii*] generated by Sherwin et al. (2000 . . .) for northern Utah were not applicable beyond the local scale. In fact, the use and application of locally derived models of roost selection across the range of this species to predict suitability of roosts could have disastrous results as incorrect types of roosts would be selected for protection."

*Most important indicators.

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big free-tailed bat (*Nyctinomops macrotis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	plant association	other	montane coniferous forest, montane mixed forest	tropical and temperate woodland, tropical deciduous forest, tropical thorn forest, tropical oak forest	lowland riparian, desert shrub	Milner et al. (1990), Oliver (2000)	
habitat	physical characteristics	—	—	—	"rugged, rocky country"	Barbour and Davis (1969), Milner et al. (1990)	This indicator may not apply in some places in the Neotropics.
habitat	roosts	other	tree cavities	buildings, caves	rock crevices in cliffs	Milner et al. (1990)	
nursery colonies	height of crevice (e.g., in cliff face)	«40 ft	<40 ft	≥40 ft	»40 ft	Milner et al. (1990)	Indicator is based on only 2 reported observations.
habitat	elevation	>9,200 ft	7,550–9,200 ft	5,900–7,550 ft	<5,900 ft	Milner et al. (1990), Oliver (2000)	

[1]This species ranges from Utah and Colorado (with extralimital records from as far north as British Columbia) through Central America and the Greater Antilles to Uruguay and northern Argentina. Its ecology is not well understood and apparently varies greatly across this vast region. There are also many areas within its overall range that appear to provide suitable habitat for the species but from which it appears to be absent (Barbour and Davis 1969). **This table is intended primarily for use in western North America**, and the "very good" indicator ratings mostly pertain to the arid lands of the American Southwest and México and may not be applicable in other areas such as the Neotropics.

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pygmy rabbit (*Brachylagus idahoensis*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (individuals per ha)	<2	2–8	9–44	≥45	Janson (1946, 2002), Green (1978)	
habitat	big sagebrush* (frequency)	<50% of woody plants	50–75% of woody plants	75–90% of woody plants	>90% of woody plants	Green (1978), Gahr (1993), Gabler (1997)	Ratings are estimates based on qualitative reports.
habitat	mean shrub height*	<25 cm	25–56 cm	56–82 cm	>82 cm	Green (1978), Weiss and Verts (1984), Gahr (1993)	
habitat	shrub cover*	<21%	21–36%	36–46%	>46%	Green and Flinders (1980), Gahr (1993), Gabler (1997)	
habitat	mean sagebrush height*	<68 cm	68–91 cm	91–127 cm	>127 cm	Weiss and Verts (1984)	
habitat	sagebrush cover*	<16%	16–25%	25–33%	>33%	Green and Flinders (1980), Weiss and Verts (1984)	
habitat	soil depth*	<36 cm	36–51 cm	51–60 cm	>60 cm	Weiss and Verts (1984)	

[1]Several authors have reported differences in soil composition (% sand versus % clay) between inhabited and uninhabited sites, but the research of others has either not strongly supported this observed difference (Weiss and Verts 1984) or contradicted it (Gabler 1997). Because soil composition (sand/clay) is a debatable and unreliable indicator, it is not included in this table.

*Most important indicators.

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white-tailed prairie dog (*Cynomys leucurus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of individuals[2]	<0.5/acre	0.5–2/acre	2–5/acre	>5/acre	Tileston and Lechleitner (1966), Clark et al. (1971), Menkens and Anderson (1989), Orabona-Cerovski (1991)	
population	density of burrow openings[2] (see Comments)	<2/acre (<1 active/acre)	2–10/acre (1–5 active/acre)	11–50/acre (6–25 active/acre)	>50/acre (>25 active/acre)	Tileston and Lechleitner (1966), Clark et al. (1971), Clark (1977), Orabona-Cerovski (1991)	Nearly all authors have reported burrow counts that combined both active and inactive burrows, which is unfortunate since such a measure does not distinguish healthy colonies from failing or even extirpated colonies. **N.B.**: Despite the use of burrow density by many other prairie dog researchers (see Knowles 2002, Table 1), Menkens (1987) strongly argued that burrow density is not a meaningful index of prairie dog populations. In 4 of the 6 colonies that he studied, "no relationship existed between prairie dog density and burrow opening density."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	maximum vegetation height[3,*]	>92 cm	62–92 cm	31–62 cm	<31 cm	Collins and Lichvar (1986)	This was the only vegetative measure that Collins and Lichvar (1986) considered to be of importance in determining the occurrence of this species. However, in some places in Utah, healthy colonies exist where shrubs are tall (1–2 m) though not dense (<10% cover). Menkens (1987) found median (not maximum) shrub heights at 6 WTPD[4] sites in Wyoming to be 22 cm (Figure 3) or 24 cm (p 61) to 35 cm, but Menkens (1987) did not find any habitat feature(s) to be useful in predicting or assessing habitat suitability for this species.[3]
food	available forage*	—	—	—	grasses, shrubs, forbs, cacti, sedges	Kelso (1939), Tileston and Lechleitner (1966), Clark (1977)	
habitat	topography*	—	—	—	level to gently rolling areas of valleys, benches, and plateaus	Collins and Lichvar (1986), Menkens (1987), Knowles (2002)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	total plant cover (see Comments)	<30% or >90%	30–42.5% or 82.5–90%	42.5–55% or 75–82.5%	55–75%	Collins and Lichvar (1986), Menkens (1987), Orabona-Cerovski (1991)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance. They wrote: "Of the vegetation parameters measured, only plant height appears to be important to white-tailed prairie dog distribution." Menkens (1987) reported 41–72% total plant cover at 6 WTPD sites in Wyoming during 3 years. Orabona-Cerovski (1991) found average plant cover of 38% on 18 WTPD plots in Wyoming in 2 years.
habitat	grass cover (see Comments)	<10%	10–25%	25–40%	>40%	Collins and Lichvar (1986), Menkens (1987), Orabona-Cerovski (1991)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance. They wrote: "Of the vegetation parameters measured, only plant height appears to be important to white-tailed prairie dog distribution." Menkens (1987) reported 26–58% grass cover at 6 WTPD sites in Wyoming during 3 years. Orabona-Cerovski (1991) found that mean cover of grasses and sedges ranged 6–40% on 18 WTPD plots in Wyoming in 2 years.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	forb cover (see Comments)	<5%	5–10%	10–15%	15–30%	Collins and Lichvar (1986), Menkens (1987), Orabona-Cerovski (1991)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance. They wrote: "Of the vegetation parameters measured, only plant height appears to be important to white-tailed prairie dog distribution." Menkens (1987) reported 0–32% forb cover at 6 WTPD sites in Wyoming during 3 years. Orabona-Cerovski (1991) found that mean forb cover ranged 0–12% on 18 WTPD plots in Wyoming in 2 years.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	shrub cover (see Comments)	>30%	20–30%	10–20%	0–10%	Collins and Lichvar (1986), Menkens (1987), Orabona-Cerovski (1991)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance (also see comment concerning Utah, below). They wrote: "Of the vegetation parameters measured, only plant height appears to be important to white-tailed prairie dog distribution." Menkens (1987) reported 1–10% subshrub cover and 0–12% shrub cover at 6 WTPD sites in Wyoming during 3 years. Orabona-Cerovski (1991) found that mean shrub cover ranged 0–16% and mean cover of subshrubs and cacti was 5–30% on 18 WTPD plots in Wyoming in 2 years. However, in some places in Utah, thriving WTPD colonies exist where shrub cover is rather dense (i.e., »30%).[3]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	shrub density (see Comments)	>3/m^2	2–3/m^2	1–2/m^2	0–1/m^2	Collins and Lichvar (1986), Menkens (1987)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance. They wrote: "Of the vegetation parameters measured, only plant height appears to be important to white-tailed prairie dog distribution." Menkens (1987) reported shrub densities of 0–0.3/m^2 at 6 WTPD sites in Wyoming during 3 years.
habitat	bare ground (see Comments)	<5% or >70%	5–10% or 50–70%	10–20% or 30–50%	20–30%	Collins and Lichvar (1986), Orabona-Cerovski (1991)	**N.B.**: Collins and Lichvar (1986) did not consider this indicator to be of importance. Orabona-Cerovski (1991) found that bare ground averaged 37–82% on 18 WTPD plots in Wyoming in 2 years.
mortality (disease)	sylvatic plague*	present locally in this or other species (e.g., ground squirrels, native rats and mice), especially with a history of recurrence	present in the region in this or other species (e.g., ground squirrels, native rats and mice) but not the immediate vicinity	formerly present in the region in this or other species (e.g., ground squirrels, native rats and mice) but not the immediate vicinity	no evidence of presence (past or current) in this or other species (e.g., ground squirrels, native rats and mice) in the immediate vicinity or the region	Knowles (2002)	Plague is a major cause of mortality in this species. "If less than 50% of the [prairie dog] burrows are active and no other significant causes of prairie dog mortality can be identified (e.g., poisoning), further investigate the possibility of plague) . . . . " (Biggins et al. 1993). Barnes (1995) recommended a micronized dust formulation of 0.5% permethrin in silica gel, used at a rate of 7 g/burrow to control flea vectors of plague in prairie dogs.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	poisoning*	occurring	—	—	none	Knowles (2002)	Poisoning has been (and may still be) the principal cause of mortality in this species.
mortality	shooting*	occurring	—	—	none	Knowles (2002)	
habitat, climate	elevation*	<4,160 ft or >9,630 ft (3 occurrences)	8,525–9,630 ft (1 occurrence)	7,640–8,525 ft (3 occurrences)	4,160–7,640 ft (757 occurrences)	Utah Natural Heritage Program data	Known Utah elevations range 4,066–9,985 ft (1,239–3,044 m) (UNHP database 2006). Within the range of this species in Utah, much higher elevations are available but are uninhabited. Much lower elevations may not be available in the Utah portion of its range. It is possible that the species occurs at lower elevations in other states—if lower elevations exist elsewhere within its range. However, this is doubtful; the range of the species straddles the continental divide and the species does not occur anywhere very far from the continental divide. Thus it is likely that the Utah elevational range is representative of the species' overall elevational range.
habitat	slope*	>10°	5–10°	0–5°	0°	Collins and Lichvar (1986)	

[1]Wagner and Drickamer (2004), in the introduction of a work on Gunnison's prairie dog in which they reviewed habitat requirements of other species of prairie dogs (i.e., black-tailed, Mexican, and Utah prairie dogs), noted: "We know of no detailed studies of the habitat requirements of white-tailed prairie dogs (*C. leucurus*), although a few authors list anecdotal information." Although exceptions to this have been found during the preparation of this table (e.g., Collins and Lichvar 1986, Menkens 1987, Orabona-Cerovski 1991), even such basic information as the inhabited elevational range for this species seems not to have been reported (see, for example, Clark et al. 1971, Clark 1977, and Knowles 2002). The small number of studies of the ecology and habitat requirements of this species is surprising for at least 2 reasons: (1) Of the 5 living species of prairie dogs, the white-tailed species has the second largest geographic distribution, and (2) the last natural

population of the federally listed black-footed ferret co-existed with and was dependent upon a large complex of white-tailed prairie dog colonies, and many—probably most—ferret reintroduction sites are within white-tailed prairie dog colony complexes.

[2]**N.B.**: Despite much useful and accurate information presented by Knowles (2002), the prairie dog density and burrow density data given by Knowles (2002, Table 1) are highly inaccurate. When the numbers presented by Knowles are compared with the original sources that he cited, it is found that there is little, if any, correspondence, and the errors are not the result of conversion of units (e.g., hectares to acres), for most of the original sources used the same units stated by Knowles (i.e., acres). Similarly, many data presented by Clark et al. (1982) are unusable, their text (p 575) and their Table 1 (and their abstract and Table 3) state different values for many variables. Data from both of these sources (Knowles 2002, Clark et al. 1982) should be used with great caution, if at all.

[3]From their study of vegetative characteristics of white-tailed prairie dog habitats (18 sites) inhabited or formerly inhabited by black-footed ferrets, Collins and Lichvar (1986) concluded: "[I]t is obvious that white-tailed prairie dogs are not dependent upon a particular vegetation type to meet habitat requirements. They appear to survive equally well in grass, shrub, or shrub/grass types where predominant plant heights do not exceed about 62 cm." (In their study of white-tailed prairie dog-inhabited sites, total vegetative cover ranged 38.5–83.3%, grass cover 13.0–55.7%, forb cover 3.3–29.9%, shrub cover 0–25.9%, bare ground 9.7–58.3%, litter (duff) 4.3–17.0%, and shrub density 0.1–2.5 m^2.) Menkens (1987), one of whose intentions was to construct a habitat suitability model for the white-tailed prairie dog, reached as similar but even more extreme conclusion based on study of white-tailed prairie dog population densities in relationship to vegetative and physical (topographic) characteristics of 6 colonies in Wyoming: "[White-tailed] [p]rairie dog densities . . . , either on individual towns or when towns were pooled, were not significantly correlated with any habitat feature examined. Construction of habitat-based models using these features for monitoring populations or evaluating habitat modifications is inappropriate."

[4]WTPD = white-tailed prairie dog.

*Most important indicators.

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Utah prairie dog (*Cynomys parvidens*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density of individuals	<0.5/acre	0.5–2/acre	2–5/acre	>5/acre	various sources, including Utah Division of Wildlife Resources data	Crocker-Bedford and Spillett (1981) proposed a "density index"; however, their index is actually a model of predicted habitat suitability rather than an index of density.[2] Although Pizzimenti and Collier (1975) stated the density range as 1–30/acre, the only sources cited in the same paragraph were for studies of other prairie dog species, from which they apparently were generalizing. Densities as high as 30/acre for this species are unrealistic except in irrigated alfalfa fields.
population	estimated colony size (no. of individuals)	<5	5–15	16–100	>100	Utah Division of Wildlife Resources annual population counts over 10 years	Collier (1975) reported the range of colony sizes as 1–1,040 individuals. Recent monitoring (UDWR data) shows that most colonies are much smaller than the maximum reported by Collier. Determination of the number of individuals in a colony, however, is difficult. (See the 2 indicators immediately below.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	total canopy (vegetative ground) cover (see Comments)	<20% or >85%	20–22.5% or 65–85%	22.5–25% or 45–65%	25–45%	Hasenyager et al. (1991)	Above 7,000 ft (2,134 m), 35–45% is recommended and 42% is ideal (Hasenyager et al. 1991, "[f]rom . . . Crocker-Bedford's work"). **N.B.**: UPDRIT (1997) questioned much of the vegetational information contained in Hasenyager et al. (1991).
food, water	cool season (spring) grasses[3] (% ground cover)*	<12% or >40%	12–18% or 34–40%	18–24% or 28–34%	24–28%	UPDRIT (1997)	UPDRIT (1997) recommended 12–40%, and ratings have been interpolated from this. "A minimum of three species are required, with at least one native species present" (UPDRIT 1997). Examples: Indian ricegrass, squirreltail, western wheatgrass, crested wheatgrass, needle and thread grass, cheatgrass, bluegrass, and wildrye.
food	warm season (summer) grasses[3] (% ground cover)*	<3% or >10%	3–4.5% or 8.5–10%	4.5–6% or 7–8.5%	6–7%	UPDRIT (1997)	UPDRIT (1997) recommended 3–10%, and ratings have been interpolated from this. "If warm season grasses are less than 3%, then forbs must be 11% - 20%" (UPDRIT 1997). Examples: sand dropseed, curlygrass, mountain muhly, and grama grass.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food, water	forbs[3, 4] (% ground cover)*	<1% or >10%	1–3% or 8–10%	3–5% or 6–8%	5–6%	UPDRIT (1997)	UPDRIT (1997) recommended 1–10%, and ratings have been interpolated from this. Forbs should be perennials, and "a minimum of 1% of forbs must be [milkvetch, alfalfa, aster, spring-parsley, buckwheat, fleabane, beardtongue, cinquefoil, phlox, globemallow, vetch, cryptantha, lupine, crazyweed, clover, and goosefoot or pigweed]" (UPDRIT 1997).[4]
ability to detect and avoid predators (negative); emergency sources of water (positive)	shrubs[3] (% ground cover)*	>3%	2–3%	1–2%	0–1%	UPDRIT (1997)	See UPDRIT for examples, most of which are undesirable. Rabbitbrush may be an exception and may be a desirable habitat component (see Hasenyager et al. 1991 and indicator immediately below).
food, water	rabbitbrush (% ground cover) (see Comments)	>15%	9–15%	0–1% or 3–9%	1–3%	Hasenyager et al. (1991)	UPDRIT (1997) did not corroborate Hasenyager et al. (1991) concerning this indicator.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	% of vegetative ground cover >1 ft tall (especially shrubs)	>10%	—	—	<10%	Collier (1975)	Invasive shrubby vegetation is a threat (Collier and Spillett 1975). Removal of shrubby vegetation such as big sagebrush and juniper should be considered. "Without fire or vegetational treatments, habitat usually becomes too brushy to support prairie dogs" (Crocker-Bedford and Spillett 1981).[5] Player and Urness (1982) found that rotobeating and railing were effective and beneficial when transplanting this species onto formerly inhabited sites now overgrown with shrubs, but an herbicide (2,4-D) was not.
preferred foods	vegetation[6]	shrubs, dead vegetation, and cattle feces	forbs other than alfalfa (especially wild buckwheats, *Eriogonum*)	grasses (especially crested wheatgrass and western wheatgrass)	alfalfa (not recommend-ed)[6]	Crocker-Bedford and Spillett (1981)	The most preferred food is "cicadas" (probably actually grasshoppers or other orthopterans)[7], followed by plants in the order of preference indicated (i.e., alfalfa is the most preferred plant food[6]) (Crocker-Bedford and Spillett 1981). "Alfalfa can override [many other factors] in promoting high prairie dog densities, because alfalfa is highly palatable and highly nutritious" (Crocker-Bedford and Spillett 1981). Mustard is also considered desirable forage (Crocker-Bedford and Spillett 1981).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
plant sources of water (moist food)	vegetation	shrubs	grasses	forbs	forbs	Collier (1975)	"Forb cover can be increased by disturbances such as grazing or plowing" (Collier 1975). Rabbitbrush, though a shrub, is considered to be desirable forage for Utah prairie dogs (Crocker-Bedford and Spillett 1981).
extended period of food availability at higher elevations; palatable spring forage for pregnant and lactating females	cool season grasses, e.g., "blue-grasses, cheat grass, squirreltail grass, wheat-grasses, and needle-and-thread grass" (see Comments)	scarce or absent	fairly common	common	abundant	Crocker-Bedford and Spillett (1981)	"Palatable forage must be available to pregnant and lactating females . . . in the vicinity of winter–spring home burrows . . . . Above 2,200 m (7,200 ft), palatable early spring forage consists almost exclusively of . . . cool season grasses, but early spring forage at lower elevations may include alfalfa and mustard. . . . [C]ool season grasses can compensate partially for short growing seasons at high elevations. In contrast, longer growing seasons at lower elevations may negate the need for cool season forage . . . . Seeding or other treatments sometimes may be necessary to provide adequate amounts of suitable cool season forage."
time required to select plant parts with adequate water (moist food)	mean number of grasses, forbs, & shrubs	high	—	—	low	Collier (1975)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
emergency plant sources of water (moist food)	heterogeneity among plant communities	low	—	—	high (>40%)	Collier (1975)	Indicator is defined as "the visual difference of plant communities within dog towns relative to plant communities at the periphery of dog towns . . . from the edge of the 'dog town unit' to 91.5 m (300 ft.) outward" (Collier 1975).
moist vegetation (succulent grasses, forbs, and rabbitbrush) throughout summer (water availability in addition to precipitation)	presence of swale or other moist area (≤300 m from home burrows[8])	no moist areas	—	—	swale, adjacent stream or irrigated field, late snow melt, or abundant summer rainfall (some high-elevation areas)	Collier (1975), Crocker-Bedford and Spillett (1981)	"A year of high precipitation allows some prairie dogs to live away from swales, but these animals usually die during a drought year", and "Utah prairie dog colonies without moist areas are decimated by drought. . . . Moist vegetation may be provided in some areas presently dry during summer through treatments such as swaling or the construction of gully plugs or ponds" (Crocker-Bedford and Spillett 1981).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (disease)	sylvatic plague	present locally in this or other species (e.g., ground squirrels, native rats and mice), especially with a history of recurrence	present in the region but not the immediate vicinity	formerly present in the region but not the immediate vicinity	no evidence of presence (past or current)	Collier and Spillett (1972, 1973), Hasenyager et al. (1991)	This disease, introduced from Asia, is known to have eliminated large colonies of other, closely related species prairie dogs. "If less than 50% of the [prairie dog] burrows are active and no other significant causes of prairie dog mortality can be identified (e.g., poisoning), further investigate the possibility of plague) . . . ." (Biggins et al. 1993). Barnes (1995) recommended a micronized dust formulation of 0.5% permethrin in silica gel, used at a rate of 7 g/burrow to control flea vectors of plague in prairie dogs.
mortality (persecution or eradication)	poisoning (e.g., use of poisoned grain)[9]	occurring illegally[9]	—	—	none (compliance or adequate enforce-ment[9])	Collier and Spillett (1972, 1973, 1975), Collier (1975), Pizzimenti and Collier (1975), Hasenyager et al. (1991)	Intentional poisoning has been the greatest threat to this species. Poisoning has eliminated entire colonies, including some of the largest. 6 colonies were exterminated in this way in 1970 (Collier 1975), and "[i]n 1972, the largest colony of the species was reduced from more than 1000 animals to less than 50, apparently from poisoning" (Pizzimenti and Collier 1975).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (persecution or eradication)	shooting[9]	occurring illegally[9]	—	—	none (compliance or adequate enforce-ment[9])	Collier and Spillett (1972)	"In Iron County, two large dogtowns . . . were recently eliminated by shooting. (Elimination of the animals apparently was the objective of the shooting in these two dogtowns)" (Collier and Spillett 1972).
predation	predators (especially American badgers, but coyotes, raptors [e.g., golden eagles, ferruginous hawks], and other predators could also be problems in rare cases)	exceptionally intense predation pressure, noticeably reducing size and viability of colony	moderate predation pressure (colony size should be carefully monitored)	slight predation pressure, not affecting viability of colony	little if any predation pressure, no effect on size and viability of colony	Collier and Spillett (1972) and other sources	"Three Utah prairie dogtowns are believed to have been eliminated by badgers within the last two years. Two of these dogtowns were small, but the third was approximately 40 acres in size" (Collier and Spillett 1972). However, Collier and Spillett (1972) found evidence of badgers in more than half of the Utah prairie dog colonies that they surveyed and concluded that "badgers generally may not constitute a threat to the species." **Control (i.e., removal) of badgers or other predators would be appropriate only in exceptional cases** (e.g., transplant or artificial colonies, which initially are quite vulnerable).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	elevation	>10,000 ft or <5,000 ft (3 known occurrences)	9,600–10,000 ft (9 known occurrences)	8,665–9,600 ft (59 known occurrences)	5,000–8,665 ft (928 known occurrences)	trend from Collier (1975) and Crocker-Bedford and Spillett (1981); break points for ratings from Utah Natural Heritage Program data	The known elevational range for this species is 4,807 ft (1,465 m) to 10,041 ft (3,060 m) (Utah Natural Heritage Program data).
avoidance of drowning of dormant and of newborn individuals	deep, well-drained soils in areas of winter–spring home burrows[10]	absent	—	—	present	Crocker-Bedford and Spillett (1981), Hasenyager et al. (1991)	"In southern Utah soils, caliche layers are an important limiting factor in the location of prairie dog colonies. Prairie dogs must be able to inhabit a burrow system 3.3 feet (1 meter) underground without becoming wet. . . . Caliche layer[s should be] below the 4 foot level" (Hasenyager et al. 1991).

[1]Collier (1975) discussed many aspects of the habitat and ecology of the Utah prairie dog in addition to those included in this table and found that a number of these additional ecological factors were of considerable importance (i.e., statistically significant) in determining the ecological suitability of a site to this species. Unfortunately, Collier (1975) did not provide quantitative data for many of the ecological factors, such as ranges of suitable conditions. For example, Collier (1975) showed statistically that heterogeneity within the plant community of the colony; heterogeneity among plant communities within versus surrounding the colony (high, >40%, is better); mean number of grasses, forbs, and shrubs (low is better); mean maximum temperature; number of days below 0 °C; and elevation all were important factors affecting occurrence of the species. However, he did not quantify these factors, nor has such quantitative information been found in secondary sources, even those of which Collier was an author or contributor (e.g., Hasenyager et al. 1991).

[2]Crocker-Bedford and Spillett (1981) incorrectly referred to Collier's (1975) "abundance index" as a "density index". Collier's (1975) "abundance index" is an index of Utah prairie dog colony size, a simple method for estimating the number of individuals in a given colony. It is the mean distance between active mounds (burrows) subtracted from 100 in order to produce numbers that increase with colony size, and it ranged from 8 to 89. Crocker-Bedford and Spillett (1981) proposed a "density index" of their own, but their text could be misunderstood to suggest that this new "index" was Collier's (1975) index (of abundance, not density). Furthermore, Crocker-Bedford and Spillett's (1981) "density index" is actually a predictive model of habitat suitability rather than an index of density (or abundance), and it should not be confused with Collier's (1975) abundance index. Despite these confusing problems in Crocker-Bedford and Spillett's (1981) work, their incorrectly named model, which has nothing to do with Collier's abundance index, is based on Collier's (1975) findings concerning habitat suitability and may have considerable value as a model of habitat suitability. In their model, habitat suitability = 138.2 – 0.0472 X elevation in meters (or 0.0144 X elevation in feet) + 2.16 X percentage of cool season grass canopy cover up to 20% + 7.27 X forage condition on moist areas (swales) in midsummer (0–3, where 0 = brown

grasses and forbs, 1 = green grasses and forbs that are fairly dry, 2 = green grasses and forbs that are moist, and 3 = soggy ground) – 0.0713 X average distance in meters from home burrows to moist areas (swales). In other words, increasing elevation and increasing average distance from burrows to moist areas have negative effects on habitat suitability, and increasing percentage of cool season grass canopy cover (up to 20%) and increasing forage condition (moisture) on moist areas (swales) in summer have positive effects on habitat suitability. A transplant site should have a score of ≥37 using their model (Crocker-Bedford and Spillett 1981).

[3]UPDRIT (1997) developed new "Interim Vegetation Composition Guidelines for Utah Prairie Dog Habitat" (UPDRIT 1997, Appendix 1) "to replace the vegetation guidelines in the Utah Prairie Dog Recovery Plan (1991). These guidelines are approved by the Utah Prairie Dog Recovery Plan Implementation team for use by all land managers, and should be used in the interim . . . until the Utah Prairie Dog Recovery Plan is amended. The guidelines for vegetation parameters found [in] the Recovery Plan are considered inadequate . . . ." Unfortunately, the recommended guidelines (UPDRIT 1997), which have been followed in this table, are ambiguously defined, which was one of the reasons UPDRIT gave for replacing the guidelines of the Recovery Plan. In UPDRIT's tabular presentation of vegetative types, the recommended ranges are called "Percentage of Ground Cover"; however, this is followed by the instruction: "The toe pace or step method will be used . . . to determine conformance with these guidelines." "Percentage of Ground Cover" presumably means the aerial percent of the ground that is covered by the particular vegetative type (i.e., % canopy cover by type), rather than, say, percentage of total vegetative ground cover (all types) made up of a particular vegetative type. The "toe pace or step method", on the other hand, is a technique that yields percent frequency—not canopy (or ground) cover—of species or vegetative types. Thus, the tabular guidelines and the instructions for their use recommend 2 different and potentially conflicting measures: % ground cover and % frequency. For example, shrubs could have high % cover and low % frequency, and grasses could have low % cover and high % frequency.

[4]UPDRIT (1997) stated that "a minimum of 1% of forbs must be species as defined below." Does this mean that ≥1% of a list of the forb species present at a site should be found in the defined list of forb species? (Probably not.) Does it mean that 1% of the forb cover, which should be 1–10% ground cover (according to UPDRIT's table), should be the recommended species? If so, assuming that the median recommended forb cover, 5.5%, is ideal, then recommended species should be ≥0.055% ground cover, which, at the minimum (0.055%), is scarcely a trace. (This, too, seems unlikely.) Possibly it means that ≥1% of ground cover—not ≥1% of forbs as stated by UPDRIT—should be the recommended species, despite UPDRIT's confusing wording.

[5]Prehistorically fire probably was important in controlling invasive shrubs in the habitat of the Utah prairie dog. However, since cheatgrass has been introduced into Utah, fire favors the conversion of habitats to almost exclusively this species. Even though cheatgrass is a cool season grass and is consumed by the Utah prairie dog, because of the invasiveness and dominance (as a disclimax) of this fire-favored species and its ability to reduce soil moisture, fire is not a good tool for control of shrub invasion of the habitat of the Utah prairie dog.

[6]Although alfalfa is a preferred food, it is not necessarily a recommended food source. Prairie dogs, including this species, can be very serious pests in agricultural areas, such as alfalfa fields. Conflicts between conservation of the Utah prairie dog and agricultural interests should be avoided. High species diversity (>10 species) of native grasses (especially cool season grasses) and forbs is best.

[7]Although Crocker-Bedford and Spillett (1981) stated that cicadas are the most preferred food of the Utah prairie dog, this may have been a lapsus or confusion concerning appropriate use of the common name "cicada". Cicadas (order Homoptera, family Cicadidae) typically are arboreal, being found on trees and shrubs, which are largely or entirely absent from typical habitat and colonies of the Utah prairie dog (and those of other species of prairie dogs). Their Plate 5, to which Crocker-Bedford and Spillett (1981) referred readers, shows a Utah prairie dog holding a grasshopper in its forefeet near its mouth, and grasshoppers often are common in prairie dog colonies. Short-horned grasshoppers (order Orthoptera, family Acrididae) are often called "locusts". In fact, the primary dictionary definition of "locust" is "short-horned grasshopper". However, a secondary definition is "cicada", and many people, especially regionally (e.g., in the American South) mean

"cicada" when they say "locust". Perhaps this semantic problem was inverted by Crocker-Bedford and Spillett (1981) in the mistaken belief that locusts (i.e., grasshoppers) are properly called cicadas. Prairie dogs of other species are well known to eat grasshoppers but are unknown to eat cicadas (e.g., Kelso 1939).

[8]Hasenyager et al. (1991), however, stated that the moist swale vegetation "should be . . . with[in] 600 feet of the home burrow area throughout summer."

[9]The Utah prairie dog is federally protected under provisions of the Endangered Species Act, and control measures can be legally undertaken only by permit from the U. S. Fish and Wildlife Service. It is hoped that the poisoning and shooting of this species that formerly were common practices have been discontinued, now being illegal (except by special permit). However, to the extent that poisoning and shooting of this species may still take place illegally, they are serious threats, since colonial species such as prairie dogs are especially vulnerable to such persecution.

[10]Hasenyager et al. (1991) wrote: "Soil in the burrow area must not easily cave in. The soil must not be sand or loamy sand." However, Collier and Spillett (1975) had earlier presented a different view, stating: "Soil probably has no direct bearing on the overall distribution of prairie dogs, except through its influence on vegetation. Koford . . . observed mounds in very sandy and in very gravelly soils. . . . Our observations tend to confirm that soil texture generally is not a limiting factor. Utah prairie dogs occur mostly on Mollisols. A few dogtowns occur on Entisols . . . ." UPDRIT (1997) stated that "[e]xisting Utah Prairie Dog complexes are associated with deep, loamy soils . . .", and "Soils are an important component of prairie dog habitat, but at this time we do not have enough information to recommend parameters."

*Most important indicators.

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Gunnison's prairie dog (*Cynomys gunnisoni*)
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (individuals/acre)[1]	≤1/acre	2–5/acre	6–9/acre	≥10/acre	Burnett and McCampbell (1926), Longhurst (1944), Lechleitner et al. (1962), Rayor (1985a), Cully et al. (1997)	Longhurst (1944) reported 1–2/acre in sagebrush >1 ft high and perhaps 15–20/acre in more open habitats. "Extreme concentrations ran as high as 30 per acre" (Longhurst 1944). Rayor (1985a) found 18.5 and 23.1/acre in 2 years prior to a plague outbreak. Burnett and McCampbell (1926) reported 62.9/acre. Lechleitner et al. (1962) reported 1.9 and 2.8/acre. Cully et al. (1997) estimated 12.1 and 20.2/acre at 2 sites before plague outbreaks.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	estimated no. of individuals in colony	<25	25–50	51–100	>100	Lechleitner et al. (1962), Pizzimenti and Hoffmann (1973), Fitzgerald and Lechleitner (1974), Rayor (1985b, 1988), Cully et al. (1997)	Lechleitner et al. (1962) reported 2 colonies of ≥25 and ≥50 individuals, and Fitzgerald and Lechleitner (1974) studied a colony of ~100 individuals. "Colonies of *C. gunnisoni* are generally smaller than those of other species of prairie dogs, often consisting of fewer than 50 to 100 individuals" (Pizzimenti and Hoffmann 1973). However, Rayor (1985b, 1988) estimated 1 colony to contain 1,000–1,500 individuals after emergence of young and another of ~125 adults and young. Cully et al. (1997) mentioned a colony of 5,000–10,000 individuals before a plague outbreak.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	burrow density (active and inactive)[1, 2]	<20/acre (<5 active/acre	20–50/acre (5–12.5 active/acre)	51–200/acre (12.5–50 active/acre)	>200/acre (>50 active/acre)	Burnett and McCampbell (1926), Lechleitner et al. (1962), Fitzgerald and Lechleitner (1974), Slobodchikoff et al. (1988)	Nearly all authors have reported burrow counts that combined both active and inactive burrows, which is unfortunate since such a measure does not distinguish healthy colonies from failing or even extirpated colonies.[2] Lechleitner et al. (1962) reported 31 and 41/acre (including inactive burrows) at 2 sites. Fitzgerald and Lechleitner (1974) found 23.2/acre and 22.4/acre (including inactive burrows). Burnett and McCampbell (1926) reported examples in the densest populations: 245.1/acre (of which ~171.4/acre were active) at 1 site and 204/acre at another. Slobodchikoff et al. (1988) reported that average burrow densities at 6 colonies ranged 175.7–438.9/acre.
population	colony area[1]	<2.5 acres	2.5–10 acres	10–100 acres	>100 acres	Lechleitner et al. (1962), Fitzgerald and Lechleitner (1974), Rayor (1985b), Cully et al. (1997)	Lechleitner et al. (1962) reported that 2 colonies (within a complex) had areas of 17.7 and 12.9 acres. Cully et al. (1997) mentioned a colony covering ~494 acres before a plague outbreak. Rayor (1985b) studied 2 colonies of ~2.67 acres and ~148.2 acres, the smaller being the more prosperous colony due to better quality habitat.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	topography	—	—	—	mesic plateaus, higher mountain valleys, arid lowlands	Knowles (1972)	"Compared to black-tailed prairie dog habitat, the habitat of *C. gunnisoni* is topographically and vegetationally highly variable. . . . [S]uitable areas are more often small and patchy, resulting in more spermophile-like [i.e., ground-squirrel-like] living habits" (Pizzimenti and Hoffmann 1973).
habitat	shrub density	high	—	—	low	Longhurst (1944)	
habitat	shrub height	>1 ft	≤1 ft	<1 ft	«1 ft	Longhurst (1944)	
habitat	total vegetative cover (July or August)	<20% or >80%	20–22.5% or 65–80%	22.5–25% or 50–65%	25–50%	Shalaway and Slobodchikoff (1988), Lechleitner et al. (1962, Fitzgerald and Lechleitner (1974)	Shalaway and Slobodchikoff (1988) reported maximum (July or August) vegetative cover of 26-56% at 3 sites in Arizona. In Colorado, Lechleitner et al. (1962) reported ~30% plant cover, and Fitzgerald and Lechleitner (1974) reported 0–80% (mean 65%) plant cover.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	shrub cover	>50%	35–50%	20–35%	<20%	Rayor (1985b)	This species apparently is able to utilize shrubbier habitats than are other species of prairie dogs, although Longhurst (1944) observed much lower densities in sagebrush >1 ft tall than in more open habitats. Rayor (1985b) reported 9.5% and 23.5% shrub cover at 2 colonies, the latter being the more prosperous, but probably because of other factors. Little quantitative information is available, and ratings are educated guesses.
habitat, forage	herbaceous cover	<20%	20–40%	40–60%	>60%	Rayor (1985b)	Rayor (1985b) reported 24.1% and 35.7% herbaceous cover at 2 colonies, the latter being the more prosperous. However, little quantitative information is available, and ratings are educated guesses.
habitat	bare ground	>70%	55–70%	40–55%	<40%	Rayor (1985b)	Rayor (1985b) reported 39.0% and 66.4% bare ground at 2 colonies, the former being the more prosperous. However, little quantitative information is available, and ratings are educated guesses.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, forage	plants	—	introduced weedy species	native weedy species	native non-weedy species	Slobodchikoff et al. (1988)	Slobodchikoff et al. (1988) found that at 4 of 5 colonies, native non-weedy species were more abundant than were native weedy or introduced weedy species and at the remaining colony native non-weedy and native weedy species together were more abundant than introduced weedy species. They concluded that ". . . Gunnison's prairie dogs must be conserved by maintaining habitats with a large component of native vegetation."
forage	available foods*	shrubs	insects (beetle larvae, grass-hoppers, moth larvae [cutworms])	forbs	grasses (including domestic cereals), alfalfa[3]	Shalaway and Slobodchikoff (1988), Rayor (1985b), Fitzgerald and Lechleitner (1974), Longhurst (1944), Taylor and Loftfield (1924), Kelso (1939), Burnett and McCampbell (1926)	High overall diversity of foods, especially native grasses and forbs, through different seasons likely is optimal.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (from disease)	sylvatic plague[4, *]	present locally in this or other species (e.g., ground squirrels, native rats and mice), especially with a history of recurrence	present in this or other species (e.g., ground squirrels, native rats and mice) in the region but not the immediate vicinity	formerly present in this or other species (e.g., ground squirrels, native rats and mice) in the region but not the immediate vicinity	no evidence of presence in this or other species (e.g., ground squirrels, native rats and mice) (past or current)	Lechleitner et al. (1962), Rayor (1985a), Cully et al. (1997), Knowles (2002)	"If less than 50% of the [prairie dog] burrows are active and no other significant causes of prairie dog mortality can be identified (e.g., poisoning), further investigate the possibility of plague) . . . . " (Biggins et al. 1993). Barnes (1995) recommended a micronized dust formulation of 0.5% permethrin in silica gel, used at a rate of 7 g/burrow to control flea vectors of plague in prairie dogs.
mortality	poisoning*	occurring	—	—	none	Lechleitner et al. (1962), Knowles (2002), many other sources	
mortality	shooting*	occurring	—	—	none	Knowles (2002)	
habitat, climate	elevation (see Comments)	<4,500 ft or >11,000 ft	4,500–5,000 ft or 10,000–11,000 ft	5,000–6,000 ft or 8,500–10,000 ft	6,000–8,500 ft	Longhurst (1944), Pizzimenti and Hoffmann (1973), UNHP database	The known elevational range of this species is ≤4,415 ft (1,346 m) (Utah Natural Heritage Program data, 2006) to ~12,000 ft (~3,660 m) (Pizzimenti and Hoffmann 1973). Ratings within this elevational range are somewhat uncertain (e.g., some high elevation meadows in Colorado support healthy colonies).
habitat, visibility	slope	>15%	5–15%	2–5%	0–2%	Fitzgerald and Lechleitner (1974), other sources	Wagner and Drickamer (2004) found that inhabited sites had an average standard deviation of slope of 1.45° (1.6%) and random uninhabited sites 3.30° (3.7%).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
burrow construction, hibernation	soil depth	<0.8 m	0.8–0.9 m	0.9–1 m	>1 m	Wagner and Drickamer (2004)	Wagner and Drickamer (2004) reported that inhabited sites had soil depths of 1.05 ± 0.06 m and random uninhabited sites 0.59 ± 0.06 m.
burrow construction	surface rocks >1 cm diameter (as % surface cover)	>18%	13–18%	7.5– 13%	<7.5%	Wagner and Drickamer (2004)	Wagner and Drickamer (2004) found that inhabited sites had 6.33 ± 1.04% surface rocks >1 cm and random uninhabited sites had 20.72 ± 2.53%. Very sandy situations (e.g., dunes) almost certainly are unsuitable, but quantitative information on sandiness apparently has not been reported.

[1]**N.B.**: Data for this species (e.g., colony area and burrow density) presented by Clark et al. (1982) are inconsistently reported. Their text, p 575, and Table 1 (as well as their abstract and Table 3) present very different values (means, standard deviations, and ranges). Beware also of later authors (e.g., Knowles 2002) who have used these data, apparently unaware of the problems. Although vegetation height for this species was reported by Clark et al. (1982) only in their Table 1, there are errors in these data too; the average for this species was well beyond the range that they reported. Prairie dog densities and burrow densities given by Knowles (2002, Table 1) contain serious errors. When the numbers presented by Knowles (2002) are compared with the original sources that he cited, it is found that there is no agreement in some cases. Such data from both of these sources (Clark et al. 1982, Knowles 2002) should be used with caution, if at all.

[2]**N.B.**: Despite the use of burrow density by many other prairie dog researchers (see Knowles 2002, Table 1), Menkens (1987) strongly argued that burrow density is not a meaningful index of prairie dog populations (any species). In 4 of the 6 white-tailed prairie dog colonies that he studied, "no relationship existed between prairie dog density and burrow opening density."

[3]Although alfalfa and domestic grasses (cereals) are preferred foods, they are not necessarily recommended food sources. Prairie dogs, including this species, can be very serious pests in agricultural areas, such as alfalfa and grain fields. Conflicts between conservation of Gunnison's prairie dog and agricultural interests should be avoided.

[4]This is the most susceptible of the 5 living species of prairie dogs. Plague has exterminated entire colonies (Lechleitner et al. 1962, Rayor 1985a). Cully et al. (1997) found that "[Gunnison's] [p]rairie dog mortality at all towns affected by plague was in excess of 99%." "Without any question, sylvatic plague is the major influence on Gunnison's . . . prairie dog populations today" (Knowles 2002).

*Most important indicators.

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silky pocket mouse (*Perognathus flavus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (no. of individuals/ha)	<5/ha	5–27/ha	28–50/ha	>50/ha	Britt (1972), Whitford et al. (1978), Best and Skupski (1994), Chapman and Chapman (1999)	In n. New Mexico, Britt (1972) estimated populations of 8.3–21.2/acre (20.5–52.4/ha) and an average of 13.4/acre (33.1/ha). In s. New Mexico, Whitford et al. (1978) found 0 to 50.0/ha. Findley et al. (1975) commented: "At times silky pocket mice may be incredibly abundant. On August 11, 1958, at the foot of the lava bluffs west of Albuquerque, four of us caught 127 of these animals by hand between dusk and 11:30 P.M." "In suitable habitats, densities as high as 370 per hectare are known, but 60 per hectare is more normal" (Chapman and Chapman 1999).
habitat	plant association (microhabitat)	very dense, tall grass	—	—	sparse, low or clumped grass, some shrubs	Armstrong (1972), Hoffmeister (1986)	"The presence of a grassy cover may be the most important requisite in habitat selection for these mice [*P. flavus*]" (Hoffmeister (1986). However, grass cover must be sparse and low or clumped. Grazing and trampling of grass cover by livestock favors this species in some places (Whitford 1976, Moulton et al. 1981).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	plant association (macrohabitat)	other (e.g., forest, riparian woodland, montane meadow)	arid woodland (open piñon–juniper, oak, oak–pine)	arid shrubland, chaparral	plains, arid grassland, desert grassland, mesquite–grassland	Armstrong (1972), Findley et al. (1975), Hoffmeister (1986)	In Arizona, Hoffmeister (1986) reported captures of this species by vegetative communities as follows: plains and desert grassland 44.4%, desert scrub 27.8%, juniper–piñon woodland 15.7%, oak and oak–pine woodland 9.3%, chaparral 2.8%.
habitat	substrate	—	rocky	clayey	sandy, loamy	Armstrong (1972), Findley et al. (1975), Best and Skupski (1994), Chapman and Chapman (1999) and other sources	
habitat, thermal biology	elevation	>8,300 ft	7,600–8,300 ft	7,000–7,600 ft	≤7,000 ft	Armstrong (1972)	The highest reported elevation for this species is 8,300 ft, in Colorado (Armstrong 1972). The disjunct, coastal population in Sonora includes occurrences that are very near the Pacific Ocean and presumably are not very far above sea level. Most reported elevations for this species are within the range 2,000–6,000 ft.

[1]This species occurs in w. and s. parts of the Great Plains, in parts of the American southwest, and in n. and c. México. All populations are in interior continental areas, except for a disjunct population in Sonora that is coastal. From 1973 until 1991 most mammalogists considered *Perognathus merriami* to be conspecific with *P. flavus*. Although these *Perognathus* have been considered separate species since 1991, as they were prior to 1973, care should be taken, when using literature pertaining to "*Perognathus flavus*", to ascertain the sense in which this name is used by authors. Much of the literature that discusses "*Perognathus flavus*" is actually about *P. merriami* or about both species, especially literature from the period 1973–1991. *P. merriami* occurs in w. Texas, se. New Mexico, and ne. México and is sympatric with *P. flavus* in some areas.

*Most important indicators.

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dark kangaroo mouse (*Microdipodops megalocephalus*)[1]
Ecological Integrity Table

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (individuals/ha) (see footnote 2)	<0.5/ha	0.5–1/ha	1.1–3/ha	>3/ha	Fautin (1946)	Fautin (1946) estimated 0.2–3.8/ha in 4 inhabited biotic communities in w. Utah: 1.0/ha in shadscale, 3.8/ha in winterfat, 0.2/ha in greasewood, and 0.8/ha in tetradymia. He did not capture this species in black sage, sagebrush, or shadscale–greasewood ecotone. He commented: "This apparent scarcity may be due to the fact that the communities studied are on the eastern border of its range. Only 23 specimens were caught during the entire period of this investigation whereas 92 specimens were caught in 198 traps during one night in Lincoln County, Nevada, near the center of its range, by Hall and Durrant (1937)."[2]
habitat	vegetative cover	none or dense	—	—	sparse	Hall and Linsdale (1929), O'Farrell (1999)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat degradation, impairment of locomotion	cheatgrass (see Comments)	dense	sparse	absent	absent	various sources including Hafner and Hafner (1998)	Invasion by cheatgrass negatively affects and can locally eliminate heteromyid rodents of many species. Hafner and Hafner (1998), discussing *M. megalocephalus*, commented that "populations have suffered from introduction of weedy grasses", seemingly a reference to cheatgrass.
habitat	physiography or landscape features	—	—	—	valley bottoms, alluvial fans, borders of alkaline dry lakes and sinks	O'Farrell (1999), Hafner and Hafner (1998)	
habitat	substrate*	other	—	gravelly	sandy (dunes and other sandy soils), silty (e.g., fine wind-blown silt)	various sources including Hall and Linsdale (1929), Hall and Durant (1937), Hall (1946), Fautin (1946), Ghiselin (1970)	Where *M. megalocephalus* is sympatric with *M. pallidus*, *M. megalocephalus* occurs on gravelly soils (Hall 1946, p 379, Ghiselin 1970). (See also Hafner et al. 1996.)
habitat, thermal biology	elevation*	<3,900 ft or >7,600 ft	6,801–7,600 ft	3,900–3,999 ft or 6,001–6,800 ft	4,000–6,000 ft	Hall (1941, 1946) and other sources	Most records of this species are from 4,000–6,000 ft elevation. The highest and lowest reported elevations are 3,900 ft and 7,600 ft (Hall 1941, pp 255, 259, 1946, pp 391, 393). The "fair" and "good" ratings are uncertain and are (in part) interpolations.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
competition	*Perognathus longimembris* (little pocket mouse), *Perognathus parvus* (Great Basin pocket mouse), and perhaps *Chaetodipus formosus* (long-tailed pocket mouse) (see Comments)	abundant	common	scarce	absent	O'Farrell and Blaustein (1974), O'Farrell (1999)	**N.B.**: The importance of this indicator is uncertain. O'Farrell and Blaustein (1974) discussed the negative effect that the presence of *P. longimembris* has on *M. megalocephalus*, displacing temporal and spatial activities of *M. megalocephalus*, which is behaviorally and seemingly competitively subordinate to *P. longimembris* and apparently to *P. parvus* as well. However, competitive exclusion of *M. megalocephalus* by *P. longimembris* and *P. parvus* has not been shown, and these species are broadly sympatric and commonly co-occur (i.e., are syntopic) with *M. megalocephalus*.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat loss	agriculture, cultivation*	existing or planned	—	—	none	Hall and Linsdale (1929), Hafner and Hafner (1998)	Hafner and Hafner (1998), discussing this species, noted: "[P]opulations have suffered from . . . cultivation of dry sinks by irrigation from limited pockets of water that collect under the pans (J.C. Hafner pers. obs.). Although the supply of water may be limited, habitat alteration at these cultivated sites is extreme, resulting in wholesale displacement of *Microdipodops*. . . . [H]uman-related habitat modifications may have amplified effects on the already fragmented, patchy distribution of *Microdipodops*."

[1]This species inhabits parts of the Great Basin in Nevada, c. to se. Oregon, w. Utah, ne. and extreme e.-c. California, and extreme s. Idaho. However, its distribution is highly discontinuous and patchy within this area, and it is absent from many sites with seemingly suitable habitat.

[2]Although Hall and Durrant (1937) did report the capture of 92 *Microdipodops* from 198 traps in 1 night (46% trap success for this species alone), as well as 62 individuals from 127 traps (49%) and 121 individuals from 313 traps (39%) in single nights, "on favored soils farther toward the center of the range of the species", far outnumbering all other rodents captured on these nights, they did not state that this was in Lincoln County, Nevada, as asserted by Fautin (1946). (In fact, the *margins* of the ranges of both *M. megalocephalus* and *M. pallidus* are in Lincoln County, Nevada.) Also, it is unclear which species of *Microdipodops* was referred to by Hall and Durrant (1937). Hall and Durrant (1937) described a new race, *albiventer*, from Utah and Nevada, which they considered to belong to the species *M. pallidus*. However, Hall later (e.g., Hall 1941, 1946) assigned all of the specimens mentioned in the description of *albiventer*, from both Utah and Nevada, to the species *M. megalocephalus*, referred all of the Utah specimens to another race, and indicated that the race *albiventer* does not occur in Utah at all. Thus, in addition to Fautin's (1946) slight augmentation of what was reported by Hall and Durrant (1937), the work by Hall and Durrant (1937) confused the 2 species of *Microdipodops*, and in some parts of that text, including the part referred to by Fautin (1946), it is impossible to determine which of the 2 species Hall and Durrant (1937), in their confusion, were referring to. Nonetheless, in some places *M. megalocephalus* does occur in higher densities than those found by Fautin (1946), and the "ratings" for the indicator "density" should be considered very conservative.

*Most important indicators.

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Mexican vole (*Microtus mexicanus*)
Ecological Integrity Table[1]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (individuals per hectare)	<5/ha	5–17/ha	18–30/ha	>30/ha	Conley (1976)	Conely (1976) referred to 30/ha, apparently a rough average for this species in his study, as "low density", but he seems to have meant this relative to densities of its congener, *M. longicaudus*, which reached a peak of ~120/ha. Actual densities of *M. mogollonensis* found by Conley (1976, Fig. 2) varied from 5/ha to ~50/ha.
habitat	microhabitat (ground cover, understory)*	other	shrub thickets (e.g., *Ceanothus*, *Symphori-carpos*, *Arcto-staphylos*, *Rosa*)	wet grasslands and meadows	dry grasslands and meadows	Findley et al. (1975), Hoffmeister (1986), also Benson (1935), Frey and LaRue (1993)	Findley and Jones (1962) noted the presence of this species "on the lower edge of the yellow pine [= ponderosa pine] zone in open sparsely vegetated situations where rabbit brush (*Chrysothamnus*), not grass, was the dominant plant cover." However, this is not typical habitat for *M. mogollonensis*.
habitat	macrohabitat (overstory)*	other	juniper woodland, sagebrush, spruce–fir forest	mixed coniferous forest	ponderosa pine forest	Findley and Jones (1962), Findley et al. (1975), Hoffmeister (1986), Frey and LaRue (1993)	Findley et al. (1975) commented concerning this species: "In years of abundance, it descends into the piñon–juniper woodland." This comment implies that such habitat is of marginal value for the species.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	elevation*	<3,800 ft or >11,000 ft	3,800–4,999 ft or 10,001–11,000 ft	5,000–5,999 ft or 9,001–10,000 ft	6,000–9,000 ft	Hoffmeister (1986) and other sources	The lowest reported elevation is 3,800 ft (Hoffmeister 1986, p 444), and the highest is "between 10,000 and 11,000 feet" (Hoffmeister 1986, p 442). Most reported elevations are in the range 6,000–9,000 ft; very few are from below 5,000 ft or above 10,000 ft.
degradation of habitat, destruction of ground cover	livestock grazing*	intense	moderate	little	none	Frey (1999)	(See Comments below.)
degradation of habitat	mining, road-building, recreation (off-road vehicles, trampling)	occurring (past, present, future)	—	—	none	Spicer and Kime (1998)	"Protect existing habitat through activities such as fencing, livestock control, signing, flood control, and erosion control. . . . Designate special management areas and implement range management plans and probably fire suppression until the role of fire is clarified" (Spicer and Kime 1998).
degradation of habitat	degradation of streams and wetlands	occurring (past, present, future)	—	—	none	Frey (1999)	(See Comments above.)

[1]Some mammalogists consider all American populations to be a separate species, *M. mogollonensis*, which occurs in Arizona, New Mexico, and (barely) into Utah, Colorado, and Texas; however, other mammalogists continue to consider the American populations to be no more than subspecies of *M. mexicanus*. Regardless of the taxonomic position taken, **this table is intended for use north of México**.

*Most important indicators.

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gray wolf (*Canis lupus*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density (no. of individuals/40 mi^2 [or 100 km^2])	<1 wolf/ 40 mi^2	1–2 wolves/ 40 mi^2	3–4 wolves/ 40 mi^2	>4 wolves/ 40 mi^2	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	"In North America, reported wolf densities range from 1/2 km^2 [1 wolf/ 0.8 mi^2] to 1/3274 km^2 [1 wolf / 1,264.1 mi^2] for stable populations . . . . Average annual wolf densities do not often exceed about 1 wolf /24 km^2 [1 wolf / 9.3 mi^2] and are usually far lower" (Paquet and Carbyn 2003). "Saturation is thought to occur at about 1 wolf/ 26 km^2 [1 wolf / 10.0 mi^2] . . . " (Paquet and Carbyn 2003, citing others).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
annual home range of pack, protection from human persecution (mortality)	area of available undeveloped, protected, public lands or wilder-ness*,[3]	<58 mi^2 (<150 km^2)	58–500 mi^2 (150–1,296 km^2)	501–1,000 mi^2 (1,297–2,590 km^2)	>1,000 mi^2 (>2,590 km^2)	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	"In most of North America, regional wolf populations require core wilderness to persist . . . . Even the largest North American parks and reserves are inadequate to fully protect wolves . . . . Packs living in highly productive environments such as Yellowstone National Park require about 150–300 km^2. In mountainous areas, annual home ranges can be as large as 3000 km^2 . . . . Wolves living in the Arctic . . . may use areas of 60,000 km^2 or larger . . . . The number of protected areas should be increased in some areas and the effectiveness of existing reserves that are too small . . . could be improved by the creation of buffer zones" (Paquet and Carbyn 2003).[3]
food, locomotion (wintering ungulate prey, snow depths)	topography (in mountainous areas)	higher slopes	—	—	valley bottoms, lower slopes	Paquet and Carbyn (2003) and sources cited therein	"In mountainous areas with high snowfall, use of low-elevation valleys increases during winter, where frozen lakes, shorelines, and ridges are preferred because of ease of travel" (Paquet and Carbyn 2003).
natal den site[4]	physiographic relief	none (flat) or very steep	—	—	moderately steep slope	Weaver (1987) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
natal den site[4]	aspect	N	E, W	—	S	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	The "fair" rating is an interpolation.
natal den site[4]	soil	wet	—	—	well-drained	Weaver (1987) and sources cited therein	
natal den site[4]	distance to surface water	o400 yards	>400 yards	—	<400 yards	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	
natal den site[4]	proximity of forested cover	far	—	—	near	Weaver (1987) and sources cited therein	Exceptions probably were common when this species inhabited the Great Plains.
natal den site[4]	distance from recreation trails*	<1 mi	—	—	≥1 mi	Weaver (1987) and sources cited therein	"Most wolf packs appear particularly sensitive to human disturbance near den sites and may abandon the den . . ." (Weaver 1987, citing other sources). "Based on a comprehensive study of North American Parks, [one source] recommended a protective buffer around den and rendezvous sites of 2.4 km [1.5 mi] radius in open country" (Paquet and Carbyn 2003).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
natal den site[4]	distance from back-country camp sites*	<1 mi	1–1.5 mi	1.5–2 mi	>2 mi	Weaver (1987) and sources cited therein	"Most wolf packs appear particularly sensitive to human disturbance near den sites and may abandon the den . . ." (Weaver 1987, citing other sources). The "fair" and "good" ratings are interpolations. "Based on a comprehensive study of North American Parks, [one source] recommended a protective buffer around den and rendezvous sites of 2.4 km [1.5 mi] radius in open country" (Paquet and Carbyn 2003).
rendezvous site[5]	landscape feature of rendezvous site	other (i.e., densely vegetated, "closed" sites)	—	—	open grassy sites such as meadows, bogs, abandoned and revegetated beaver ponds, stream margins	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	
rendezvous site[5]	landscape feature adjacent to rendezvous site	other (i.e., sparsely vegetated, open areas)	—	—	hillside timber	Weaver (1987) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
rendezvous site[5]	size of open site	<0.5 acre or o1 acre	—	—	~1 acre	Weaver (1987) and sources cited therein	
rendezvous site[5]	distance to surface water	>50 m	—	—	≤50 m	Paquet and Carbyn (2003) and sources cited therein	
rendezvous site[5]	distance from human activity*	<1.5 mi	—	—	>1.5 mi	Weaver (1987) and sources cited therein, Paquet and Carbyn (2003) and sources cited therein	"Based on a comprehensive study of North American Parks, [one source] recommended a protective buffer around den and rendezvous sites of 2.4 km [1.5 mi] radius in open country" (Paquet and Carbyn 2003).
first rendezvous site[5] (late May to early July)	distance from natal den site[4]	>6 mi or <1 mi	—	—	1–6 mi	Weaver (1987) and sources cited therein	"A wolf pack will usually move from the natal den site (or occasionally a second den site) to the first rendezvous site when the pups are 6-10 weeks of age which is late May-early June . . ." (Weaver 1987, citing other sources).
successive rendezvous sites[5] (July to September or early October)	distance from first or previous rendezvous site[5]	>4 mi or <1 mi	—	—	1–4 mi	Weaver (1987) and sources cited therein	"A succession of rendezvous sites are used by the pack until the pups are mature enough to travel with the adults. This usually occurs in September or early October . . . . Occupancy times vary from 10-67 days . . ." (Weaver 1987, citing other sources).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
food	abundant available prey*	other	—	—	ungulates, (especially deer, elk, moose, caribou, bison, muskoxen, mountain goats, and mountain sheep) (1°), beavers (2°)	Weaver (1987), Paquet and Carbyn (2003) and sources cited therein	"Wolves commonly prey on beaver during ice-free times (spring-fall). Beaver may serve as an important alternate prey source during summer, in part buffering or reducing wolf predation on young ungulates. In some wolf-prey systems, survivorship of wolf pups may be linked to beaver abundance" (Weaver 1987).
mortality	domestic dogs (disease reservoirs)	present	—	—	absent	Weaver (1987), Paquet and Carbyn (2003) and sources cited therein	"Recent studies have shown gray wolves, especially juveniles, are susceptible to canine parvovirus and distemper" (Weaver 1987). "The transmission of disease, such as parvovirus, from domestic dogs to wild wolves is a serious conservation concern . . . . Important viral infections thought to be significant are distemper and canine hepatitis . . ." (Paquet and Carbyn 2003, citing other sources). Other potentially serious diseases include heartworm and sarcoptic mange.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	human persecution (e.g., shooting, poisoning, trapping)*	no legal protection or inadequate enforcement and compliance	some legal protection, enforcement, and compliance	partial legal protection, enforcement, and compliance	full legal protection, adequate enforcement, and compliance		
mortality, behavioral avoidance	human visitation (in wilderness areas) (people per month)	>10,000 people/month	101–10,000 people/month	1–100 people/month	0 people/month	Paquet and Carbyn (2003) and sources cited therein	"In the Bow River Valley, Alberta, the selection or avoidance of particular habitat types was related to human use levels and habitat potential . . . . Changes in patterns of habitat use were evident when human activity exceeded 100 people/month. Nearly complete alienation of wolves occurred when >10,000 people/month used an area, regardless of habitat suitability" (Paquet and Carbyn 2003, citing another source). The "good" and "very good" ratings are extrapolations.
mortality, behavioral avoidance	human population density in region (people per km^2)*	>8 people/km^2	4–8 people/km^2	1.55–4 people/km^2	<1.54 people/km^2	Paquet and Carbyn (2003) and sources cited therein	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality, behavioral avoidance	road density in region (km roads per km^2)* Since the areal unit of measure is simply the square of the linear unit, any other units that bare the same relationship to each other can be substituted (e.g., mi and mi^2) without changing any of the numbers; i.e., 0.15 mi roads/mi^2 is the same as 0.15 km roads/km^2.	>0.70 km roads/km^2	0.51–0.70 km roads/km^2	0.15–0.50 km roads/km^2	<0.15 km roads/km^2	Paquet and Carbyn (2003) and sources cited therein	"Persistent occupancy of wolves is usually assured at mean road densities below 0.6–0.70 km/km^2 . . . . Landscape level analysis in northern Great Lakes region found mean road density was much lower in pack territories (0.23 km/km^2 in 80% use area) than in random nonpack areas (0.74 km/km^2) or the region overall (0.71 km/km^2). Few areas used by wolves had a road density of >0.45 km/km^2) . . . . In the Rocky Mountains, wolves killed by humans died closer to roads than wolves that died of other causes . . . . However, the relationship of road density and wolf distribution is not well understood in mountainous topography . . . ." (Paquet & C. 2003).
mortality (predator "control"), behavioral avoidance	livestock*	high presence (many)	moderate presence (moderate numbers)	very low presence (few)	absent (none)	Paquet and Carbyn (2003) and sources cited therein	

[1]The taxonomic "boundaries" of this species are unstable. Wozencraft (2005) considered it to be holarctic and in North America to include the red wolf (*Canis rufus* of other authors), the eastern timber wolf (*C. lycaon* of others), and the domestic dog (*C. familiaris* of others). Whether any of the last 3 should be considered valid species is debatable, and in various places, but *not* including w. North America, *C. lupus* is known or presumed to interbreed with all of them (and with the coyote, *C. latrans*). (Most European mammalogists, as well as the International Commission on Zoological Nomenclature [ICZN], do not recognize domestic animals as separate species, do not accept application of unique specific names for domestic animals, and apply to domestic animals the names of their closest wild ancestors. Thus, according to the ICZN and European mammalogists, the correct name of the domestic dog must be *C. lupus*, the gray wolf.) On the other hand, Baker et al. (2003) listed the eastern timber wolf (*C. lycaon*), the red wolf (*C. rufus*), and the "feral dog" (*C. familiaris*) as valid species (in addition to and

distinct from *C. lupus*) occurring in North America. The differences between Baker et al. (2003) and Wozencraft (2005) exemplify not only the difference between European and American mammalogists but also the age-old philosophical disagreement between taxonomic "splitters" and "lumpers" and perhaps differing species concepts as well. Paquet and Carbyn (2003), writing of *Canis lupus* (*sensu lato*), noted: "Except for humans the only mammalian species that has ever had a more extensive natural range is the lion (*Panthera leo*)." However, "[b]y 1960, the wolf was extirpated by federal and state governments from all of the United States except Alaska and northern Minnesota."

[2]This table is intended for use in w. North America, especially the Rocky Mountains and vicinity (and thus conveniently avoids at least 2 of the taxonomic problems mentioned in footnote 1—"*C. lycaon*" of ne. North America and "*C. rufus*" of se. America). *C. lupus* (whether *sensu lato*, including *lycaon*, *rufus*, and *familiaris*, or *sensu stricto*, excluding those nominal taxa) is an extreme ecological generalist that, except for human persecution since European colonization, has been successful in nearly all available habitats north of the tropics, including forests, woodlands, steppes, prairies, tundra, and deserts, and at a very wide range of elevations from sea level to mountains and on plains. Although an attempt has been made to utilize sources or parts of sources that are specific to wolves in w. North America, such as Weaver (1987), such sources often are syntheses that have made heavy use of information on wolves in e. North America (i.e., *C. lycaon* rather than *C. lupus*, *sensu stricto*). Regardless of whether they should be considered separate species, the wolves of w. and e. North America appear to be very similar in their ecology and behavior. Thus, the incorporation of information from e. North America is unlikely to have produced significant errors. Wolves in w. North America are extreme ecological generalists that utilize the extremely great habitat diversity that exists in the western part of the continent. More importantly, as Paquet and Carbyn (2003) summarized: "Habitat use by wolves is strongly influenced by availability and abundance of prey . . . , snow conditions . . . , protected and public lands . . . , absence or low occurrence of livestock . . . , road density . . . , human presence . . . , and topography . . . .", and ". . .habitat use is strongly related to availability of ungulate prey . . ., ease of travel . . ., availability of dens sites . . ., and availability of rendezvous areas . . . ."

[3]"Wolves do move through human-occupied landscape, across many unfavorable areas, but establishment success is restricted to higher quality habitat characterized by low human presence. . . . Protected and public lands encourage wolf presence, likely because there are fewer lethal encounters with humans . . . . Some authors . . . maintain that such areas are the least accessible to humans, and that the lack of human presence is the most important variable on predicting wolf viability" (Paquet and Carbyn 2003, citing other sources).

[4]Natal den sites typically are underground burrows, but other sheltered places such as hollow logs, spaces between roots of trees, caves or crevices in rocks, and abandoned beaver lodges are sometimes used. "The natal den serves a brief but important purpose by providing protection from the elements and potential predators for the first few weeks of life. Temperature and humidity in the den are generally moderate and stable compared with the outside environment. Even after pups emerge from the den and begin to eat semisolid food regurgitated by the adults, at 3–4 weeks . . ., wolf dens temporarily remain the center of activity, the point from which adults go out to hunt and to which they return with food for the young" (Paquet and Carbyn 2003).

[5]After pups have been moved from the natal den site, a succession of rendezvous sites are used as the center of pack activity. "Rendezvous sites are areas where pups are left, usually with an adult, while pack members forage" (Paquet and Carbyn 2003).

*Most important indicators.

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kit fox (*Vulpes macrotis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	biome*	other	—	semi-arid areas	desert	McGrew (1979), Cypher (2003)	
habitat	plant community*	other (e.g., dense brush, woodland, forest)	barren	—	shrub, shrub–grass	McGrew (1979), Cypher (2003)	Dominant shrub species include saltbush in c. California; shadscale and creosote bush in the Mojave Desert; and shadscale, greasewood, and sagebrush in the Great Basin (McGrew 1979).
habitat, visibility of predators (especially coyotes[3])	% ground cover*	≥20%	—	—	<20%	McGrew (1979)	At 6 natal dens in sw. Utah, O'Neal et al. (1987, Table III) reported grass cover as 5.9–16.8% and forb cover as 2.5–7.7%. (Combining their figures for grass and forb cover, the range is 13.6–19.3%, but this apparently does not include shrub cover.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
general habitat (foraging), visibility of predators (especially coyotes[3])	vegetation height*	>5 ft	<1 ft or 3–5 ft	2–3 ft	1–2 ft	Egoscue (1962), Daneke and Sunquist (1984)	Egoscue (1962) found *V. macrotis* in 3 associated plant communities in nw. UT. For 2 of these, he mentioned vegetation height: "Dominant plants of this relatively sparsely vegetated community [shadscale flats] average less than 24 inches in height . . . . . The dominant plant [of the greasewood flats] is greasewood which is 3 to 5 ft in height, and usually quite widely spaced . . . ." Daneke and Sunquist (1984), who studied *V. macrotis* in sw. UT, reported: "Most [kit] foxes were located in flat, shrub-grassland areas with a vegetation height between 30 cm and 91 cm. A few locations were in sparse shrub (<31 cm high) and one was in tall shrub (>91 cm)."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
denning habitat, visibility of predators (especially coyotes[3])	average vegetation height	>10 in.	<8 in.	—	8–10 in.	Egoscue (1956)	Egoscue (1956), in a study of *V. macrotis* in nw. Utah, noted: "About eighty per cent of the [kit fox] dens were found in sparsely vegetated shadscale flats. Here vegetation averages about eight to ten inches in height . . . . The low vegetation provides good visibility." Also, Daneke and Sunquist (1984) noted that most of the kit fox dens found in their study "were on a southerly aspect" even though "most slopes drained in other directions." (See also footnote 4.) In wet years, cheatgrass may become tall enough and dense enough to degrade habitat quality for *V. macrotis*.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat, dens	soil texture (see Comments)	—	coarse, gravelly or rocky	clayey, sandy (Places where sand is extremely fine, loose, and deep may be uninhabitable by this species because the substrate makes creation of stable dens impossible.)	loose, loamy	McGrew (1977), O'Neal et al. (1987), Cypher (2003), and other sources	**N.B.: The importance of this indicator is questionable.** Although a tendency or preference exists, it is not limiting. "Kit foxes prefer loose-textured soils . . ., but are found on virtually every soil type" (Williams et al. 1998, p 129). In some places (e.g., in the Chihuahuan Desert), *V. macrotis* occurs in areas of almost entirely rocky or gravelly substrates. In such areas (as well as many areas with loose soils) *V. macrotis* typically modifies burrows or dens of other species (e.g., badgers) rather than digging its own dens. In addition to texture, soils must be of adequate depth; soils that are shallow, with bedrock or slickrock near the surface, are unsuitable.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
habitat	terrain (slope)*	steep, rugged (>20%)	rolling (11–20%)	slight slope (5–10%)	flat (<5% slope)	Daneke and Sunquist (1984), Warrick and Cypher (1998), Cypher (2003), and other sources	Warrick and Cypher (1998), studying this species in California, found: "Topographic ruggedness was the only consistent factor that affected capture rates of kit foxes . . . . Kit foxes appear to be most abundant and persist longest in the flat or rolling terrain . . . . Relatively flat or rolling terrain probably has the greatest potential for sustaining viable populations of this species, and this terrain should be considered in habitat conservation efforts." Use of much steeper slopes was reported by Arjo et al. (2003), but their findings to represented a shift from historically selected habitats, perhaps as a result of increased abundance of coyotes and conversion of native nonnative habitats.[4]
habitat, thermal ecology	elevation*	>6,100 ft	5,501–6,100 ft	5,001–5,500 ft	≤5,000 ft	McGrew (1977) and other sources	McGrew's (1977) elevational analysis was based on 92 observations throughout Utah. 74% of these were at ≤5,000 ft, and 90% were at ≤5,500 ft. The highest was at 6,100 ft.
thermal biology	freeze-free season (average no. of days between last spring frost and first fall frost)	<100 days	100–119 days	—	≥120 days	McGrew (1977)	McGrew's (1977) analysis was based on 92 observations throughout Utah. 90% of these were from areas with a freeze-free season of ≥120 days.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
thermal biology	average annual minimum temperature	< –15 °F	–11 to –15 °F	—	≥ –10 °F	McGrew (1977)	McGrew's (1977) analysis was based on 92 observations throughout Utah. 90% of these were from areas with average annual minimum temperatures of –10 °F or higher.
food	available prey (see Comments)	other	Ground-nesting birds, reptiles, insects, and carrion have been reported in diet (see McGrew 1979, Cypher 2003) but possibly are not sufficient to support a population for the long term. At the edge of agricultural areas, some plant foods (cotton seeds, almonds, tomatoes) are consumed (see Cypher 2003).	other nocturnal small mammals diurnal sciurids: ground squirrels; prairie dogs	nocturnal rodents, especially kangaroo rats, pocket mice; jack rabbits, cottontails (Leporid abundance, however, may favor coyotes and red foxes [see below] and may allow these other canids to survive in areas otherwise too dry for them.)	Morrell (1972), McGrew (1979), Cypher (2003)	**N.B.: The importance of this indicator is questionable.** Some authors have suggested a dependency of this species on kangaroo rats and have even suggested that distribution and abundance of kangaroo rats determines the distribution and abundance of *V. macrotis* in some places. However, in some studies, black-tailed jack rabbits and cottontails have been more important in the diet, even when kangaroo rats were common (see McGrew 1979 for discussion). McGrew (1979) commented: "The primary food item in the kit fox diet is usually the most abundant nocturnal rodent or lagomorph in the vicinity of the den."

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
predation, competition (both interference [i.e., mortality] and exploitation competition)	coyotes, red foxes*,[3]	abundant	common	scarce	absent	O'Neal et al. (1987), White and Ralls (1993), Cypher (2003)	Coyotes are the main cause of death in this species.[3]
poisoning, mortality	use of toxicants for predator control (coyotes) or rodent control	occurring	—	—	none	Schitoskey (1975), McGrew (1979), Williams et al. (1998), Cypher (2003)	Poisoning to control predators (such as coyotes) and rodents is now much less frequent than in the past.
mortality	roads	many, large, with heavy traffic	many or large or with heavy traffic	few, small, unpaved, with little traffic	none	Morrell (1972), Williams et al. (1998), Cypher (2003)	"Vehicles have been and continue to be a an important source of kit fox mortality . . . , and in some locations are responsible for over 10% of kit fox mortalities . . . " (Cypher 2003). Also, by providing access, roads almost certainly increase mortality from shooting (see below).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality	shooting, trapping	occurring	—	—	none	Morrell (1972), McGrew (1979), Williams et al. (1998), Cypher (2003)	"Kit foxes are relatively unwary and easy to trap or shoot. . . . Kit foxes are harvested in Arizona, Colorado, Nevada, New Mexico, Texas, Utah, and Mexico. Harvests are prohibited in California, Oregon, and Idaho. During 1994–95, 247 kit foxes were harvested in Nevada and 531 in Utah" (Cypher 2003). Discussing the unwariness and vulnerability of *V. macrotis*, Egoscue 1962) observed: "Unfortunately, many [kit] foxes were shot by hunters who either mistook them for coyotes or merely wanted easy targets. With a little patience it was sometimes possible to walk to within 6 or 8 ft of a [kit] fox before it bolted . . . ."

[1]This species, occurring in the deserts and arid lands of w. (mainly sw.) America and n. and nw. México, has been combined or "lumped" with *Vulpes velox*, the swift fox (occurring on the Great Plains of c. America and s.-c. Canada) for long periods, and the taxonomy of these animals is unstable. Currently most mammalogists regard these foxes as separate species, but, in using literature, care should be taken to ascertain the taxonomic concept of authors.

[2]Although population densities of *V. macrotis* have been reported by many authors, population density is not included in this table as an "indicator". Reported population densities have been highly variable, both geographically and temporally. In long-term studies, observed population densities have changed greatly in response to changes in precipitation patterns (e.g., drought) and changes in prey populations. Thus, population density in this species is the result of complex ecological factors (i.e., is multivariate), and an attempted univariate consideration of population density (e.g., "rating" of density as an "indicator") would be misleading or meaningless.

[3]White and Ralls (1993), who studied this species in California, reported: "Predation by coyotes (*Canis latrans*) was the main cause of death." Cypher (2003), reviewing numerous studies of *V. macrotis*, commented: "Coyotes . . . will kill kit foxes . . . , and generally are the primary source of mortality for [this] species. Thus, coyotes can have a significant impact on the populations of [this] species, and at times may limit [its] abundance. . . . However, coyotes naturally occur everywhere that kit foxes . . . occur, and therefore some degree of coevolution has occurred. Some resource partitioning occurs relative to food availability, . . . and year-round den use by [kit] foxes and the presence of multiple dens within home ranges allow [kit] foxes to avoid coyotes . . . . Also, in an interesting

interaction among species, the presence of coyotes potentially provides a benefit to kit foxes . . . by limiting red fox abundance . . . . Red foxes historically were uncommon or absent in habitats occupied by kit foxes . . ., and therefore [this] species [has] not evolved strategies for mitigating competition from red foxes. Because of anthropogenic landscape modifications, red foxes are increasing within the range of kit foxes . . . and pose a significant threat to [this] species . . . . Interspecific aggression from coyotes appears to limit red fox abundance in kit fox . . . habitat." Warrick and Cypher (1998) found a negative correlation between kit fox abundance and coyote abundance, which was higher in areas of denser, taller, shrubbier vegetation and lower in a more open area that had been burned. They commented: "Predator control could potentially increase both the distribution and abundance of kit foxes, but previous attempts at [the study site] were labor and cost intensive and did not produce satisfactory results . . . . Another option may be to modify certain types of habitats to decrease their suitability for larger predators (bobcats, coyotes) and to increase the ability of kit foxes to detect or avoid these predators. In some areas, shrub control (via burning or other methods) may provide this type of advantage to kit foxes, and the potential positive effect of this technique should be further investigated."

[4]O'Neal et al. (1987, Table III) reported average shrub heights at 6 *V. macrotis* natal den sites in sw. Utah. Average shrub heights that they observed ranged 5.0–37.7 cm (2.0–14.8 in.), in fair agreement with Egoscue's (1956) observation that vegetation near dens in shadscale habitat in nw. Utah averages ~8–10 in. However, if species that represented <1% of shrubs near the dens are excluded from the data presented by O'Neal et al. (1987), average shrub heights of the remaining species ranged only 9.4–31.9 cm (3.7–12.6 in.), in even better agreement with Egoscue's findings. Interestingly, the lowest average shrub heights that O'Neal et al. (1987) reported were at the only natal den that was in an area that was not grazed by livestock. Arjo et al. (2003) reported many habitat characteristics of *V. macrotis* den sites in an area in nw. Utah that was earlier studied by Egoscue (1956, 1962). Their findings showed a shift from habitats historically selected by *V. macrotis* in this area. They interpreted the changes in habitat use by *V. macrotis* as ecological displacement resulting from increased abundance and distribution of coyotes and conversion of native plant associations to nonnative ones. Although their data are of great interest and demonstrate considerable ecological plasticity and adaptability in *V. macrotis*, they have not been used for the "ratings" of the "indicators" in this table because the data are assumed to represent departure from preferred natural conditions.

*Most important indicators.

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black-footed ferret (*Mustela nigripes*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey	prairie dog density (mean no. of prairie dogs/ha of colony)*	<3.63/ha	3.63–5/ha	5–7/ha	>7/ha	Houston et al. (1986), Biggins et al. (1993)	For comparison, in the Meeteetse, Wyoming, complex, WTPD density was 5/ha (Houston et al. 1986). Biggins et al. (1993) concluded that 3.63 prairie dogs/ha in mid-July was the minimum density that would support a BFF population. This minimum density is equivalent to visual counts of 1.8 WTPDs/ha or 2.06 BTPDs/ha. Of 9 sites where BFFs raised litters on the Meeteetse complex, the lowest visual count was 2.59 WTPDs/ha.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
cover, reproduction, prey	total area of prairie dog colonies within complex*	<800 ha	800–1,900 ha	1,900–3,000 ha	>3,000 ha	see Comments	The models of Houston et al. (1986), Forrest et al. (1985), Miller et al. (1988), and Minta and Clark (1989) all recommend much larger areas than those used here. However, the Meeteetse, WY, complex comprised 37 colonies totaling 2,990 ha (Houston et al. 1986) or 2,790 ha (Forrest et al. 1985) or 5,200 or 4,860.5 ha, of which 2,727.0 ha was "good habitat" (Biggins et al. 1993). It supported a thriving ferret population. The BFF population in Mellette County, SD, inhabited an 810-ha complex that grew to 1,284 ha in 5 years. See the 4 models cited above for other opinions, or simply double the areas in the ratings here to approximate other models (e.g., Minta and Clark 1989).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
cover, reproduction, prey	shape of prairie dog complex = 1/ (perimeter /(2 √(area·π))) (see Comments)	<0.25	0.25–0.5	0.5–0.75	>0.75	Minta and Clark (1989)	Indicator "measures the 'roundness' of a complex by comparing its area-to-perimeter ration to that of a circle with identical area" (Minta and Clark 1989), normalized between 0 and 1 (for use in a model). If the model by Minta and Clark (1989) is not being used, a simpler area/perimeter ratio could be employed —the higher this ratio, the better.
cover, reproduction, prey	axis ratio of prairie dog complex = minor axis/major axis (see Comments)	<0.25	0.25–0.5	0.5–0.75	>0.75	Minta and Clark (1989)	Major axis = longest dimension of complex; minor axis = longest dimension of complex that is perpendicular to the major axis. The axis ratio "gives small values for linear (elongate) complexes and a value of one for 'compact' complexes" (Minta and Clark 1989).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
cover, reproduction, prey	prairie dog colony size (within a complex of colonies)	<12 ha	12–50 ha	>50 ha	»50 ha	Forrest et al. (1985)	"Each colony used in computing the complex area should be 12 ha or greater, which is the smallest area known to be persistently occupied by ferrets at Meeteetse. Colonies of a minimum 50 ha appear to be necessary fro each breeding female, and therefore the majority of colonies comprising the total complex should be 50 ha or greater" (Forrest et al. 1985). Others (e.g., Minta and Clark 1989) have recommended that only colonies ≥5 ha be considered in determining size of complex.
cover, reproduction, prey	total within-complex colony area as % of overall prairie dog complex area	<1%	1–4%	4–22%	>22%	Minta and Clark (1989)	For comparison, the Mellette County, South Dakota, natural BFF population inhabited a prairie dog complex only 1% (or 1.7%) of which was colonies, and the Meeteetse, Wyoming, natural BFF population occurred in a complex 22% of which was colonies. The model of Miller et al. (1988) calls for higher percentages (i.e., ≥30% would be "very good").

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
cover, reproduction, prey	prairie dog burrow density (mean no. of burrow openings/ ha of colony)*	<31/ha (<25 active WTPD burrows/ha or <12 active BTPD burrows/ha; **see Comments**)	31–50/ha (25–45 active WTPD burrows/ha)	51–62/ha (45–65 active WTPD burrows/ha)	>62/ha (>65 active WTPD burrows/ha)	Houston et al. (1986), Biggins et al. (1993), Miller et al. (1988), Minta and Clark (1989)	For comparison, in the Meeteetse, Wyoming, complex, mean WTPD burrow density was 57/ha, ranked here as "good"; however, it is not clear from Houston et al. (1986) whether this represented all prairie dog burrows or only *active* prairie dog burrows. Biggins et al. (1993), however, calculated that minima of 25 active WTPD burrows/ha or 12 active BTPD burrows/ha were required to support a BFF population, and they provided instructions for counting burrows. The model of Miller et al. (1988) calls for higher densities (i.e., ≥75/ha would be "very good").

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
dispersal, gene flow (& cover, reproduction, prey)	prairie dog intercolony distance (mean distance between colonies within a complex)[3]	>4.3 km	3.2–4.3 km	2.1–3.2 km	<2.1 km	Minta and Clark (1989), but see also Houston et al. (1986) and Forrest et al. (1985), which suggest longer distances may be acceptable, or Miller et al. (1988), which recommends very much shorter distances	For comparison, mean intercolony distance within the Meeteetse, WY, complex was 0.92 km (Forrest et al. 1985, Houston et al. 1986) and in a complex supporting BFFs in South Dakota was 2.4 km (Hillman et al. 1979), ranking here as "very good" and "good", respectively. "BFFs have been observed to travel up to seven km/night . . . . A ferret carcass was found 11.1 km from the [Meeteetse] complex . . . . Based on the BFF carcass and visual sighting, ferrets may travel up to 17 km, which suggests that BFFs will interchange freely among colonies interspersed at 17 km or less" (Forrest et al. 1985).
prey	prairie dog "control" and persecution (poisoning, shooting, etc.)	regularly taking place	irregularly taking place	believed not to occur	none	various authors	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey (disease)	sylvatic plague[3,*]	present locally in prairie dogs or other species (e.g., ground squirrels, native rats and mice), especially with a history of recurrence	present in prairie dogs or other species (e.g., ground squirrels, native rats and mice) in the region but not the immediate vicinity	formerly present in prairie dogs or other species (e.g., ground squirrels, native rats and mice) in the region but not the immediate vicinity	no evidence of presence (past or current)	Forrest et al. (1985), Cully (1989), Biggins et al. (1993)	"If less than 50% of the [prairie dog] burrows are active and no other significant causes of prairie dog mortality can be identified (e.g., poisoning), further investigate the possibility of plague) . . . . " (Biggins et al. 1993). Barnes (1995) recommended a micronized dust formulation of 0.5% permethrin in silica gel, used at a rate of 7 g/burrow to control flea vectors of plague in prairie dogs.
mortality (disease)	canine distemper[3,*]	present locally	present in the region but not the immediate vicinity	formerly present in the region but not the immediate vicinity	no evidence of presence	Biggins et al. (1993)	"Demonstration of canine distemper serum antibodies in other carnivores on or near potential reintroduction sites is cause for concern. An abundance of domestic or wild carnivores may increase the probability of introduction and spread of canine distemper" (Biggins et al. 1993). Domestic dogs and people who have had contact with dogs, such as their owners, are threats.

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
mortality (predation), competition (for prey)	other predators (e.g., great horned owls, ferruginous hawks, golden eagles, coyotes, bobcats, badgers)	abundant	common	fairly common	scarce	Biggins et al. (1993)	Forrest et al. (1985) commented: ". . . [I]t is probably not crucial to figure predators into the selection process for [BFF] reintroduction sites unless there is reason to suspect they occur at very high densities." In that case, "[p]redator reduction may be an option prior to BFF reintroduction."
disease (canine distemper) and predation from domestic dogs and cats	proximity to human settlements	very near	near	far	very far	Forrest et al. (1985)	
barriers to dispersal, mortality	proximity to highways & freeways	very near	near	far	very far	Forrest et al. (1985)	
habitat	development potential	heavy development (e.g., strip mining, agriculture)	moderate development with potential expansion	some development, but well planned for wildlife	no development pending	Miller et al. (1988)	

[1]The black-footed ferret is believed to be extinct as a naturally occurring taxon. The prevailing view is that it is a valid species, but morphological and genetic differences between it and the steppe or Siberian polecat (*Mustela eversmanii*) of Asia are very slight. The 2 readily interbreed in captivity, and not all mammalogists are convinced that they are different species. Whether they are different species or only different races of the same species, an ecological difference between the 2 is the purportedly absolute dependence of the black-footed ferret on prairie dogs (*Cynomys* spp.), which comes very close to being true, though a few exceptions existed historically (i.e., black-footed ferret populations outside the ranges of any species of prairie dogs). Houston et al. (1986) stated: "Suitability of BFF habitat depends entirely on attributes of prairie dog colonies." Prairie dogs are an exclusively North American group of terrestrial squirrels. Siberian polecats have more varied diets than does (or did) the black-footed ferret, consuming ground squirrels (susliks), other rodents, and even other kinds of prey (as does the black-footed ferret, though less frequently). Forrest et al. (1985) concluded: ". . . BFFs probably occupied nearly all adequate prairie dog habitat available to them regardless of prairie dog species, vegetation, soils, or climate."

[2]In this table, the following abbreviations are used: black-footed ferret = BFF, black-tailed prairie dog = BTPD, and white-tailed prairie dog = WTPD. (Although the BFF historically co-occurred with Gunnison's prairie dog, no population or other quantitative data are available for BFF-inhabited Gunnison's prairie dog

complexes. To apply this table within the range of Gunnison's prairie dog, use the measures for the WTPD. The BFF is not known to have co-occurred with the Mexican prairie dog. If this table is to be applied within the range of the Mexican prairie dog, which seems unlikely and is not recommended, use the measures for the BTPD. The BFF also is not known to have co-occurred with the Utah prairie dog; if the table were to be employed within the range of the Utah prairie dog, which would be inadvisable since the Utah prairie dog is federally listed as threatened and introduction of the BFF probably would be impermissible, use the measures for the WTPD.) Prairie dogs (*Cynomys* spp.) are highly social rodents that live in colonies; these colonies are loosely aggregated in groups or clusters of colonies known as "complexes". There is dynamic tension between the on-going processes of extinctions of individual colonies and colonization (i.e., dispersal resulting in the formation of new colonies), which is an example of the metapopulation phenomenon. The last known and best studied natural population of BFFs occurred near Meeteetse, Wyoming, which is referred to in the table. The Meeteetse BFF population was quite large, healthy, and thriving before it was destroyed by canine distemper (believed to have been transmitted to the BFFs by researchers). Because it provided a good or very good example of a natural BFF population, reference to it is made in some of the comments, for comparison with some of the ratings.

[3]Unfortunately, "the same morphology of prairie dog complex that promotes easy moves among colonies also facilitates spread of disease" (Biggins et al. 1993).

*Most important indicators.

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Canada lynx (*Lynx canadensis*)[1]
Ecological Integrity Table[2]

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
population	density	<1/100 km^2	1/100 km^2	2/100 km^2	>2/100 km^2	Koehler and Aubrey (1994)	Density ratings are for lower latitudes or for population lows at higher latitudes. Much higher densities (≥10X) occur—following snowshoe hare population highs—in the north and east (e.g., as high as 37.2/100 km^2 in the Yukon) (see Koehler and Aubrey 1994).
habitat	plant community*	—	—	—	boreal forest	Koehler and Aubry (1994)	"Boreal" forest in the mountains of western America closely resembles the true boreal forest of the north. Examples of dominant tree species in such montane forest in the west include Engelmann spruce, subalpine fir, lodgepole pine, Douglas-fir, and quaking aspen. Although lynx disperse through other habitats, viable, reproducing populations occur only in boreal forest. Lynx occur near sea level and at very low elevations in the north and east, but in the mountains of the interior west suitable habitat exists only at higher elevations (e.g., >1,463 m in n.-c. Washington and w. Montana, >1,900 m in Wyoming, and >2,900 m in Colorado and Utah.)

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
foraging habitat (prey: snowshoe hares) and denning habitat (natal sites)	forest stand age[3]	uniform stand age	varying stand ages	varying stand ages	mosaic including early successional forest and late successional forest	Koehler and Aubry (1994)	A mosaic of stand ages is important at northern latitudes, and "[l]ynx habitat in the western mountains consists primarily of two structurally different forest types occurring at opposite ends of the stand age gradient. Lynx require early successional forests that contain high numbers of prey (especially snowshoe hares) for foraging and late-successional forests that contain cover for kittens (especially deadfalls) and for denning . . . . Intermediate successional stages may serve as travel cover for lynx but function primarily to provide connectivity within a forest landscape [and] 'fill in the gaps' between foraging and denning habitat . . . ."
natal den sites	dense, large, woody debris (e.g., fallen trees or upturned stumps)	absent or scarce	somewhat common in certain areas	common (at least in some areas)	abundant	Koehler and Aubry (1994), Anderson and Lovallo (2003)	For natal den sites, mature conifer stands (see indicator above) of ≥1 ha are preferred, especially those with N–NE aspects, high frequency (>1/m) of downed trees supported 0.3–1.2 m above the ground, minimal human disturbance, and proximity to foraging habitat (early successional forest) (Koehler and Aubry 1994).

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey (and thus reproduction and survival of young)	snowshoe hares*	rare (<0.5/ha) or absent	uncommon (0.5–1.5/ha)	common (1.5–2/ha)	abundant (>2/ha)	studies reviewed by Koehler and Aubry (1994), Anderson and Lovallo (2003), Murray (2003)	Although other prey are taken (e.g., squirrels, "mice", voles, ungulate fawns and calves, and grouse) and supplement the diet of lynx (especially during snowshoe hare population "lows"), lynx do not occur in or successfully colonize areas that lack snowshoe hares altogether. 2 hares/ha is considered high density in southern areas (Murray 2003). At hare densities lower than 1.4/ha, there may be no reproduction by lynx (and even at higher densities kittens may starve). At hare densities lower than 0.5/ha, lynx may abandon home ranges and become nomadic (see review by Koehler and Aubrey (1994).
prey (snowshoe hare) winter habitat[4]	dominant tree species	"hardwoods" (e.g., aspens)	mixed (hardwoods and conifers)	conifers	conifers	studies reviewed by Koehler and Aubry (1994), Murray (2003)	". . . [C]onifer cover is critical for hares during winter", providing "greater concealment from predators, lighter snowpacks, and warmer temperatures during winter than hardwood stands", and "stem density is more important to hares than species of conifer" (Koehler and Aubry 1994) (see indicator below).
prey (snowshoe hare) winter habitat[4]	tree and shrub stem density	<6,000/ha	6,000–11,000/ha	11,000–16,000/ha	>16,000/ha	studies reviewed by Koehler and Aubry (1994), Murray (2003)	

Key Ecological Attribute	Indicator	Indicator Rating				Basis for Indicator Rating	Comments
		Poor	Fair	Good	Very Good		
prey (snowshoe hare) winter habitat[4]	understory visual obstruction (horizontal cover density) above snow level	<40%	40–50%	50–60%	>60%	Wolfe et al. (1982)	Snow depths in the area studied (N Utah) commonly exceed 1.0 m, and horizontal cover densities ≥40% must exist 1.0–2.5 m above ground level.
prey (snowshoe hare) winter habitat[4]	tree and shrub stem height	<1 m or >6 m	3–4.5 m	4.5–6 m	1–3 m	studies reviewed by Koehler and Aubry (1994), Murray (2003)	**N.B.**: Indicator ratings are approximate, and they vary with location because of different snow depths.
mortality and competition	roads and trails	present	—	—	absent	studies reviewed by Koehler and Aubry (1994), Anderson and Lovallo (2003)	Mortality is from vehicular traffic and human access for trapping, hunting, etc. Competition is the result of roads and trails providing corridors that facilitate invasion by less snow-adapted (and forest-adapted) predators such as coyotes and bobcats.
mortality	trapping*	ongoing	past	past	none, past or present	Koehler and Aubry (1994)	Where trapping of lynx occurs, it is often the most important mortality factor, sometimes removing ≥80% of a lynx population, or is second only to starvation. ". . . [T]rapping of lynx in northern boreal forests should cease during the 3–4 years when hare populations are at their lowest levels. Because hare populations are always at generally low levels in the western mountains, . . . complete protection of lynx populations in the western states may be appropriate to ensure their population persistence" (Koehler and Aubry 1994).

[1]Taxonomy of lynx is unstable, not only at the species level but also at the level of genus. Generic arrangement (*Felis* versus *Lynx*) does not affect the contents of this table. However, specific arrangement does have implications here. For the purposes of this table, the generally (but not universally) accepted division of what some mammalogists (e.g., Tumlison 1987) consider a single Holarctic species, *Lynx* (or *Felis*) *lynx*, into 2 species, 1 of them restricted to the Nearctic (i.e., North America) and called *Lynx* (or *Felis*) *canadensis*, the Canada lynx, is followed here, but with reluctance. Because much of the literature pertaining to lynx combines Nearctic and Palearctic populations, it is often difficult to separate and restrict ecological information to that which pertains only to North America.

[2]This table is intended for use in North America (consistent with the nomenclature used in its title), primarily the western part of the continent and the southern parts of the species' range in western North America (i.e., mountains of western America—especially Colorado, Utah, Wyoming, Montana, Idaho, and Washington), which is where populations of this species are of greatest conservation concern. There are important ecological differences between northern and southern populations. The Canada lynx is a specialist predator, and **the critical factor in Canada lynx ecology and demography is the presence and abundance of its principal prey, the snowshoe hare**, which in the north (and east) undergoes dramatic, 10-year cycles of abundance. Two very important factors in the mountains of western America that affect lynx are: (1) Snowshoe hares exhibit minimal population cycling in these areas, maintaining relatively stable but low populations (comparable to population lows in the north and east), and (2) winter snow depths are much greater in these areas than they are in the north and east, which affects habitat selection (i.e., vegetative characteristics) by snowshoe hares.

[3]Forest stand age is relative to latitude: "Because succession progresses slowly at northern latitudes, older-aged (~40 years old) stands there may provide optimal conditions for hares, whereas at southern latitudes, younger-aged stands (15–30 years old) appear to provide the best habitat for hares" (Koehler and Aubry 1994).

[4]In other seasons snowshoe hares select habitats with characteristics that are different from those selected during winter. "During snow-free periods, thermal cover is not a critical factor and alternate sources of food are available. During these times, hares will occupy habitats that are more open and where hardwoods and herbaceous vegetation are more prevalent . . . . During snow-free months, . . . hares avoided very dense stands where shade created by dense canopy reduces the growth of herbaceous understory" (Koehler and Aubry 1994).

*Most important indicators.

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