1.0 INTRODUCTION

1.1 Background

The Colorado pikeminnow (*Ptychocheilus lucius*) is the largest cyprinid fish endemic to the Colorado River Basin (Tyus 1991). The common name for this species was changed from Colorado squawfish by the American Fisheries Society (Nelson et al. 1998). Adults attain a maximum size of about 1.8 m total length (TL) and 36 kg in weight (Miller 1961). The Colorado pikeminnow is currently listed as "endangered" under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq.*). It was first included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967 (32 FR 4001) and was considered endangered under provisions of the Endangered Species Conservation Act of 1969 (16 U.S.C. 668aa). The Colorado squawfish (pikeminnow) was included in the United States List of Endangered Native Fish and Wildlife issued on June 4, 1973 (38 FR No. 106), and it received protection as endangered under Section 4(c)(3) of the original ESA of 1973. The latest revised Colorado squawfish (pikeminnow) recovery plan was approved on August 6, 1991 (U.S. Fish and Wildlife Service 1991). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994.

The Colorado pikeminnow is a member of a unique assemblage of fishes native to the Colorado River Basin, consisting of 35 species with 74% level of endemism (Miller 1959). It is one of four mainstem, big-river fishes currently listed as endangered under the ESA; others are the humpback chub (*Gila cypha),* bonytail (*Gila elegans*), and razorback sucker (*Xyrauchen texanus*). The native fish assemblage of the Colorado River Basin is jeopardized by large mainstem dams, water diversions, habitat modification, nonnative fish species, and degraded water quality (Miller 1961; Minckley and Deacon 1991).

1.2 Purpose and Scope

This document amends and supplements the Colorado Squawfish Recovery Plan of 1991 (Recovery Plan; U.S. Fish and Wildlife Service 1991). The purpose and scope are to assimilate current information on the life history of the species and status of populations to develop recovery goals associated with the five listing factors that [as specified under Section 4(f)(1) of the ESA] identify site-specific management actions necessary to minimize or remove threats; establish objective, measurable recovery criteria; and provide estimates of the time and costs required to achieve recovery. In developing the recovery goals, the full body of available information pertinent to issues related to species life history and conservation was considered. However, it is not the intent of this document to provide a comprehensive treatise of information on Colorado pikeminnow; a synopsis of the life history that includes a description of habitat requirements is provided in Appendix A. Additional and more detailed information can be found in literature cited in this document and in reports and publications referenced in those citations.

These recovery goals were developed as an amendment and supplement to the Recovery Plan to focus on the requirements of Section 4(f)(1)(B) of the ESA, which requires that the Secretary of

the Interior incorporate into each plan site-specific management actions; objective, measurable criteria; and estimates of the time and costs to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal. The Recovery Plan did not contain those key requirements of the ESA; therefore, these recovery goals take precedence over the Recovery Plan. Recovery programs that include the Colorado pikeminnow (see section 1.3) will direct research, management, and monitoring activities and determine costs associated with recovery. The recovery goals are not intended to include specifics on design of management strategies nor are they intended to prescribe ways that management strategies should be implemented. Those details (and associated costs) need to be developed by the respective recovery programs in their implementation plans.

An important aspect in development of these recovery goals was to attain a balance between reasonably achievable criteria and ensuring the viability and security of the species beyond delisting. Reasonably achievable criteria considered demographic and genetic requirements of self-sustainability in balance with available estimates of carrying capacity. These recovery goals are intended to be used by the U.S. Fish and Wildlife Service (Service) in rule-making processes to downlist and/or delist the Colorado pikeminnow. The Service intends to review, and revise as needed, these recovery goals at least once every 5 years from the date they are made public through a Notice of Availability published in the *Federal Register*, or as necessary when sufficient new information warrants a change in the recovery criteria. Review of these recovery goals will be part of the review of listed species as required by Section 4(c)(2)(A) of the ESA, *"The Secretary shall ... conduct, at least once every five years, a review of all species..."*.

1.3 Recovery or Conservation Programs

Two of the five major endangered-species recovery or conservation programs in the Colorado River Basin include the Colorado pikeminnow (highlighted in Box 1). These are the Upper Colorado River Endangered Fish Recovery Program (UCRRP) and the San Juan River Basin Recovery Implementation Program (SJRRIP). The UCRRP is a recovery program that was initiated under a Cooperative Agreement signed by the Secretary of the Interior on January 22, 1988, as a coordinated effort of State and Federal agencies, water users, energy distributors, and environmental groups to recover the four endangered fishes in the upper basin downstream to Glen Canyon Dam, excluding the San Juan River (U.S. Department of the Interior 1987; Wydoski and Hamill 1991; Evans 1993). It functions under the general principles of adaptive management (see section 5.1.2) and consists of seven program elements, including instream flow protection; habitat

Box 1. Recovery or Conservation Programs

1. ***Upper Colorado River Endangered Fish Recovery Program (UCRRP)***
2. ***San Juan River Basin Recovery Implementation Program (SJRRIP)***
3. Glen Canyon Adaptive Management Program (GCDAMP)
4. Native Fish Work Group (NFWG)
5. Lower Colorado River Multi-Species Conservation Program (MSCP)

restoration; reduction of nonnative fish and sportfish impacts; propagation and genetics management; research, monitoring, and data management; information and education; and program management. The SJRRIP is a similar recovery program, established under a cooperative agreement signed in 1992, to conserve populations of Colorado pikeminnow and razorback sucker in the San Juan River Basin (U.S. Department of the Interior 1995a). As stated in the governing documents of the UCRRP and SJRRIP, the goal is to recover the endangered fishes while water development proceeds in compliance with State and Federal laws, including the ESA, State water law, interstate compacts, and Federal trust responsibilities to American Indian tribes. Funding for the UCRRP and SJRRIP will continue through 2011 under legislation passed in October 2000 (P.L. 106-392); Congress will review the UCRRP and SJRRIP to determine if funding should be authorized beyond 2011.

2.0 THE RECOVERY PROCESS

2.1 Definition of Recovery

Understanding the Service's strategy for recovery of the Colorado pikeminnow, as provided in the ESA and implementing regulations, first requires an understanding of the meaning of "recover" and "conserve". The ESA does not specifically define recover, and the term "recovery" is used with respect to recovery plans *"...for the conservation and survival..."* of listed species. An endangered species, as defined in Section 3(6) of the ESA, means *"any species which is in danger of extinction throughout all or a significant portion of its range."* A threatened species is defined in Section 3(19) of the ESA as *"any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."* According to Service policy (U.S. Fish and Wildlife Service 1990), *"Recovery is the process by which the decline of an endangered or threatened species is arrested or reversed, and threats to its survival are neutralized, so that its long-term survival in nature can be ensured. The goal of this process is the maintenance of secure, self-sustaining wild populations of species with the minimum necessary investment of resources."* The ESA's implementing regulations (50 CFR § 402.02) further define recovery as *"...improvement in the status of listed species to the point at which listing is no longer appropriate under the criteria set out in section 4(a)(1) of the Act."* The policy and regulations use the word recovery a narrow ESA sense, giving it meaning that is different from returning a species to its normal position or condition.

The definition provided for recovery in the implementing regulations and the definition provided for conserve in the ESA have essentially the same meaning. Section 3(3) of the ESA states: *"The terms "conserve," "conserving," and "conservation" mean to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary."* Hence, recovery and conserve both mean to bring a species to the point at which it no longer needs the protection of the ESA, because the species is no longer in danger of extinction throughout all or a significant portion of its range. This definition of recovery falls far short of requiring that a species must be restored to its historic range and abundance before it can be considered

recovered or delisted. It also falls short of requiring the restoration of a species to all the remaining suitable habitat, unless this is necessary to sufficiently reduce the species' susceptibility to threats to a level at which the species is no longer threatened or endangered.

The phrase "throughout all or a significant portion of its range" is used in both definitions of endangered and threatened. Neither "significant" nor "range" are defined in the ESA or implementing regulations. Hence, the ESA provides the Service with latitude to use its discretion, based on the best scientific information available, to develop recovery goals and implement recovery plans designed to conserve and recover species. The ESA clearly does not use the term significant in a statistical sense. Significance cannot be reliably and safely applied in any strictly quantitative framework, because of the great variety of organisms, habitats, and threats that must be evaluated for protection under the ESA.

Given that the ESA is intended to avoid species extinction, the Service avoids the pitfalls of a purely quantitative approach by instead viewing significant in the context of a species' long-term survival needs. The term becomes logical, meaningful, and useful if applied in this context. A significant portion of the range is that area that is important or necessary for maintaining a viable, self-sustaining, and evolving population or populations, in order for a taxon to persist into the foreseeable future. That "significant portion" may constitute a large portion of the historic range of a species or a relatively small portion of the historic range. Other parts of a species' range (regardless of whether it is historical, current, or potential range) may not be significant to its long-term survival, regardless of its geographic extent. Therefore, a species extirpated from such areas does not necessarily mean it is threatened or endangered, regardless of the geographic extent of those areas.

Implicit in the ESA definitions of threatened and endangered and in the principles of conservation biology is the need to consider genetics, demographics, population redundancy, and threats (as identified by the listing factors). The ESA is mandated to recover species to the point that they are "not likely" to be in danger of extinction for the foreseeable future throughout all or a significant portion of their range. The Service believes that the "not likely" standard is exceeded by the requirement of the recovery goals to maintain multiple widespread populations that are independently viable, because it is unlikely that future singular threats will endanger widely separated multiple populations. Viable populations have sufficient numbers of individuals to counter the effects of deleterious gene mutations as a result of inbreeding, and to counter the effects of deaths exceeding births and recruitment failure for periods of time. Thus, the conservation biology principle of redundancy is satisfied by the required multiple genetically and demographically viable, self-sustaining populations (section 3.1.3). Furthermore, the principle of resiliency is satisfied with sufficiently large populations to persist through normal population variations, as well as through unexpected catastrophic events (section 3.1.4).

The principles of recovery and conservation as defined in the ESA, implementing regulations, and Service policy demonstrate the strong relationship between the delisting criteria used for recovery and the five listing factors in Section 4(a)(1) of the ESA. These five listing factors must

be addressed in any reclassification of a species [ESA Section 4(c)(2)(B); section 4.0 of this document], and are:

> "*(A) The present or threatened destruction, modification, or curtailment of its habitat or range;*
> *(B) overutilization for commercial, recreational, scientific, or educational purposes;*
> *(C) disease or predation;*
> *(D) the inadequacy of existing regulatory mechanisms; and*
> *(E) other natural or manmade factors affecting its continued existence.*"

Recovery is based on reduction or removal of threats and improvement of the status of a species during the period in which it is listed, and not just from the time a listed species is proposed for reclassification. Environmental conditions and the structure of populations change over time, and threats recognized at listing or in subsequent recovery plans may no longer be directly applicable when reclassification is considered. Management actions and tasks conducted by recovery or conservation programs for listed species are expected to minimize or remove threats and improve the species' status.

When delisting a species, the Service must determine that the five listing factors no longer apply, e.g., the habitat is no longer threatened with destruction or modification, the current abundance and range is adequate, and the habitat needed to sustain recovered populations is present. Therefore, the recovery goals (section 5.0) include management actions and tasks, as well as downlisting and delisting criteria, presented by "recovery factor". These recovery factors were derived from the five listing factors and state the conditions under which threats are minimized or removed.

Recovery is achieved when management actions and associated tasks have been implemented and/or completed to allow genetically and demographically viable, self-sustaining populations to thrive under minimal ongoing management and investment of resources. Achievement of recovery does not mandate returning a species to all or a significant portion of its historic range, nor does it mandate establishing populations in all possible habitats, or everywhere the species can be established or reestablished. Removing a species from protection of the ESA remands the primary management responsibility of that species to the States, who may choose to further expand its range and populations. The standard of establishing and protecting viable, self-sustaining populations is applied to the recovery of Colorado pikeminnow, and was used in developing recovery goals for the other three endangered fishes of the Colorado River Basin (U.S. Fish and Wildlife Service 2002a, 2002b, 2002c). This approach is consistent with recovery of other vertebrate species, such as the bald eagle (*Haliaeetus leucocephalus*; 64 FR 36453), peregrine falcon (*Falco peregrinus*; 64 FR 46541), desert tortoise (*Gopherus agassizii*; Berry 1999), Pacific salmon (*Oncorhynchus spp.*; Allendorf et al. 1997), and southern sea otter (*Enhydra lutris nereis*; Ralls et al. 1996).

2.2 Recovery Units

Recovery of Colorado pikeminnow in the Colorado River Basin is considered necessary only in the Upper Colorado River Basin because of the present status of populations and because existing information on Colorado pikeminnow biology support application of the metapopulation concept to extant populations (see section 3.1.4). For the purpose of these recovery goals, the upper basin is upstream of Glen Canyon Dam, Arizona, including the San Juan River. The need for self-sustaining populations in the lower basin (i.e., downstream of Glen Canyon Dam) and associated site-specific management actions/tasks necessary to minimize or remove threats will be reevaluated at the status review of the species. The upper basin encompasses two management areas under different and separate recovery programs (i.e., UCRRP and SJRRIP; see section 1.3 for description of geographic coverage by each of the programs). Designation of the recovery units is consistent with goals established by these programs. For example, the governing document for the UCRRP (U.S. Department of the Interior 1987) states: *"Since the recovery plans* [for the Colorado pikeminnow, humpback chub, and bonytail; razorback sucker was not federally listed in 1987, but was included in the UCRRP] *refer to species recovery in both the upper and lower basins, these goals* [recovery/management goals in the original recovery plans] *also apply to both basins, until revised for the upper basin, through implementation of this recovery program. However, the goal of this program for the three endangered species is recovery and delisting in the upper basin. In general, this would be accomplished when the habitat necessary to maintain self-sustaining populations has been determined and provisions are in place to maintain and protect that habitat and these species. The Implementation Committee will be expected to revise these goals for the upper basin as the program develops. Attainment of these goals will result in recovery and delisting of the listed species in the upper basin."* Parties to the UCRRP agreed that the four endangered species could be downlisted and delisted separately in the upper basin. However, the document also states: *"... this program can not, and does not in anyway, diminish or detract from or add to the Secretary's ultimate responsibility for administering the Endangered Species Act."*

The Colorado pikeminnow was listed prior to the 1996 distinct population segment (DPS) policy, and the Service may conduct an evaluation to designate DPSs in a future rule-making process if, in the future, lower basin populations are determined necessary for recovery. In the Policy Regarding the Recognition of Distinct Vertebrate Population (61 FR 4721–4725), the U.S. Fish and Wildlife Service and the National Marine Fisheries Service clarified their interpretation of the phrase *"distinct population segment of any species of vertebrate fish or wildlife"* for the purposes of listing, delisting, and reclassifying species under the ESA. Designation of DPSs is a separate listing process that is different from recovery plans/goals, and is accomplished by a rule-making process. A DPS is a segment of the population and includes a part of the range of a species or subspecies. Like all listings, the DPS is described geographically, but it is important to retain the purpose of the ESA *"...to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved..."*. The elements considered for designation of DPSs are: *"1) Discreteness of the population segment in relation to the remainder of the species to which it belongs; 2) The significance of the population segment to the species to which it belongs; and 3) The population segment's conservation status in relation*

to the Act's standards for listing (i.e., is the population segment, when treated as if it were a species, endangered or threatened?)."

Species listed prior to the DPS policy may be reconsidered for DPS designation at the time of reclassification or at the 5-year status review. The DPS policy states: *"Any DPS of a vertebrate taxon that was listed prior to implementation of this policy will be reevaluated on a case-by-case basis as recommendations are made to change the listing status for that distinct population segment. The appropriate application of the policy will also be considered in the 5-year reviews of the status of listed species required by section 4(c)(2) of the Act."* Section 4(c)(2)(A) of the ESA requires a review of listed species *"at least once every five years"*. If DPSs are designated, these recovery criteria will need to be reevaluated.

2.3 Development of Recovery Goals

Development of recovery goals for the Colorado pikeminnow followed a specific process. First, current data on the life history of the species and on existing populations were assimilated (Appendix A; section 3.0). Second, the assimilated data were used to evaluate population viability and self-sustainability (section 3.0). Third, past and existing threats were identified according to the five listing factors (section 4.0). Finally, site-specific management actions were identified to minimize or remove threats, and objective, measurable recovery criteria were developed based on the five factors (section 5.0). The process of developing the recovery goals was interactive and iterative, and the recovery goals are the product of considerable input from stakeholders and scientists from throughout the Colorado River Basin and from rigorous peer review. Input from biologists and managers throughout the basin was received through meetings with the Colorado River Fishes Recovery Team; Biology, Management, and Implementation committees of the UCRRP; Biology and Coordinating committees of the SJRRIP; Colorado River Fish and Wildlife Council; American Indian tribes; State game and fish agencies; water and power interests; and appropriate Federal agencies. Input was also received through independent reviews of previous drafts (see acknowledgments). Development of these recovery goals considered the approach taken by Lentsch et al. (1998) to develop interim management objectives, and paralleled similar efforts by the Colorado Division of Wildlife and benefitted from exchange of information with the principal author (Nesler 2000).

The process of downlisting and delisting described in this document is consistent with provisions specified under Section 4(b), Basis For Determinations, and Section 4(f)(1), Recovery Plans, of the ESA. Under Section 4(b), the Secretary of the Interior shall determine if a species is endangered or threatened *"...solely on the basis of the best scientific and commercial data available..."*. Specifically, under Section 4(f)(1)(B), each recovery plan must incorporate (i) *"a description of such site-specific management actions as may be necessary to achieve the plan's goal for conservation and survival of the species"*; (ii) *"objective, measurable criteria which, when met, would result in a determination, in accordance with the provisions of this section, that the species be removed from the list"*; and (iii) *"estimates of the time required and cost to carry out those measures needed to achieve the plan's goal and to achieve intermediate steps toward that goal."* Objective, measurable recovery criteria identify downlisting and delisting

requirements for each management action, and define viable, self-sustaining populations consisting of target numbers of adults and subadults for wild populations. Under Section 4(c)(2)(B) of the ESA, each determination of reclassification of a species shall be made in accordance with provisions of Sections 4(a) and 4(b).

3.0 POPULATION VIABILITY AND SELF-SUSTAINABILITY

Population viability and self-sustainability are the cornerstones to defining a recovered species. Factors that determine population viability and self-sustainability are demographics (size and age structure of populations), population redundancy (number and distribution of populations), habitat carrying capacity (resource limitations), and genetic considerations (inbreeding and genetic viability). This section discusses the development of genetic and demographic viability standards for achieving the primary objective of the Recovery Plan, i.e., *"To recover the Colorado squawfish ...by establishing naturally self-sustaining populations..."* (U.S. Fish and Wildlife Service 1991). Guidelines for population viability and self-sustainability are stated in Box 2 (Franklin 1980; Soulé 1980; Shaffer 1987; Allen et al. 1992).

Box 2. Guidelines for Population Viability and Self-Sustainability

- A viable, self-sustaining population has negligible probability of extinction over a 100- to 200-year period.
- A population should be sufficiently large to survive historically observed environmental variation.
- A population should be sufficiently large to maintain long-term genetic diversity and viability.
- Multiple demographically viable (redundant) populations greatly reduce the probability of extinction if the populations are independent in their susceptibility to catastrophic events.
- A viable, self-sustaining population must have positive recruitment potential sufficient to replace adult mortality near carrying capacity, and on average, exceed adult mortality when the population is below carrying capacity.
- Carrying capacity is not expected to be the same for different populations, because physical habitat, water quality, and biological components are likely to vary.

3.1 Demographic Viability

3.1.1 Demographic characteristics, environmental uncertainty, and catastrophic events

Demographic or population viability refers to the persistence of a species over time, as affected by uncertainties in population dynamics. A viable, self-sustaining population has negligible probability of extinction over a 100- to 200-year time frame (Franklin 1980; Soulé 1980).

Population viability can be affected by demographic characteristics, environmental uncertainty, and catastrophic events (Shaffer 1987; Allen et al. 1992). Demographic characteristics relate to random changes in birth and death rates, primarily reflecting differences at the population level. Persistence time for a population faced only with demographic variability increases geometrically as the population increases, and only populations with individuals that number in the "10s to 100s" are vulnerable to extinction due simply to demographic variability (Shaffer 1987). Hence, demographic viability is generally considered to be an issue only with severely depleted populations (Goodman 1987; Allen et al. 1992). Wild populations of Colorado pikeminnow in the Green River and upper Colorado River subbasins are not considered to be severely depleted, and a population-viability analysis conducted by Gilpin (1993) indicated that the species is unlikely to go to extinction. However, the current status of the species is being evaluated through population estimates.

In contrast, population persistence decreases linearly with environmental uncertainty (Shaffer 1987), and thus is of more concern for population viability of Colorado pikeminnow. Environmental uncertainty results from changes in environmental factors such as variability in food supply; weather; population dynamics of predators, competitors, and parasites; and in the case of riverine fishes, variability in seasonal flow characteristics. Many of these environmental factors may be highly correlated to population demographics, such as reproductive success, survival, and recruitment. Population sizes necessary for persistence under environmental variability reflect the resulting variability in birth and death rates (Allen et al. 1992). Specifically linking environmental variability to birth and death rates is difficult (Ewens et al. 1987), and use of a demographic model for Colorado pikeminnow is limited because of the lack of reliable empirical data on these life-history parameters. Population viability analyses (PVA; Gilpin 1993; Soulé 1987; Shaffer 1987) were considered but not employed because of a lack of conclusive data on state and rate variables for the species.

As an alternative to demographic models, the concept of carrying capacity can be used to approximate population sizes and potential. Populations can be viewed as having some potential with respect to resource limitations or theoretical carrying capacity. The variance (V) in potential growth rate (r), without limitations of carrying capacity, has to be sizably greater than r ($V > 2r$) before the population is susceptible to extinction, otherwise the population tends toward the carrying capacity (Roughgarden 1979). For the Colorado pikeminnow, increasing population sizes of adults suggests that recruitment is greater than adult mortality for this species. It is doubtful that environmental uncertainty will affect Colorado pikeminnow populations that meet genetic considerations if the environment is protected and secured against changes that exceed environmental stochasticity for the species; e.g., anthropogenic changes such as dams and introductions of nonnative fish species can impose environmental conditions that exceed the range of conditions experienced by the species historically.

Catastrophic events, however, could dramatically impact Colorado pikeminnow populations. Catastrophic events are rare incidents that may cause sizable mortality in one or more age groups. A catastrophe is an event that would, with a single act, eliminate one or more ages of Colorado pikeminnow in a reach of river. This may include such factors as dramatic and extensive alteration of riverine habitat, invasion of nonnative fishes as highly successful

predators or competitors, or spills of toxic substances. Abundance and distribution of Colorado pikeminnow were greatly reduced by the 1930's as a result of land-use practices, degraded water quality, and nonnative fishes (Dill 1944; Miller 1961). Colorado pikeminnow were extirpated from the Lower Colorado River Basin shortly after construction of major mainstem dams because direct and indirect effects of these dams affected specific life-history events by impeding passage to spawning, feeding, and nursery areas; causing reproductive failure from cold-water releases; and reducing survival through the introduction of successful nonnative predators and competitors. A rotenone treatment in Flaming Gorge Canyon in the early 1960's killed unknown numbers of Colorado pikeminnow (Holden 1991) but did not extirpate the species from the Green River, nor did an oil spill on the Yampa River in 1987. In order for the Colorado pikeminnow to be extirpated from a large portion of its existing range, a catastrophe would have to be of the magnitude where the entire ecosystem is fragmented and altered.

The Colorado pikeminnow is a long-lived fish (40+ years; Osmundson et al. 1997) that evolved in a variable system, with high adaptability to natural environmental variability and resilience to natural catastrophes. This evolution has become manifest as pulsed recruitment from periodic strong year classes, great longevity of adults, and low vulnerability of adults to environmental influences. Great longevity and stability of adults provides a "storage effect" for populations, into which periodic recruitment from strong year classes allows fish to become stored (Gilpin 1993). This is seen as a way that Colorado pikeminnow maintain long-term population viability and stability under environmental variation.

A critical aspect of recovery is increased frequency of strong year classes. Strong year classes of Colorado pikeminnow have been linked to years immediately following wet hydrologic conditions resulting in high spring-runoff flows (McAda and Ryel 1999; Valdez et al. 1999). High to moderate spring flows rework sediment deposits, which seems to increase larval survival and results in a strong year class (Van Steeter and Pitlick 1998; Osmundson 1999). Characteristically, two or three strong year classes occur in consecutive years, with a recurrence interval of 7–10 years. Shortening this recurrence interval by increasing the frequency of high spring flows increases the likelihood of greater recruitment, population expansion, and long-term stability. Mid-summer, rain-induced flow spikes have been linked to spawning cues (Nesler et al. 1988) and may stimulate reproduction and add to the success of strong year classes.

3.1.2 Existing populations of Colorado pikeminnow

Three wild populations of Colorado pikeminnow are found in about 1,753 km of riverine habitat in the Green River, upper Colorado River, and San Juan River subbasins (Table 1, Figure 1; Appendix A). Occupied habitat occurs in the Green River from Lodore Canyon to the confluence of the Colorado River (Tyus 1991; Bestgen and Crist 2000); the Yampa River downstream of Craig, Colorado (Tyus and Haines 1991); the Little Snake River from its confluence with the Yampa River upstream into Wyoming (Marsh et al. 1991; Wick et al. 1991); the White River downstream of Taylor Draw Dam and Kenney Reservoir (Tyus and Haines 1991); the lower 143 km of the Price River (Cavalli 1999); the lower Duchesne River; the upper Colorado River from Palisade, Colorado, to Lake Powell (Valdez et al. 1982a; Osmundson et al. 1997, 1998); the lower 54 km of the Gunnison River (Valdez et al. 1982b; Burdick 1995); the

Table 1. Occupied habitat of wild Colorado pikeminnow in the Upper Colorado River Basin and limits to distribution.

River	Occupied Habitat	Limits to Distribution
Green River Subbasin		
1. Green River	Lodore Canyon to Colorado River confluence (580 km)	Cold releases from Flaming Gorge Dam have been warmed and species has naturally expanded upstream into Lodore Canyon; species distributed continuously downstream to Colorado River confluence
1a. Yampa River	Craig, Colorado, to Green River confluence (227 km)	Present distribution similar to historic
1b. Little Snake River	Wyoming to Yampa River confluence (80 km)	Habitat is marginal; flows are reduced; historic distribution unknown
1c. White River	Taylor Draw Dam to Green River confluence (100 km)	Upstream distribution blocked by Taylor Draw Dam
1d. Price River	Lower 143 km above Green River confluence	Streamflow reduced; barriers occur above current distribution
1e. Duchesne River	Lower 10 km above Green River confluence	Streamflow reduced; barriers occur above current distribution
Upper Colorado River Subbasin		
2 Upper Colorado River	Palisade, Colorado, to Lake Powell inflow (298 km)	Passage by Grand Valley Diversion completed in 1998; Price-Stubb and Government Highline diversion dams restrict upstream distribution; Lake Powell inflow defines downstream distribution
2a. Gunnison River	Lower 54 km above Colorado River confluence	Redlands Fishway allowed passage in 1996; upstream distribution is limited by Hartland Diversion Dam and possibly cold-water releases from the Aspinall Unit
2b. Dolores River	Lower 2 km above Green River confluence	Streamflow altered; no barriers in potential historic habitat
San Juan River Subbasin		
3. San Juan River	Shiprock, New Mexico, to Lake Powell inflow (241 km)	Irrigation diversions block upstream movement; Lake Powell defines downstream distribution

lower 2 km of the Dolores River (Valdez et al. 1992); and 241 km of the San Juan River downstream from Shiprock, New Mexico, to the Lake Powell inflow (Jordan 1891; Koster 1960; Olson 1962; Holden 1999; Propst 1999). Natural reproduction of Colorado pikeminnow is currently known from the Green, Yampa, upper Colorado, Gunnison, and San Juan rivers.

Recent preliminary estimates of abundance summed for the three Colorado pikeminnow populations range from about 6,600 to 8,900 wild adults. The precision and reliability of these estimates vary, and approximate numbers are provided as a general indication of the size of populations in the basin. Estimates of subadults are not currently available for all populations, and precise estimates of adults and subadults will be developed in order to determine if demographic criteria are met for downlisting and delisting. Estimates of adults for the three subbasins are: Green River, 6,000–8,000 (Nesler 2000; personal communication, K. Bestgen,

Figure 1. Distribution of wild Colorado pikeminnow in the Colorado River Basin.

Colorado State University); upper Colorado River, 600–900 (Nesler 2000; Osmundson 2002 [includes some subadults]); and San Juan River, 19–50 (Holden 1999; personal communication, D. Ryden, U.S. Fish and Wildlife Service).

Two principal spawning sites have been identified in the Green River subbasin (Tyus 1990). Crowl and Bouwes (1998) estimated that 1,000 adults were associated with the spawning site near Three Fords Canyon in Gray Canyon of the lower Green River, and 1,400 adults were associated with the spawning site in the lower 32 km of the Yampa River. Fish associated with the two spawning sites may be demographically independent with individual stock-recruitment characteristics (personal communication, T. Modde, U.S. Fish and Wildlife Service), but overlap in adult and juvenile distributions and no significant differences in allele frequencies suggest essential panmixia or mixing of these two stocks (Ammerman and Morizot 1989; Williamson et al. 1999; Morizot et al. 2002). Fish in the upper Colorado River subbasin are believed to spawn near Grand Junction, Colorado, and in the lower Gunnison River (personal communication, C. McAda, U.S. Fish and Wildlife Service).

In addition to adults, age-0 fish and juveniles are found in the lower Yampa River; Green River downstream of the Yampa River confluence; upper Colorado River downstream of Palisade, Colorado, to the Lake Powell inflow, Utah; and lower 40 km of the Gunnison River. Small numbers of age-0 Colorado pikeminnow have been collected in the San Juan River (Holden 1999). Subadults and small adults have also been found in the lower Price, Duchesne, and White rivers (Tyus and Haines 1991; Cavalli 1999; Muth et al. 2000). The Interagency Standardized Monitoring Program (ISMP) of the UCRRP (McAda et al. 1994a, 1994b, 1995, 1996, 1997) has determined catch-rate indices of age-0 and subadult fish in the Green and upper Colorado rivers since 1988. Average of geometric mean catch-per-effort (CPE) during 1986–1997 for Reach 1 (lower Colorado River), Reach 2 (upper Colorado River), Reach 3 (lower Green River), and Reach 4 (upper Green River) are approximately 0.4, 0.03, 1.5, and 0.4 fish/10 m^2, respectively. Numbers of age-0 and subadult fish in the other rivers are low, but with no extensive surveys, except for the San Juan River. All data collected under ISMP for age-0 are catch-rate indices, with a few mark-recapture estimates in backwaters (Haines et al. 1998).

Efforts to reestablish populations of Colorado pikeminnow have taken place in the Lower Colorado River Basin and the San Juan River. Over 623,000 Colorado pikeminnow were reintroduced into the Salt and Verde rivers, tributaries of the Gila River subbasin in Arizona, during 1981–1990 (Hendrickson 1994). These reintroductions were part of conservation efforts and considered nonessential experimental populations [Section 10(j) of the ESA]. Long-term survival was not reported as a result of these releases (Maddux et al. 1993), but some of these stocked fish still persist in the Verde River. Also, over 300,000 hatchery-produced Colorado pikeminnow have been released in the mainstem as part of the SJRRIP (Ryden and Ahlm 1996; Holden 1999; personal communication, F. Pfeifer, U.S. Fish and Wildlife Service).

3.1.3 Populations of Colorado pikeminnow as redundant units

Maintaining several populations with relatively independent susceptibility to threats is an important consideration in the long-term viability of a species (Shaffer 1987; Goodman 1987).

These redundant populations provide security in case of a catastrophic event or repeated year-class failure. The positive effect of relatively independent populations can be demonstrated by the following examples. Consider that a single population has a probability of extinction from a catastrophic event of 10% in 200 years. If two populations are independent, the probability of both going extinct is 1% (0.1^2). For three populations, the probability reduces to 0.1% (0.1^3). Even with an extinction probability of 25% for one population, the probability of extinction for two and three populations is 6.3% and 1.6%, respectively. Maintenance of Colorado pikeminnow populations in discrete subbasins contributes to redundancy as protection against threats and catastrophic events simultaneously affecting all or most populations. The migratory nature of the species and connectedness of the riverine system allows individuals to repopulate patches in the event of local extirpation.

3.1.4 Colorado pikeminnow as a metapopulation

The metapopulation concept is a natural phenomenon that should be considered when evaluating species persistence. A metapopulation is defined as a network of populations or subpopulations that have some degree of intermittent or regular gene flow among geographically separate units occupying habitat patches (Meffe and Carroll 1994). Populations that make up a metapopulation exist along a continuum of connectedness, with no clear break points, from totally isolated units to those that experience regular and high gene flow (Ehrlich and Murphy 1987; Harrison et al. 1988). Connectedness among units of a metapopulation may vary seasonally or annually (U.S. Fish and Wildlife Service 1995), and the best way to identify population units is that they have some ecological and evolutionary significance (Hanski and Gilpin 1997). Under metapopulation dynamics, habitat patches that become unoccupied due to local extirpations may become repopulated by dispersing individuals from other subpopulations. Metapopulations depend on the ability of individuals to disperse and repopulate empty patches in a manner timely enough to ensure that sufficient numbers of patches always contain viable subpopulations.

Colorado pikeminnow in the Upper Colorado River Basin are distributed in three geographically separate subbasins, where the migratory nature of the species and documented mixing of stocks indicate that Colorado pikeminnow function as a metapopulation (see section 3.1.2 and Appendix A). The largest self-sustaining population occurs in the Green River subbasin with direct and unimpeded riverine connection to a smaller self-sustaining population in the upper Colorado River subbasin. Colorado pikeminnow in San Juan River subbasin are separated from the other two subbasins by about 320 km across Lake Powell, habitat not normally inhabited by Colorado pikeminnow, but through which passage is possible. Several adults have been captured in this reservoir (Valdez 1990); most recently near Bullfrog, Utah (personal communication, W. Gustaveson, Utah Division of Wildlife Resources), a midpoint between the San Juan River and upper Colorado River, but movement of Colorado pikeminnow between these subbasins has not been documented. Several tagged adults have been recaptured to substantiate exchange of Colorado pikeminnow between the Green and upper Colorado rivers (personal communication, C. McAda, U.S. Fish and Wildlife Service). Gilpin (1993) hypothesized that mixing of Colorado pikeminnow from the Green River and upper Colorado River subbasins also occurs when young fish in downstream areas begin to mature and return randomly to upstream feeding and spawning areas. High densities of age-0 Colorado pikeminnow have been found below the confluence of

the Green and Colorado rivers and in the Lake Powell inflow (Valdez 1990), suggesting that fish from both systems are transferred passively or move actively downstream and mix in these regions. Longitudinal distributions show decreasing sizes of fish with distance downstream, and tag-recapture data show fish moving back upstream as they mature (Valdez et al. 1982a; Osmundson et al. 1998). Gilpin (1993) hypothesized that this upstream return by subadults provides connectivity and gene flow between the Green and upper Colorado rivers, resulting in a panmictic population for the entire upper basin with evidence of source/sink dynamics. Although Colorado pikeminnow show fidelity to four primary spawning locales (Tyus 1985, 1991), fish in the Green River and upper Colorado River subbasins are linked genetically, based on movement throughout the system and lack of genetic separation (Ammerman and Morizot 1989; Gilpin 1993). Williamson et al. (1999) and Morizot et al. (2002) reported that Colorado pikeminnow from the San Juan River are genetically similar to fish from the Green River and upper Colorado River subbasins, and they suggested that exchange of genes occurred historically and may continue today.

Populations of Colorado pikeminnow within the Green River and upper Colorado River subbasins consist of separate spawning stocks, whose progeny and adults mix (see section 3.1.2 and Appendix A). Two spawning stocks are recognized in the Green River subbasin; fish spawn in the lower Yampa River (i.e., Cleopatra's Couch) and in lower Desolation/Gray Canyons (i.e., Three Fords). Radio telemetry studies show considerable fidelity of adults to respective spawning locations, but with some exchange of adults between these spawning locations on different years. Young produced in the lower Yampa River drift downstream and nurse primarily in alluvial backwaters upstream of Desolation/Gray Canyons, and young produced in lower Desolation/Gray Canyons nurse primarily in alluvial backwaters downstream of Desolation/Gray Canyons. There is considerable downstream transport and movement of these young fish and, eventually, there is mixing of these age-0 fish, as well as the juveniles, such that the progeny of the two stocks become mixed and indistinguishable. Hence, although there are two separate and distinct spawning stocks in the Green River subbasin, there is only one mixed population. A similar situation exists for the upper Colorado River subbasin, where spawning occurs in the mainstem Colorado River and the Gunnison River. Although stock recruitment dynamics are not well documented, exchange of adults between the upper Colorado and Gunnison rivers is documented through a selective fish passage structure in the lower Gunnison River.

3.2 Carrying Capacity

Carrying capacity is the theoretical size of a population that can be sustained by the existing environment, and is determined by population demographics and resource limitations (i.e., limiting factors), including habitat. Functional carrying capacity is the population at its equilibrium state in the presence of resource limitations, and is determined as the level where births equal deaths, or lambda (λ) is equal to 1.0 (Begon et al. 1990). Potential carrying capacity is the maximum possible population size with resource limitations minimized or removed.

Carrying capacity of Colorado pikeminnow is not expected to be the same for different populations because physical habitat (e.g., river channel, flow, and cover), chemical constituents

(water quality), and biological components (e.g., food and predators) are likely to vary among river reaches. Hence, the same or even similar numbers and densities of fish in each population should not be expected for recovery. Carrying capacity, as a function of recovery, must be considered on its own merits for each population.

3.2.1 Green River

For the period 1986–1997, the catch of adult Colorado pikeminnow per hour of electrofishing in the Green River steadily increased (McAda et al. 1998; Figure 2). Catch rates from the 1986–1988 period to the 1996–1997 period increased by three-fold from about 0.8 fish/hour to about 2.5 fish/hour. Relative condition of adult Colorado pikeminnow in the Green River declined between these two time periods, suggesting that the population was at or near carrying capacity under existing conditions. Recently, small adult Colorado pikeminnow have moved into the Price River, where they were not reported from surveys in the 1970's (Cavalli 1999), also suggesting dispersal as a result of carrying capacity.

3.2.2 Upper Colorado River

Preliminary estimates of Colorado pikeminnow carrying capacity in the upper Colorado River were provided by Osmundson (1999). These estimates are based on existing population abundance, prey abundance and distribution, and water temperature regime for 298 km of the upper Colorado River from the Green River confluence to the Grand Valley Diversion near Palisade, Colorado. Estimates of Colorado pikeminnow (includes some subadults) in the uppermost 98 km (upstream of Westwater Canyon) increased from 205 in 1991 to 332 in 1994 and 435 in 1998 (Osmundson and Burnham 1998; Osmundson 1999), an increase of 112% during the 8-year period. Relative condition of adult Colorado pikeminnow in this upper reach remained constant during 1991–1994 but declined significantly with higher numbers in 1998 (Osmundson 1999), suggesting that carrying capacity had been reached or exceeded at about 435 Colorado pikeminnow, or about 4 fish/km. One possible explanation for increased dispersal, as indicated by increased numbers of adults migrating into the Gunnison River through the Redlands Fishway (1 in 1996, 18 in 1997, and 23 in 1998), is density-dependent dispersal from populations at or near carrying capacity under existing conditions.

Estimates of adult Colorado pikeminnow (includes some subadults) in 180 km of the upper Colorado River downstream of Westwater Canyon increased from 224 in 1992 to 512 in 1993 but decreased to 297 in 1994, for an average of 344 fish, or about 2 fish/km. Condition of Colorado pikeminnow declined following the 1991–1994 period, suggesting that the population was also at or near carrying capacity at current conditions (Osmundson 1999). In 1998, the estimates of Colorado pikeminnow upstream and downstream of Westwater Canyon were 435 and 330, respectively for a total of 765. Total estimates in 1999 and 2000 were 768 and 801 fish, respectively. Concurrent with these increases in population estimates, catch of adult Colorado pikeminnow per hour of electrofishing increased steadily for the period 1986–1997 (McAda et al. 1998; Figure 3). Catch rates from the 1986–1990 period to the 1995–1997 period increased by over ten times from about 0.1fish/hour to about 1.2 fish/hour.

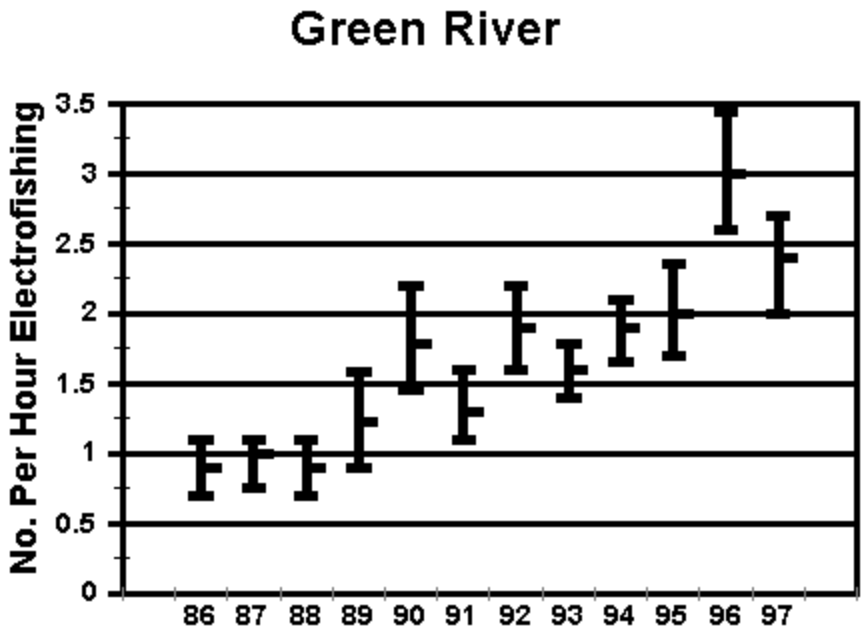

Figure 2. Mean catch rate (fish per hour of electrofishing) for Colorado pikeminnow in the Green River during spring ISMP sampling in 1986–1997. Bars indicate ± 1 standard error.

Osmundson (1999) estimated a carrying capacity of 700 adult Colorado pikeminnow for the Colorado River from the Grand Valley Diversion Dam to the Green River confluence and the lower 3.5 km of the Gunnison River based on forage base, thermal units, and fish condition. He also hypothesized that carrying capacity could be increased to 1,000 adults through range expansion by providing fish passage into a total of 22 km of the upper Colorado River (past the Grand Valley, Price-Stubb, and Government-Highline diversions) and into a total of 54 km of the lower Gunnison River from the recent Redlands Fishway. This range expansion constitutes year-around home-feeding range for adult Colorado pikeminnow, based on prey supply and a threshold of 40 annual thermal units (ATU; Kaeding and Osmundson 1989). Water-temperature augmentation in the Gunnison River, by modifying penstocks at Aspinall Unit dams, could expand the ATU threshold upstream about 40 km and hypothetically increase carrying capacity to 1,200 adults. This translates to densities of about 4 adults/km for the upper reach and about 3 adults/km (present density) for the lower reach. Penstock modification at Aspinall Unit dams has not been investigated to determine if water-temperature augmentation is feasible.

3.2.3 San Juan River

Under the current conditions, carrying capacity of Colorado pikeminnow in the San Juan River is estimated at 800 adults, based on a majority opinion of members of the San Juan Biology Committee. This estimate of carrying capacity is preliminary and subject to revision.

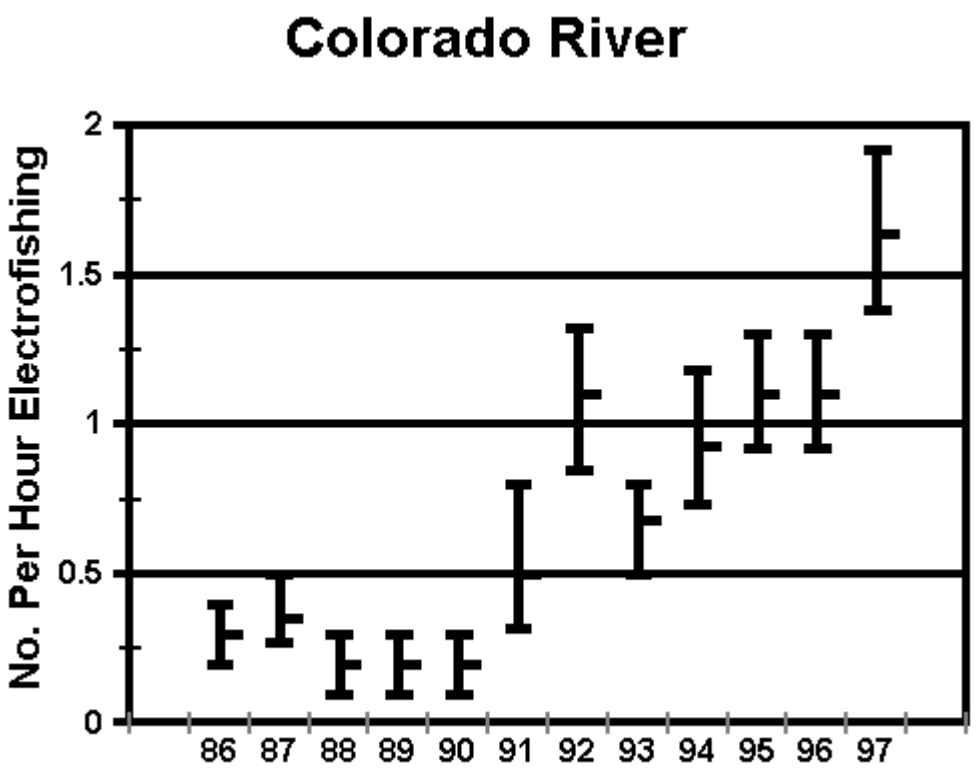

Figure 3. Mean catch rate (fish per hour of electrofishing) for Colorado pikeminnow in the Colorado River during spring ISMP sampling in 1986–1997. Bars indicate ± 1 standard error.

3.3 Genetic Viability

Genetic viability describes the pool of genetic diversity adequate to allow a population of animals to survive environmental pressures that may exceed the limits of developmental plasticity (Frankel 1983). Genetically viable populations maintain 90% of the genetic diversity present in the ancestral (pre-disturbance) population for 200 years (Soulé 1980; Soulé and Wilcox 1980; Soulé and Simberloff 1986). Ammerman and Morizot (1989) reported that Colorado pikeminnow maintain a high level of heterozygosity throughout their natural range. Genetic variability consists of within-population genetic diversity and genetic variation found among linked populations or stocks (Meffe 1986; Meffe and Carroll 1994), such as populations in the Green River and upper Colorado River subbasins. Genetic concepts that were considered are summarized in Box 3.

3.3.1 Genetic effective population size

One way to judge genetic viability is through consideration of "genetic effective population size" (N_e), which is the number of individuals contributing genes to the next generation (Crow and Kimura 1970; Gilpin and Soulé 1986; Soulé 1987; Allendorf et al. 1997). N_e was derived in

Box 3. Genetics Concepts and Considerations

- Genetic viability describes the pool of genetic diversity adequate to allow a population of animals to survive environmental pressures that may exceed the limits of developmental plasticity.
- Genetic variability consists of within-population genetic diversity and genetic variation found among linked populations.
- Genetic effective population size (N_e) is the number of individuals contributing genes to next generation.
- Rate of inbreeding is an index of the amount of genetic exchange among closely related individuals and is of particular importance because it may result in offspring that are sterile or inviable after one to several generations.
- N_e of at least 50 adults avoids inbreeding depression and is necessary for conservation of genetic diversity in the short-term; N_e of 500 is needed to avoid serious long-term genetic drift; N_e of 1,000 provides a conservative estimate beyond which significant additional genetic variation is not expected.
- Minimum viable population (MVP) is defined as a population that is sufficiently abundant and well adapted to its environment for long-term persistence without significant artificial demographic or genetic manipulations.

order to gauge the number of adults needed in a population to maintain genetic viability. The concept of N_e was defined by Wright (1931) as the size of an ideal population whose genetic composition is influenced by random processes in the same way as the real population. Low heterozygosity is the dynamic result of low N_e, and N_e likely differs by species (Meffe 1986). The concept of N_e was used to determine if wild populations are at risk genetically, but lack of genetic structural characterization with functional relationships for Colorado pikeminnow precludes a specific determination of N_e at this time. In the absence of this information, N_e for Colorado pikeminnow was derived from principles in conservation genetics by using the "50/500 rule" (Franklin 1980). It has been suggested that a minimum genetic effective population size of 50 is required to avoid inbreeding depression (Soulé 1980), and a minimum genetic effective population size of 500 is required to reduce long-term genetic drift (Franklin 1980). Lynch (1996) suggested an N_e of 1,000 as the number of adults beyond which significant additional genetic variation is not expected. An N_e of 500 is commonly used for fishes (Waples 1990; Bartley et al. 1992; Allendorf et al. 1997) and other vertebrate species (Mace and Lande 1991; Ralls et al. 1996), therefore an N_e of 500 was used to derive an estimate of the number of adults needed to maintain genetic viability of a population of Colorado pikeminnow. Recent research by fish geneticists support use of the 50/500 rule (Reiman and Allendorf 2001). An important consideration to genetic viability is maintaining natural connectedness and potential for gene flow among populations, regardless of size (Reiman and Dunham 2000). For Colorado pikeminnow populations in the Green River and Colorado River subbasins, natural connection is maintained and gene exchange indicates panmixis (Morizot et al. 2002).

It is important to note that the number of individuals in a population required to achieve a genetic effective population size of 500 may be several times greater than 500 (Frankel and Soulé 1981). Sex ratio and proportion of breeding individuals in the population are two important considerations in deriving the number of individuals necessary to support N_e. A 3:1 male to female ratio is used as the effective sex ratio for Colorado pikeminnow based on a consensus decision of biologists (Lentsch et al. 1998). To maintain an N_e of 500 with a 3:1 sex ratio the total number of breeding adults (N_b) must be increased according to the following relationship:

$$N_e = 4M_bF_b/M_b+F_b \qquad [1]$$

where: M_b = number of breeding males,
F_b = number of breeding females, and
$N_b = M_b + F_b$.

The number of breeding males (M_b) needed is 499 and the number of breeding females (F_b) is 167 for a total of 666 adults needed to maintain an N_e of 500. Hence, according to Equation [1]:

$$N_e = 4(499)(167)/666 = 500 \qquad [2]$$

If all adults in a population breed every year and contribute genes to the following generation, some minimum number of adults (N_g) would equal N_e. However, as with most populations, it is believed that not all Colorado pikeminnow spawn every year or contribute genes to the following generation, and hence, N_g is not equal to N_e. It is important to determine a ratio of genetic effective population size (N_e) to minimum population size (N_g), or N_e/N_g.

For various fish species (rainbow trout, *Oncorhynchus mykiss*; chinook salmon, *O. tshawytscha*; white seabass, *Atractoscion nobilis*), the ratio N_e/N_g varies from 0.013 to 0.90 (Table 2; Bartley et al. 1992; Avise 1994; Hedrick et al. 1995; Allendorf et al. 1997) for an overall average of about 0.30, which is the ratio reported for chinook salmon (McElhany et al. 2000) and other Pacific salmon species (Waples et al. 1990a, 1990b). This overall average ratio for fishes of 0.30 was used to determine the number of adult Colorado pikeminnow needed to support an N_e of 500. Mace and Lande (1991) reported that the genetic effective population size is typically 20–50% of the actual population size.

Table 2. Estimates of effective/actual population size (N_e/N_g) ratios for various fish species.

Species	N_e/N_g	Reference
Sea bass (*Atractoscion nobilis*)	0.27–0.40	Bartley et al. (1992)
Coho salmon (*Oncorhynchus kisutch*)	0.24	Simon et al. (1986)
Rainbow trout (*Oncorhynchus mykiss*)	0.90	Bartley et al. (1992)
Chinook salmon (*Oncorhynchus tshawytscha*)	0.013–0.043	Bartley et al. (1992)
Chinook salmon (*Oncorhynchus tshawytscha*)	0.30	McElhany et al. (2000)

Using an N_e of 500, a 3:1 sex ratio, and an N_e/N_g ratio of 0.30, an estimated N_g of 2,217 was derived as the estimated number of adult Colorado pikeminnow necessary to maintain a genetic effective population size. This approach does not imply that existing populations should be allowed to decrease to this level; the estimate of 2,217 is used as a gauge to evaluate genetic viability of isolated populations.

3.3.2 Minimum viable population

Genetic effective population size provides a gauge for genetic viability but does not necessarily account for demographic viability. The concept of a minimum viable population (MVP) is defined as a population that is sufficiently abundant and well adapted to its environment for long-term persistence without significant artificial demographic or genetic manipulations (Shaffer 1981; Soulé 1986, 1987; Soulé and Simberloff 1986). Meffe and Carroll (1994) define an MVP as *"the smallest isolated population size that has a specified percent chance of remaining extant for a specified period of time in the face of foreseeable demographic, genetic, and environmental stochasticities, plus natural catastrophes."* Use of MVP does not mean that populations should be allowed to drop to these levels, but is used to assess their genetic and demographic viability. It must be recognized that some populations of any wild animal species may be below an MVP, as dictated by carrying capacity. It cannot be expected that every population will exceed an MVP; linkages to other populations help to keep smaller populations viable. As stated by Thomas (1990), *"There is no single 'magic' population size that guarantees the persistence of animal populations."* Thomas (1990) also stated that MVPs are rarely lower than a few 100 individuals and often correspond to an actual population count of about 1,000.

A minimum viable population size of 2,600 adults was derived by adding 15% to the N_g of 2,220 to account for an estimate of the average annual mortality of adult Colorado pikeminnow (2,220 x 1.15 = 2,553 or about 2,600; Box 4; Osmundson and Burnham 1998). An average annual adult mortality factor was added to buffer against an event that may result in recruitment failure for a year. The concept of adding a mortality factor to a genetically viable population as demographic security is taken from recovery criteria established for the southern sea otter, in which the estimated mortality from exposure to simulated oil spills was added to the estimate of N_g, based on an N_e of 500 (Ralls et al. 1996).

Box 4. Computation of Minimum Viable Population (MVP)

$$N_g = N_e/(N_e/N_g)$$

where: N_e = genetic effective population size, 666

N_e/N_g = proportion of adults contributing genes to next generation; ~0.30 for most fish

therefore: $N_g = 666/0.30$

$N_g = 2{,}220$

hence: MVP = 2,220 x 1.15 = 2,553 (rounded to 2,600)

where: 1.15 compensates for annual adult mortality of 15%

The population of Colorado pikeminnow in the Green River subbasin is the largest and most important unit of the upper basin metapopulation. It contains sufficient numbers of adults to

ensure genetic and demographic viability, and subadult numbers show that reproduction and recruitment provide self-sustainability (see Appendix A). Maintenance of the Green River subbasin population is vital for the upper basin metapopulation that includes the upper Colorado River subbasin and potentially the San Juan River subbasin.

4.0 THREATS TO COLORADO PIKEMINNOW BY LISTING FACTOR

The Colorado pikeminnow was designated as an endangered species prior to enactment of the ESA, and a formal listing package identifying threats was not assembled. Construction and operation of mainstem dams, nonnative fish species, and local eradication of native minnows and suckers in advance of new human-made reservoirs in the early 1960's were recognized as early threats (Miller 1961; Holden 1991), and the species was included in the United States List of Endangered Native Fish and Wildlife on June 4, 1973 (38 FR No. 106). A description of Threatened Wildlife of the United States compiled by the Office of Endangered Species and International Activities (U.S. Bureau of Sports Fisheries and Wildlife 1973) identified the reasons for decline of the Colorado pikeminnow as:

> *"Modification of habitat by man through construction of large reservoirs. The species will not reproduce in cold tailwaters below high dams nor in reservoirs behind these dams. The species is adapted to life in turbid, swift, warm rivers. Introduced fishes may have a decimating effect in waters not affected by dams."*

Although habitat losses were documented, the threats were poorly understood and distribution and abundance of the species were not well known. Threats were further identified in the Recovery Plan (U.S. Fish and Wildlife Service 1991):

> *"In summary, the absolute cause for the decline of Colorado squawfish is not fully understood but is probably related to a combination of factors, including direct loss of habitat, changes in flow and temperature, blockage of migration routes, and interaction with introduced fish species."*

Hence, the primary threats to Colorado pikeminnow populations are streamflow regulation and habitat modification (including cold-water dam releases, habitat loss, and blockage of migration corridors); competition with and predation by nonnative fish species; and pesticides and pollutants (Box 5). These threats are associated with the five listing factors (see section 2.1), and a summary of each is presented in the following sections. Site-specific management actions and objective, measurable criteria associated with five recovery factors to minimize or remove threats are provided in section 5.0.

Box 5. Primary Threats To Colorado Pikeminnow

- Streamflow regulation.
- Habitat modification.
- Competition with and predation by nonnative fish species.
- Pesticides and pollutants.