APPENDIX A.

LIFE HISTORY OF THE COLORADO PIKEMINNOW

Following is a synopsis of Colorado pikeminnow life history. This assimilation of information represents an overview of the best scientific information available for the species at this time. Additional and more detailed information can be found in literature cited in this document and in reports and publications referenced in those citations.

A.1 Species Description

The Colorado pikeminnow is the largest member of the minnow family (Cyprinidae) in North America, with an estimated maximum total length (TL) of about 1.8 m and weight of 36 kg (Miller 1961). These large individuals were reported from the lower basin in the late 1800's and early 1900's. Largest confirmed weights are 12.2 and 15.5 kg in the 1950's from the lower basin (Wallis 1951), and about 11.4 kg in the 1990's from the upper basin (personal communication, T. Chart, U.S. Bureau of Reclamation). The species was known as the "salmon", "white salmon", "whitefish" (Evermann and Rutter 1895), and "Colorado River salmon" (Measeles 1981), although it was officially described as the "Colorado squawfish" (Girard (1856). The common name was recently changed to the Colorado pikeminnow (Nelson et al. 1998).

The Colorado pikeminnow is a long, slender, cylindrical fish with silvery sides, greenish back, and creamy-white belly. The tail trunk is thick with a triangular black patch at the base of the caudal fin. The head is large with a terminal mouth and thickened lips and jaws that lack teeth, and a maxillary (upper jaw) that extends past the middle of the eye. Large adults are silvery-white throughout and salmon-like in appearance. Spawning adults in June–August are tinged with light rosy-red on the head and body, with pimple-like tubercles on the head and paired fins. Dorsal and anal fins typically have 9 principal rays each. Scales are small, cycloid, and silvery with 83–87 along the lateral line. Teeth of the pharyngeal arch are spaced apart and barely hooked in a typical pattern of 2,5-4,2 (Girard 1856).

A.2 Distribution and Abundance

The Colorado pikeminnow is endemic to the Colorado River Basin, where it was once widespread and abundant in warm-water rivers and tributaries (Kirsch 1889; Jordan and Evermann 1896; Tyus 1991; Quartarone 1995). It was common in the lower basin in California and Arizona, where it was commercially harvested in the early 1900's (Minckley 1973). Numbers in the lower basin declined in the 1930's (Miller 1961), with few caught in the 1960's (Minckley 1973), and the last specimens reported in the mid-1970's (Moyle 1976; Minckley 1985).

The species was first reported in the upper basin in 1825 by Colonel William H. Ashley (Morgan 1964), and it was common to abundant in the Green and upper Colorado rivers and their tributaries (Banks 1964; Vanicek 1967; Holden and Stalnaker 1975; Seethaler 1978). It was

found from Rifle, Colorado, downstream in the mainstem upper Colorado River (Beckman 1963); from Delta, Colorado, downstream on the Gunnison River (Burdick 1995); and from Paradox Valley downstream on the Dolores River (Lynch et al. 1950). In the Green River, it was reported as far upstream as Green River, Wyoming (Ellis 1914; Baxter and Simon 1970); from Craig, Colorado, downstream on the Yampa River; from Rangely, Colorado, downstream and in the White, lower Price, and Duchesne rivers (Tyus and Haines 1991; Cavalli 1999; Muth et al. 2000).

Wild populations of Colorado pikeminnow are found only in the upper basin, and the species currently occupies only about 25% of its historic range basin-wide (Table 1). 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 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; Propst 1999).

Natural reproduction of Colorado pikeminnow is currently known from the Green, Yampa, upper Colorado, Gunnison, and San Juan rivers. Tyus (1991) and Nesler (2000) estimated an average of about 8,000 adults in the Green River subbasin, for an estimated average of about 14 and 8 adults/km for about 552 and 984 km of river, respectively. Crowl and Bouwes (1998) estimated that 1,000 adults were associated with spawning sites near Three Fords Canyon in Gray Canyon of the lower Green River, and 1,400 adults were associated with spawning sites 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 panmixis of genetic material suggests the mixing of these two stocks (Ammerman and Morizot 1989; Williamson et al. 1999). Fish in the upper Colorado River subbasin total about 600–900 adults (Nesler 2000; Osmundson 2002) and are believed to spawn near Grand Junction, Colorado, and in the lower Gunnison River (personal communication, C. McAda, U.S. Fish and Wildlife Service). Although fish in the Green and upper Colorado River systems spawn at four primary locales (Tyus 1985, 1991), they are likely linked genetically, based on movement throughout the system and lack of genetic separation (Ammerman and Morizot 1989).

Biochemical genetics (Ammerman and Morizot 1989) showed no differences between fish from the Green and Colorado river systems, suggesting one panmictic upper basin population, with possible exchange occurring through unmarked subadults returning randomly to upstream areas (Gilpin 1993; Osmundson 1999). Heterozygosity of Colorado pikeminnow from the upper basin was roughly 5%, an unusually low diversity due primarily to two polymorphic loci (Ammerman and Morizot 1989). Low heterozygosity may be correlated with delayed first reproduction, low adult mortality, and with K-selected species (Mitton and Lewis 1989), and possibly with fish that

return to spawn at their natal sites (Nevo 1978). Approximately 1,500 Carlin-tagged hatchery-reared juvenile Colorado pikeminnow of Green River parentage were released in the Colorado River near Moab, Utah, in February 1980 (Valdez et al. 1982a); small numbers of recaptures during annual sampling indicates that few of these fish survived and were not represented in the genetic analysis.

There are few wild fish remaining in the San Juan River; preliminary estimates range from 19 to 50 adults (Holden 1999; personal communication, D. Ryden, U.S. Fish and Wildlife Service). Over 300,000 hatchery-produced Colorado pikeminnow have been released in the mainstem as part of the San Juan River Basin Recovery Implementation Program (Ryden and Ahlm 1996; Holden 1999; personal communication, F. Pfeifer, U.S. Fish and Wildlife Service).

Over 623,000 Colorado pikeminnow were reintroduced into the Salt and Verde Rivers, Arizona, between 1981 and 1990 (Hendrickson 1994). These reintroductions are considered experimental, nonessential populations, and low survival with no successful reproduction has been documented as a result of these releases (Maddux et al. 1993).

In addition to adults, age-0 fish and juveniles are found in the lower Yampa River, the Green River downstream of the Yampa River confluence; the upper Colorado River downstream of Palisade, Colorado, to Lake Powell, Utah; and the lower 40 km of the Gunnison River. Subadults and small adults have also been found in the lower Price and Duchesne rivers (Cavalli 1999) and the lower White River (Irving and Modde 2000). The Interagency Standardized Monitoring Program (ISMP) of the Upper Colorado River Endangered Fish Recovery Program (McAda et al. 1994a, 1994b, 1995, 1996, 1997) has determined catch-rate indices of age-0 and subadult Colorado pikeminnow in the Green and upper Colorado rivers since 1988. Numbers of age-0 fish and subadults in the other rivers are believed low with no extensive surveys, except for the San Juan River. All data collected under ISMP are catch-rate indices, and there are a few mark-recapture estimates of subadults in backwaters (Haines et al. 1998).

A.3 Habitat

The Colorado pikeminnow is a long-distance migrator; adults move hundreds of kilometers to and from spawning areas, and require long sections of river with unimpeded passage. Adults require pools, deep runs, and eddy habitats maintained by high spring flows. These high spring flows maintain channel and habitat diversity, flush sediments from spawning areas, rejuvenate food production, form gravel and cobble deposits used for spawning, and rejuvenate backwater nursery habitats. Spawning occurs after spring runoff at water temperatures typically between 18 and 23°C. After hatching and emerging from spawning substrate, larvae drift downstream to nursery backwaters that are restructured by high spring flows and maintained by relatively stable base flows. Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by Colorado pikeminnow in the upper basin, and were designed to enhance habitat complexity and to restore and maintain ecological processes (see section 4.1). The following is a description of observed habitat uses in the Upper Colorado River Basin.

Colorado pikeminnow live in warm-water reaches of the Colorado River mainstem and larger tributaries, and require uninterrupted stream passage for spawning migrations and dispersal of young. The species is adapted to a hydrologic cycle characterized by large spring peaks of snow-melt runoff and low, relatively stable base flows. High spring flows create and maintain in-channel habitats, and reconnect floodplain and riverine habitats, a phenomenon described as the spring flood-pulse (Junk et al. 1989; Johnson et al. 1995). Throughout most of the year, juvenile, subadult, and adult Colorado pikeminnow utilize relatively deep, low-velocity eddies, pools, and runs that occur in nearshore areas of main river channels (Tyus and McAda 1984; Valdez and Masslich 1989; Tyus 1990, 1991; Osmundson et al. 1995; Table A-1). In spring, however, Colorado pikeminnow adults utilize floodplain habitats, flooded tributary mouths, flooded side canyons, and eddies that are available only during high flows (Tyus 1990, 1991; Osmundson et al. 1995). Such environments may be particularly beneficial for Colorado pikeminnow because other riverine fishes gather in floodplain habitats to exploit food and temperature resources, and may serve as prey. Such low-velocity environments also may serve as resting areas for Colorado pikeminnow. River reaches of high habitat complexity appear to be preferred.

Because of their mobility and environmental tolerances, adult Colorado pikeminnow are the most widely distributed life stage. During most of the year, distribution patterns of adults are stable (Tyus 1990, 1991; Irving and Modde 2000), but distribution of adults changes in late spring and early summer, when most mature fish migrate to spawning areas (Tyus and McAda 1984; Tyus 1985, 1990, 1991; Irving and Modde 2000). High spring flows provide an important cue to prepare adults for migration and also ensure that conditions at spawning areas are suitable for reproduction once adults arrive. Specifically, bankfull or much larger floods mobilize coarse sediment to build or reshape cobble bars, and they create side channels that Colorado pikeminnow sometimes use for spawning (Harvey et al. 1993).

Colorado pikeminnow spawning sites in the Green River subbasin have been well documented. The two principal locations are in Yampa Canyon on the lower Yampa River and in Gray Canyon on the lower Green River (Tyus 1990, 1991). These reaches are 42 and 72 km long, respectively, but most spawning is believed to occur at one or two short segments within each of the two reaches. Another spawning area may occur in Desolation Canyon on the lower Green River (Irving and Modde 2000), but the location and importance of this area has not been verified. Although direct observation of Colorado pikeminnow spawning was not possible because of high turbidity, radiotelemetry indicated spawning occurred over cobble-bottomed riffles (Tyus 1990). High spring flows and subsequent post-peak summer flows are important for construction and maintenance of spawning substrates (Harvey et al. 1993). In contrast with the Green River subbasin, where known spawning sites are in canyon-bound reaches, currently suspected spawning sites in the upper Colorado River subbasin are at six locations in meandering, alluvial reaches (McAda 2000).

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 their first year of life (Holden 1977; Tyus and Haines 1991; Muth and Snyder 1995). Backwaters and the physical factors that create them are vital to successful recruitment of early life stages of Colorado pikeminnow, and age-0 Colorado pikeminnow in backwaters have received much

Table A-1. Seasonal frequency (%) of use of macrohabitats in the Grand Valley of the upper Colorado River subbasin by radio-tagged adult Colorado pikeminnow, 1986–1989 (Osmundson et al. 1995). Habitats: FR = fast runs, SR = slow runs, RA = rapids, RI = riffles, ED = eddies, PO = pools, SH = shorelines, BA = backwaters, and GP = off-channel flooded gravel pits.

Months	Habitats								
	FR	SR	RA	RI	ED	PO	SH	BA	GP
April–June (Spring)	3–19	13–32	0–1	0–2	2–9	8–12	3–8	22–42	3–25
July–September (Summer)	7–26	26–55	3–5	3–10	9–16	13–16	0–4	3–7	0–4
October	0	61	0	0	4	26	0	9	0
November–February (Winter)	0	27–41	0	0	0–8	42–62	0	5–15	0
March	4	43	0	0	7	32	0	14	0

research attention (e.g., Tyus and Karp 1989; Haines and Tyus 1990; Tyus 1991; Tyus and Haines 1991; Bestgen et al. 1997). 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 (Tyus and Haines 1991). Recent research (Day et al. 1999a, 1999b; Trammell and Chart 1999a, 1999b) has confirmed these preferences and suggested that 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. An optimal river-reach environment for growth and survival of early life stages of Colorado pikeminnow has warm, relatively stable backwaters, warm river channels, and abundant food (Muth et al. 2000).

A.4 Movement

Young Colorado pikeminnow remain near nursery areas for the first 2–4 years of life, then move upstream to recruit to adult populations and establish home ranges (Osmundson et al. 1998). In the upper Colorado River, distance moved was inversely related to fish size; displacement of fish < 550 mm TL averaged 33.6 km and displacement for fish ≥550 mm TL was only 7.5 km (Osmundson et al. 1998). Similar average movement of 31.8 km was observed for 43 radio-tagged adults during fall and spring in the Green River (Archer et al. 1985). Adult Colorado pikeminnow remain in home ranges during fall, winter, and spring and may move considerable distances to and from spawning areas in summer. Individuals move to spawning areas shortly after runoff in early summer, and return to home ranges in August and September (Tyus 1990; Irving and Modde 2000). Round-trip movements of up to 950 km have been reported (Irving

and Modde 2000), with some fish "straying" between rivers within the Green River subbasin (Tyus 1985, 1990; Tyus and McAda 1984). Adults may return in consecutive years to overwinter in the same areas (Wick et al. 1981; Valdez and Masslich 1989).

A.5 Reproduction

The Colorado pikeminnow is an obligate warm-water species that requires relatively warm temperatures for spawning, egg incubation, and survival of young. Hatchery-reared males became sexually mature at 4 years of age and females at 5 years. Average fecundity of 24, 9-year old females was 77,400 (range, 57,766–113,341) or 55,533 eggs/kg, and average fecundity of 9 ten-year old females was 66,185 (range, 11,977–91,040) or 45,451 eggs/kg (Hamman 1986). Average-sized Colorado pikeminnow in the upper basin are 450–550 mm TL and weigh 1–2 kg. The information on sex ratio is highly variable because most observations were made from field sampling during a short interval of the total spawning event; high turbidity precludes direct observation of spawners and fish are captured with trammel nets over spawning bars. Male to female ratios reported from catches over spawning bars are 9:1 (Holden and Stalnaker 1975), 13.85:1 (Tyus 1990), and 5.6:1 (Seethaler 1978). Ratios of active males to females visually observed spawning naturally under hatchery conditions are 2:1 (Hamman 1980), and 2–3:1 (Hamman 1981, 1986). It is believed that the ratios observed under hatchery conditions more accurately reflect conditions in the wild that were not observed or reported by other investigators because sampling on spawning grounds may reflect a relatively common set of males remaining on the spawning area to service a number of transient females; hence, sampling at any one time would bias the sex ratio highly in favor of males.

Spawning activity begins after the peak of spring runoff during June–August at water temperatures typically 16°C or higher (Vanicek and Kramer 1969; Hamman 1981; McAda 2000; Muth et al. 2000). In the lower Yampa River, reproduction was initiated within days of mean daily water temperature exceeding 18°C, with water temperature at initiation ranging 16.0–22.3°C on the Yampa River and 19.8–23.0°C on the lower Green River (Bestgen et al. 1998). Colorado pikeminnow are broadcast spawners that scatter adhesive eggs over cobble substrate which incubate in interstitial spaces. Hatching success is greatest at 20–24°C with incubation time of 90–121 h (Hamman 1981; Marsh 1985). Newly hatched larvae are 6.0–7.5 mm long (Hamman 1981), which emerge from spawning cobbles 3–15 days after hatching and drift predominantly as protolarvae (Haynes et al. 1984; Nesler et al. 1988). Larvae hatched in the lower Yampa River may drift 50–120 miles downstream to nursery backwaters.

High densities of age-0 Colorado pikeminnow have been found downstream of 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 into these regions. Osmundson et al. (1998) showed that subadult Colorado pikeminnow in the Colorado River move back upstream as they mature. Gilpin (1993) hypothesized that this upstream return by subadults provides connectivity and gene flow between the Green and Colorado rivers, resulting in a panmictic population for the entire upper basin with evidence of source/sink dynamics. Marked fish have been recaptured to substantiate exchange of Colorado pikeminnow between the

Green and Colorado rivers, thus supporting the hypothesis of panmixis (personal communication, C. McAda, U.S. Fish and Wildlife Service).

A.6 Survival

Survival and recruitment of Colorado pikeminnow is pulsed, as a strong year class appears and is reflected in the size composition of the population over time. This "storage effect" (Gilpin 1993) enables long-lived populations to maintain themselves despite several years of failed or low reproductive success. Greatest cohort strength in the upper Colorado River (i.e., 1986, 1996) and in the Green River (1986, 1988, 1991; McAda et al. 1998) occurred 1–2 years after high river flows. High to moderate flows rework sediment deposit and this reworking seems to increase larval survival and is linked to strong year classes (Van Steeter and Pitlick 1998; Osmundson 1999). Successful cohorts during high flows may be precluded by delayed warming of the river which causes delayed spawning and age-0 fish that lack size and fat content to survive overwinter (Thompson et al. 1991; Converse et al. 1999).

Studies of overwinter survival show a significant relationship between densities of age-0 fish in fall and spring, suggesting that high spawning success and egg and larval survival by fall (i.e., 3–4 months of age) largely determine cohort strength (Valdez et al. 1999; McAda and Ryel 1999). Overwinter survival also influences cohort strength, but the linkage to environmental correlates (e.g., flow variability, river temperature and ice formation, average backwater depth, and nonnative fish density) is unclear. Overwinter survival (October–March) of age-0 fish in backwaters of the upper Green River, based on the difference between fall and spring seine catch rates for 1989, 1990, 1991, 1992, and 1993 was 96, 29, 31, 38, and 62% (mean, 51%), respectively (Valdez et al. 1999). Survival was related to backwater depth with higher survival (85%) in backwaters deeper than 120 cm and lowest survival (18%) in backwaters less than 30 cm deep. In the upper Colorado River, overwinter survival ranged 7–77% (mean, 49%; McAda and Ryel 1999). Overwinter survival of age-0 Colorado pikeminnow in Green River backwaters, based on mark-recapture population estimates, ranged 6–62% (mean, 45%), compared to catch rate estimates for the same period of 11–49% (mean, 34%; Haines et al. 1998).

Survival rates of adults ≥550 mm TL from the upper Colorado River ranged from 0.83–0.87, with the best fit at 0.85 (Osmundson et al. 1997). Similar survival rate of 0.81 was calculated by Gilpin (1993) for a population viability analysis of Colorado pikeminnow. Survival of adults in the Yampa River may be slightly lower because of incidental catch and handling from angler pressure on sympatric game species, especially northern pike (*Esox lucius*).

A.7 Predation

Nonnative fishes dominate the ichthyofauna of Colorado River Basin rivers, and certain species have been implicated as contributing to reductions in the distribution and abundance of native fishes (Carlson and Muth 1989). At least 67 species of nonnative fishes have been introduced into the Colorado River Basin during the last 100 years (Tyus et al. 1982; Carlson and Muth 1989; Minckley and Deacon 1991; Maddux et al. 1993; Tyus and Saunders 1996; Pacey and Marsh 1998). Tyus et al. (1982) reported that 42 nonnative fish species have become established

in the upper basin, and Minckley (1985) reported that 37 nonnative fish species have become established in the lower basin. Many of these species were intentionally introduced as game or forage fishes, whereas others were unintentionally introduced with game species or passively as bait fish. Potential negative interactions (i.e., predation and competition) between nonnative and native fishes have been identified (reviewed by Minckley 1991; Hawkins and Nesler 1991; Lentsch et al. 1996; Tyus and Saunders 1996; Pacey and Marsh 1998).

Colorado pikeminnow populations in the upper basin live sympatrically with about 20 species of warm-water, nonnative fishes (Tyus et al. 1982; Lentsch et al. 1996) that are potential predators, competitors, and vectors for parasites and diseases. Hawkins and Nesler (1991) identified red shiner (*Cyprinella lutrensis*), common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), channel catfish (*Ictalurus punctatus*), northern pike, and green sunfish (*Lepomis cyanellus*) as the nonnatives considered by Colorado River Basin researchers to be of greatest concern because of their suspected or documented negative interactions with native fishes. Sand shiner (*Notropis stramineus*), white sucker (*Catostomus commersoni*), black bullhead (*Ameiurus melas*), smallmouth bass (*Micropterus dolomieu*), and largemouth bass (*M. salmoides*) were identified by Hawkins and Nesler (1991) as nonnatives of increasing concern because of their increasing abundance, habitat preferences, and/or piscivorous habits. Lentsch et al. (1996) identified existing threats to native fishes in the upper basin from six species of nonnative fishes including red shiner, common carp, sand shiner, fathead minnow, channel catfish, and green sunfish.

Backwaters and other low-velocity shoreline habitats in alluvial reaches of the upper Colorado, Green, and San Juan rivers are important nursery areas for larval and juvenile Colorado pikeminnow (Tyus 1991; Holden 1999; McAda 2000; Muth et al. 2000), and researchers believe that nonnative fish species in those habitats limit the success of Colorado pikeminnow recruitment (e.g., Muth and Nesler 1993; Bestgen 1997; Bestgen et al. 1997; McAda and Ryel 1999; Valdez et al. 1999). Osmundson (1987) confirmed predation by black bullhead, green sunfish, largemouth bass, and black crappie (*Pomoxis nigromaculatus*) as a significant mortality factor of young-of-year and yearling Colorado pikeminnow stocked in riverside ponds along the upper Colorado River. Adult red shiner are known predators of larval native fish in backwaters of the upper basin (Ruppert et al. 1993), and predation by nonnative fishes such as red shiner may influence within-year-class recruitment of Colorado pikeminnow (Bestgen et al. 1997). In laboratory experiments on behavioral interactions, Karp and Tyus (1990) observed that red shiner, fathead minnow, and green sunfish shared activity schedules and space with young Colorado pikeminnow and exhibited antagonistic behaviors toward smaller Colorado pikeminnow. They hypothesized that Colorado pikeminnow may be at a competitive disadvantage in an environment which is resource limited and concluded that nonnative fishes could have a negative impact on growth and survival of young Colorado pikeminnow. High spatial overlap in habitat use has been documented among young Colorado pikeminnow, red shiner, sand shiner, and fathead minnow (McAda and Tyus 1984; McAda and Kaeding 1989). Muth and Snyder (1995) compared the diet of young-of-year Colorado pikeminnow with the diets of other small fishes collected from backwaters of the Green River. They concluded that the potential for competition for food between Colorado pikeminnow and other fishes in

backwaters appeared greatest with red shiner, which are often the most abundant fish in backwaters.

Channel catfish and northern pike have been identified as the principal nonnative threats to subadult and adult Colorado pikeminnow in the upper basin. Adult Colorado pikeminnow apparently use the same habitats as adult channel catfish and northern pike suggesting the potential for competitive interactions, especially during periods of limited resource availability (Wick et al. 1985; Tyus and Karp 1989; Tyus and Beard 1990; Nesler 1995). Channel catfish were first introduced into the Upper Colorado River Basin in 1892 (Tyus and Nikirk 1990) and are now considered common to abundant throughout much of the upper basin (Tyus et al. 1982; Nelson et al. 1995). The species is one of the most prolific predators in the upper basin and, among the nonnative fishes, is thought to have the greatest adverse effect on the endangered fishes (Hawkins and Nesler 1991; Lentsch et al. 1996; Tyus and Saunders 1996), largely due to predation on juveniles and resource overlap with subadults and adults. Additionally, mortality of adult Colorado pikeminnow that prey on channel catfish has occurred due to choking on pectoral spines (McAda 1980; Pimental et al. 1985). Northern pike accidentally became established in the Yampa River in the early 1980's when individuals escaped from Elkhead Reservoir (Tyus and Beard 1990). Since then, northern pike have established a reproducing population in the Yampa River and have expanded their numbers and range in both the Yampa and middle Green rivers (Tyus and Beard 1990; Hawkins and Nesler 1991; Nesler 1995) where they pose a competitive or predatory threat to endangered and other native fishes (Wick et al. 1985; Tyus and Karp 1989; Tyus and Beard 1990; Martinez 1995; Nesler 1995).

In the lower basin, the recapture rate of Colorado pikeminnow stocked in the Salt and Verde rivers, Arizona, has been low. This low recapture rate has been attributed to severe predation by nonnative flathead catfish (*Pylodictis olivaris*; Hendrickson 1994). Hendrickson and Brooks (1987) documented predation by yellow bullhead (*Ameiurus natalis*) and largemouth bass on young Colorado pikeminnow stocked in the Verde River, Arizona.

A.8 Age and Growth

Oldest Colorado pikeminnow documented from scale annuli are 11 years (610 mm TL) from the Green River (Vanicek and Kramer 1969; Seethaler 1978); 16 years from the White River; 12 years from the Colorado River (Hawkins 1992); and 13 years (879 mm TL; Musker 1981) and 18 years (2 fish average of 804 mm TL; Hawkins 1992) from the Yampa River. However, Osmundson et al. (1997) cautioned that scale-based estimations are probably unreliable for Colorado pikeminnow beyond about age 10, and concluded that growth-rate data indicated that large fish (e.g., > 900 mm TL) average 47–55 years old with a minimum age of 34 years.

Larvae at hatching are 6.0–7.5 mm long (Hamman 1981) and average about 40 mm TL (range, 29–47 mm) in October at about 3 months of age (Valdez 1990; Tyus and Haines 1991). Growth under laboratory conditions averaged about 13 mm/30 days (Hamman 1981). Growth of adults in the Green River was about 10.2 mm/year (Tyus 1988). Mean annual growth rate of fish from the upper Colorado River aged 3–6 years ranged from 32.2 (age 6) to 82.0 (age 3) mm/year and declined to 19.8 mm/year for fish 500–549 mm TL (Osmundson et al. 1997); fish ≥ 550 mm

grew an average of 9.5 mm/year. Preliminary evidence indicates that females grow larger and perhaps live longer than males (Vanicek 1967; Tyus and Karp 1989).

The first scale annulus apparently does not form, and the first visible annulus reflects the second winter of life (Musker 1981; Hawkins 1992). Average length at the end of the second annulus formation ranged 90–123 mm TL (Hawkins 1992). Maximum length of fish examined recently is just over 800 mm TL. Asymptotic lengths, based on scale back-calculations and derived from Walford plots, indicate that maximum potential length of Colorado pikeminnow in the upper basin is 1,152 mm TL (Hawkins 1992). Historical accounts of fish in the lower basin indicate maximum length of about 1.8 m. Kaeding and Osmundson (1989) hypothesized that growth and overall size of Colorado pikeminnow in the upper basin is limited by more restrictive temperature regimes than in the lower basin.

Age to length relationships for Colorado pikeminnow are available from several investigations (Vanicek and Kramer 1969; Seethaler 1978; Musker 1981; Hawkins 1992; Osmundson 2002; Figure A-1). Vanicek and Kramer (1969) found that nearly all fish from the Green River age 7 or older (estimated at 454 mm total length [TL] from scale back-calculated lengths; Table A-2) were sexually mature. Seethaler (1978) determined that age-7 Colorado pikeminnow from the Green and Yampa rivers averaged 451 mm TL (scale back-calculations). He also necropsied 147 Colorado pikeminnow between 184 and 652 mm TL and found that all fish longer than 503 mm TL were sexually mature, and fish less than 428 mm TL were immature; 76% of 34 fish examined between 428 and 503 mm TL were sexually mature. Hamman (1981) found that hatchery-reared Colorado pikeminnow were sexually mature at age 5 (males) and age 6 (females), at total lengths of 317–376 mm and 425–441 mm, respectively. Musker (1981) found that age-7 wild fish from all rivers of the Upper Colorado River Basin averaged 461 mm TL (scale back-calculations; recalculated by Hawkins 1992). Hawkins (1992) surmised that Colorado pikeminnow hatch in late summer and either fail to form scales in their first winter or fail to form a first annulus. He assumed that all previous studies had missed the first annulus, and determined that age-7 fish averaged 396 mm TL, and age-8 fish averaged 440 mm TL. Hawkins defined mature Colorado pikeminnow as fish over 428 mm TL, based primarily on findings of Seethaler (1978). Osmundson et al. (1997) used growth-rate data from mark-recapture information and scale back-calculations from fish of the Upper Colorado River subbasin and determined that age-7 Colorado pikeminnow averaged 456 mm TL (range, 430–479 mm TL). Mark-recapture, growth-rate data from Osmundson (2002) were also used to develop the length to age relationship shown in Figure A-1. Based on the best available information on age at sexual maturity and age to length relationships, adult Colorado pikeminnow are defined as fish that are 450 mm TL or larger. This is based on the conservative assumption that all age-7 fish are sexually mature, and average length at age 7 is 450 mm TL. Subadults (age 6) are defined as those fish that are 400–449 mm TL (Table A-2).

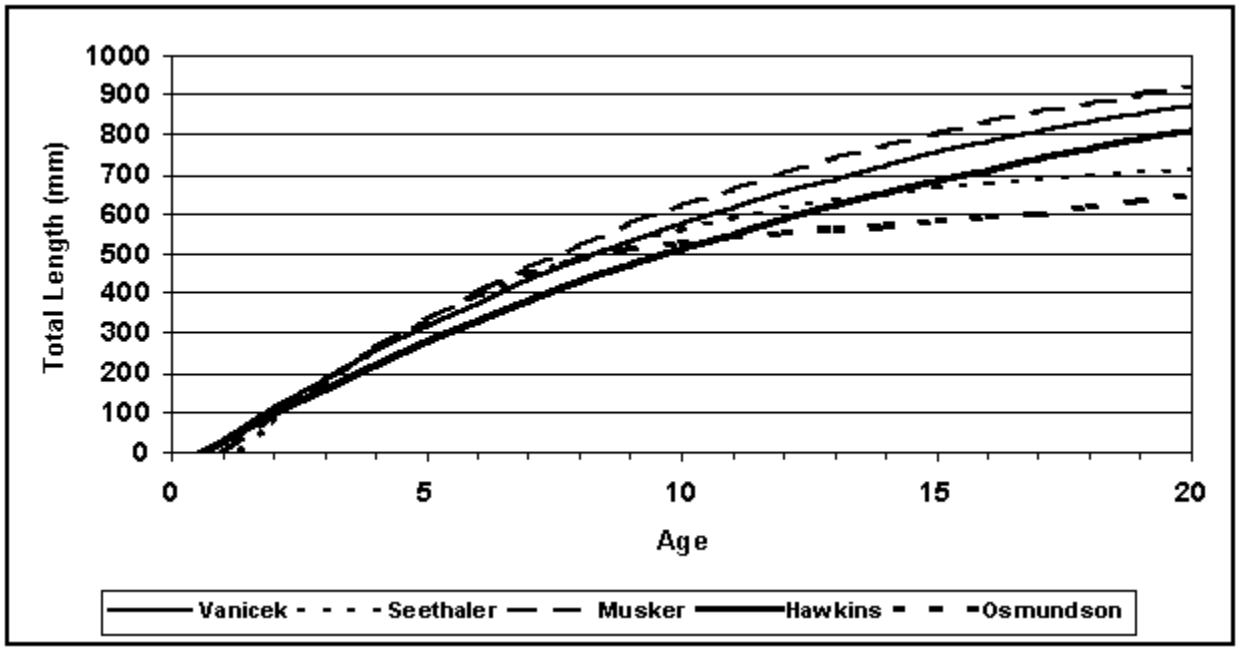

Figure A-1. Predicted length at age for Colorado pikeminnow; computed from von Bertalanffy growth functions (Vanicek and Kramer 1969; Seethaler 1978; Musker 1981; as presented in Hawkins 1992) and from growth-rate data (Osmundson 2002).

Table A-2. Lengths of adult and subadult Colorado pikeminnow as determined from scale back-calculations, mark-recapture growth data, and hatchery-reared fish.

Investigator	Area or Population	Adult		Subadult	
		Age	Total Length (mm)	Age	Total Length (mm)
Vanicek and Kramer (1969)	Dinosaur National Monument, Green River, Utah	7	454	6	391
Seethaler (1978)	Yampa and Green rivers, Colorado and Utah	7	451	6	406
Hamman (1981)	Willow Beach National Fish Hatchery	5 6	Males: 317–376 Females: 425–441		
Musker (1981)	Upper Colorado River Basin, Colorado and Utah	7	461	6	407
Hawkins (1992)	Upper Colorado River Basin, Colorado and Utah	7, 8	396, 440	6, 7	345, 396
Osmundson et al. (1997)	Upper Colorado River, Colorado and Utah	7	456 (430–479)	6	424 (375–472)

A.9 Length-Weight and Condition Factor

Length-weight relationships for Colorado pikeminnow from four rivers in the upper basin (Hawkins 1992) are:

Colorado River	$Log_{10}W = -6.384 + 3.463 * Log_{10}L$,
Green River	$Log_{10}W = -5.692 + 3.206 * Log_{10}L$,
White River	$Log_{10}W = -5.555 + 3.156 * Log_{10}L$, and
Yampa River	$Log_{10}W = -6.026 + 3.339 * Log_{10}L$,

where W is weight in grams and L is total length in millimeters. Length-weight relationships were not significantly different among rivers. Similar relationships were provided by Vanicek and Kramer (1969) and Seethaler (1978). Exponents above 3.0 suggest allometric growth in Colorado pikeminnow; i.e., the relationship of weight as a cube of the length (exponent > 3.0) changes as the fish grows (LeCren 1951; Lagler 1956), whereas exponents of ≤ 3.0 indicate isometric growth or a constant relationship between length and weight.

Mean relative condition of adult Colorado pikeminnow (>428 mm TL) ranged from about 0.92 to about 1.12 (Hawkins 1992). Highest condition usually occurred in June and was probably related to increase in fat reserves or gametes in preparation for spawning. Lowest condition occurred in July and August following pre-spawning migration and spawning activity. Condition usually increased again in fall after the migratory period returned fish to their home ranges.

A.10 Diet

Adult Colorado pikeminnow are generally considered piscivores and the main native predator of the Colorado River Basin because of their large size and large mouth (Vanicek and Kramer 1969; Minckley 1973; Holden and Wick 1982). As a member of the cyprinid family, Colorado pikeminnow lack jaw, vomerine, or palatine teeth, but possess instead large pharyngeal teeth, located on the first modified gill arch at the base of the throat. Cladocerans, copepods, and midge larvae are the principal food items of young up to 50 mm TL in nursery backwaters (Vanicek 1967; Jacobi and Jacobi 1982; Muth and Snyder 1995). Insects became important for fish up to 100 mm TL, after which fish are the main food item; Vanicek (1967) reported Colorado pikeminnow as small as 50 mm TL with fish remains in its gut, and Muth and Snyder (1995) reported fish remains in the gut of a Colorado pikeminnow 21 mm TL. Young in hatchery troughs may become cannibalistic at sizes of less than 50 mm TL (personal communication, F. Pfeifer, U.S. Fish and Wildlife Service). Adults consume primarily soft-rayed fishes, including bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*C. latipinnis*), red shiner, sand shiner, and fathead minnow (Osmundson 1999). Colorado pikeminnow have also been reported with channel catfish lodged in their throat, possibly leading to death of the fish (McAda 1980; Pimental et al. 1985). Colorado pikeminnow have been caught by anglers using various baits, including Mormon crickets (*Anabrus migratorius*; Tyus and Minckley 1988), carcasses of mice, birds, and rabbits (Beckman 1963), as well as artificial lures and spoons (Quartarone 1995).

A.11 Parasites

A survey of diseases and parasites of endangered fishes in the Upper Colorado River Basin in 1981 (Flagg 1982) revealed that Colorado pikeminnow are infected by two principal parasites (an intestinal tapeworm and an external parasitic copepod) and the protozoans *Myobolus* sp. and *Trichodina sp.*, as well as the trematode *Ornithodiplostomum* sp. Bass tapeworms (*Proteocephalus ambloplites*) were found in 65% of stomachs from fish longer than 200 mm TL in the Green River (Vanicek 1967). Vanicek (1967) also reported that P. Dotson (unpublished data, Utah Department of Fish and Game, Salt Lake City, 1962) found tapeworms in 80% of Colorado pikeminnow examined. A cestode identified as *Proteocephalus ptychocheilus* was found in Colorado pikeminnow from the upper basin (Flagg 1982). This may be the same species reported by Vanicek (1967), but further study has not been conducted to resolve the taxonomic discrepancy. Osmundson (1987) reported the first occurrence of Asian tapeworm (*Bothriocephalus achielognathii*) in hatchery-raised Colorado pikeminnow stocked in riverside ponds along the upper Colorado River. Asian tapeworms were identified in wild Colorado pikeminnow from the Colorado River downstream of Moab, Utah, in 1991 (personal communication, D. Osmundson, U.S. Fish and Wildlife Service). The parasitic copepod (*Lernaea cyprinacea*) is common in Colorado pikeminnow and has been reported by several investigators (Hagan and Banks 1963; Vanicek 1967; Flagg 1982). This parasite is believed to be alien to the Colorado River Basin, and transferred from other river basins via nonnative fishes.

APPENDIX B.

PROVISIONAL RECOVERY GOALS FOR COLORADO PIKEMINNOW IN THE LOWER COLORADO RIVER BASIN

Following are provisional site-specific management actions/tasks and objective, measurable recovery criteria presented as guidelines for conservation efforts (e.g., nonessential, experimental populations) for Colorado pikeminnow in the Lower Colorado River Basin. The need for self-sustaining populations in the lower basin and associated site-specific management actions/tasks necessary to minimize or remove threats will be reevaluated at the status review of the species. Anthropogenic changes in the lower basin have extensively modified the riverine ecosystem, including native-fish habitats. Therefore, these provisional recovery goals in the lower basin are based on a limited amount of habitat and taking aggressive actions that allow for the establishment and maintenance of populations in riverine and/or repatriated habitats (e.g., riverside habitats, such as oxbows, depressions, bottomlands, that are connected where feasible to the mainstem Colorado River).

B.1 Provisional Site-Specific Management Actions and Tasks by Recovery Factor

B.1.1 Factor A.—Adequate habitat and range for recovered populations provided

Management Action A-1.—Provide flows necessary for all life stages of Colorado pikeminnow to support recovered populations, based on demographic criteria.

Task A-1.1.—Identify, implement, evaluate, and revise (as necessary through adaptive management) flow regimes that are necessary for the establishment and maintenance of Colorado pikeminnow populations in the mainstem and/or tributaries.

Task A-1.2.—Provide flow regimes (as determined under Task A-1.1) that are necessary for all life stages of Colorado pikeminnow to support recovered populations in the mainstem and/or tributaries.

Management Action A-2.—Minimize entrainment of subadult and adult Colorado pikeminnow in diversion and/or out-take structures.

Task A-2.1.—Identify measures (e.g., screens, baffles) to minimize entrainment of subadult and adult Colorado pikeminnow at problematic diversion and/or out-take structures.

Task A-2.2.—Install devices and/or implement other measures (as determined under Task A-2.1) to minimize entrainment.

B.1.2 Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes

Management Action B-1.—Protect Colorado pikeminnow populations from overutilization for commercial, recreational, scientific, or educational purposes.

Task B-1.1.—Reevaluate and, if necessary, identify actions to ensure adequate protection from overutilization of Colorado pikeminnow for commercial, recreational, scientific, or educational purposes; not currently identified as an existing threat (see section 4.2).

Task B-1.2.—Implement identified actions (as determined in Task B-1.1) to ensure adequate protection of Colorado pikeminnow from overutilization for commercial, recreational, scientific, or educational purposes.

B.1.3 Factor C.—Adequate protection from diseases and predation

Management Action C-1.—Minimize adverse effects of diseases and parasites on Colorado pikeminnow populations.

Task C-1.1.—Reevaluate and, if necessary, identify actions to minimize adverse effects of diseases and parasites on Colorado pikeminnow populations; not currently identified as an existing threat (see sections 4.3.1 and A.11 for discussion of diseases and parasites).

Task C-1.2.—Implement identified actions (as determined under Task C-1.1) to ensure adequate protection of Colorado pikeminnow populations from deleterious diseases and parasites.

Management Action C-2.—Regulate nonnative fish releases and escapement into the mainstem, floodplain, and tributaries.

Task C-2.1.—Develop, implement, evaluate, and revise (as necessary through adaptive management) procedures for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and Colorado pikeminnow (see sections 4.3.2 and A.7 for discussion of effects of nonnative fishes).

Task C-2.2.—Finalize and implement procedures (as determined under Task C-2.1) for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interaction between nonnative fishes and Colorado pikeminnow.

Management Action C-3.—Control problematic nonnative fishes as needed.

Task C-3.1.—Develop control programs for problematic nonnative fishes in the mainstem, floodplain, and tributaries to identify levels of control that will minimize negative interactions between nonnative fishes and Colorado pikeminnow.

Task C-3.2.—Implement identified levels (as determined under Task C-3.1) of nonnative fish control in the mainstem, floodplain, and tributaries.

B.1.4 Factor D.—Adequate existing regulatory mechanisms

Management Action D-1.—Legally protect habitat (see definition of habitat in section 5.1.2) necessary to provide adequate habitat and sufficient range for all life stages of Colorado pikeminnow to support recovered populations, based on demographic criteria.

Task D-1.1.—Determine mechanisms for legal protection of adequate habitat through instream-flow rights, contracts, agreements, or other means (see section 4.4 for discussion of regulatory mechanisms).

Task D-1.2.—Implement mechanisms for legal protection of habitat (as determined under Task D-1.1) that are necessary to provide adequate habitat and sufficient range for all life stages of Colorado pikeminnow to support recovered populations.

Management Action D-2.—Provide for the long-term management and protection of Colorado pikeminnow populations and their habitats.

Task D-2.1.—Identify elements needed for the development of conservation plans that are necessary to provide for the long-term management and protection of Colorado pikeminnow populations; elements of these plans may include (but are not limited to) provision of flows for maintenance of adequate habitat conditions for all life stages of Colorado pikeminnow, regulation and/or control of nonnative fishes, and monitoring of populations and habitats (see section 4.4 for discussion of need for conservation plans).

Task D-2.2.—Develop and implement conservation plans and execute agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties to provide reasonable assurances that conditions needed for recovered Colorado pikeminnow populations will be maintained.

B.1.5 Factor E.—Other natural or manmade factors for which protection has been provided

No other factors have been identified as threats.

B.2 Provisional Objective, Measurable Recovery Criteria

B.2.1 Downlist criteria

B.2.1.1 Demographic criteria for downlisting

1. Two self-sustaining populations (e.g., in the mainstem and/or tributaries) are maintained over a 5-year period, starting with the first point estimates acceptable to the Service, such that for each population:

    a. the trend in adult (age 7+; ≥450 mm TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-6 (400–449 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

    c. each point estimate exceeds 2,600 adults (Note: 2,600 adults is the estimated MVP number, see section 3.3.2).

B.2.1.2 Recovery factor criteria for downlisting

Factor A.—Adequate habitat and range for recovered populations provided.

1. Flow regimes that are necessary for the establishment and maintenance of Colorado pikeminnow populations in the mainstem and/or tributaries identified, implemented, evaluated, and revised (Task A-1.1), such that:

    a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section B.2.1.1.

    b. Adequate nursery habitat is available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section B.2.1.1.

    c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) is available to maintain self-sustaining populations, as reflected by downlisting demographic criteria in section B.2.1.1.

2. Measures identified to minimize entrainment of subadult and adult Colorado pikeminnow at problematic diversion and/or out-take structures (Task A-2.1).

Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.

3. Overutilization of Colorado pikeminnow for commercial, recreational, scientific, or educational purposes reevaluated and, if necessary, actions identified to ensure adequate protection (Task B-1.1).

Factor C.—Adequate protection from diseases and predation.

4. Effects of diseases and parasites on Colorado pikeminnow populations reevaluated and, if necessary, actions identified to ensure adequate protection (Task C-1.1).

5. Procedures developed, implemented, evaluated, and revised for stocking and to minimize escapement of nonnative fish species into the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and Colorado pikeminnow (Task C-2.1).

6. Control programs for problematic nonnative fishes in the mainstem, floodplain, and tributaries developed and implemented to identify levels of control that will minimize negative interactions between nonnative fishes and Colorado pikeminnow (Task C-3.1).

Factor D.—Adequate existing regulatory mechanisms.

7. Mechanisms determined for legal protection of adequate habitat (Task D-1.1).

8. Elements of conservation plans identified that are necessary to provide for the long-term management and protection of Colorado pikeminnow populations (Task D-2.1).

Factor E.—Other natural or manmade factors for which protection has been provided.

No other factors have been identified as threats.

B.2.2 Delist criteria

B.2.2.1 Demographic criteria for delisting

1. Two self-sustaining populations (e.g., mainstem and/or tributaries) are maintained over a 7-year period beyond downlisting, starting with the first point estimates acceptable to the Service, such that for each population:

    a. the trend in adult (age 7+; ≥450 mm TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-6 (400–449 mm TL) naturally produced fish equals or exceeds mean annual adult mortality, and

    c. each point estimate exceeds 2,600 adults (MVP).

B.2.2.2 Recovery factor criteria for delisting

Factor A.—Adequate habitat and range for recovered populations provided.

1. Flow regimes provided that are necessary for all life stages of Colorado pikeminnow to support recovered populations in the mainstem and/or tributaries (Task A-1.2), such that:

    a. Adequate spawning habitat and appropriate spawning cues (e.g., flow patterns and water temperatures) are available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section B.2.2.1.

    b. Adequate nursery habitat is available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section B.2.2.1.

    c. Adequate juvenile and adult habitat (e.g., cover, resting, and feeding areas) is available to maintain self-sustaining populations, as reflected by delisting demographic criteria in section B.2.2.1.

2. Devices installed and/or measures implemented at problematic diversion and/or out-take structures to minimize entrainment of subadult and adult razorback sucker (Task A-2.2).

Factor B.—Protection from overutilization for commercial, recreational, scientific, or educational purposes.

3. Adequate protection of Colorado pikeminnow from overutilization for commercial, recreational, scientific, or educational purposes attained (Task B-1.2).

Factor C.—Adequate protection from diseases and predation.

4. Adequate protection of Colorado pikeminnow populations from deleterious diseases and parasites attained (Task C-1.2).

5. Procedures finalized and implemented for stocking nonnative fish species in the mainstem, floodplain, and tributaries to minimize negative interactions between nonnative fishes and Colorado pikeminnow (Task C-2.2).

6. Identified levels of nonnative fish control to minimize negative interactions between nonnative fishes and Colorado pikeminnow attained in the mainstem, floodplain, and tributaries (Task C-3.2).

Factor D.—Adequate existing regulatory mechanisms.

7. Habitat necessary to provide adequate habitat and sufficient range for all life stages of Colorado pikeminnow to support recovered populations is legally protected in perpetuity (Task D-1.2).

8. Conservation plans developed and implemented, and agreements among State agencies, Federal agencies, American Indian tribes, and other interested parties executed to provide reasonable assurances that conditions needed for recovered Colorado pikeminnow populations will be maintained (Task D-2.2).

Factor E.—Other natural or manmade factors for which protection has been provided.

No other factors have been identified as threats.