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PROTOCOLS FOR COLORADO PIKEMINNOW AND HUMPBACK CHUB POPULATION ESTIMATES

Prepared By

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PREFACE

This report was prepared by the Program Director's Office of the Upper Colorado River Endangered Fish Recovery Program for the U.S. Fish and Wildlife Service (Service) to recommend direction to groups responsible for developing population estimates for Colorado pikeminnow (*Ptychocheilus lucius*) and humpback chub (*Gila cypha*). The purpose of this report is to describe current population-estimate protocols, and to make recommendations to revise those protocols for more precise estimates. Population estimates will be used by the Service to assess population status related to the downlisting and delisting demographic criteria of the recovery goals for the four endangered fish species of the Colorado River.

To ensure the greatest scientific validity possible and at the request of Region 6 of the Service, the Program Director convened a workshop of species experts and statisticians in Fort Collins, Colorado, on December 6–7, 2001. The purpose of the workshop was to develop initial guidance for the Service in determining acceptable population and recruitment estimates for Colorado pikeminnow and humpback chub. The objectives of the workshop were to bring together experts on population and recruitment estimates for a focused examination of the statistical validity of existing and future estimates, and to provide initial guidance on those estimates that should be accepted toward tracking population trends as required by the demographic criteria of the draft recovery goals. The workshop was attended by 35 researchers, statisticians, and representatives of the Biology Committee of the Upper Colorado River Endangered Fish Recovery Program (UCRRP), the Biology Committee of the San Juan River Basin Recovery Implementation Program (SJRRIP), and representatives of the Grand Canyon Monitoring and Research Center (GCMRC). Presentations were made by individual researchers for respective regions of river where population estimates are being conducted. Following the presentations, a moderator solicited input from the attendees and all information was recorded.

Several issues were identified at the workshop that needed further investigation and reporting, and a subsequent meeting was held in Grand Junction, Colorado, on February 11–12, 2002, to further address and resolve those issues. The results of the workshop and meeting were assimilated into this report. Researchers and principal investigators are acknowledged for sharing their information in preparation of this report. Most of the population estimates presented in this report are preliminary and subject to revision. Estimates are included only to illustrate issues and concerns associated with statistical validity and precision.

ACKNOWLEDGMENTS

The following individuals attended a workshop on December 6–7, 2001, in Fort Collins, Colorado, on population-estimate protocols for Colorado pikeminnow and humpback chub. A follow-up meeting was held February 11–12, 2002, in Grand Junction, Colorado. Input at both meetings is greatly appreciated. (* attended both meetings; † attended only follow-up meeting).

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We wish to thank the following individuals for presentations and specific contributions to the respective sections of this report at the December 6–7, 2001, workshop in Fort Collins, Colorado. Information provided by these researchers and interactions during the workshop were incorporated into the appropriate sections of this report.

Introduction and Moderator . . . . . Bob Muth

Overview of Recovery Goals . . . . . Tom Czapla

Rationale Behind Statistics . . . . . Rich Valdez, Ron Ryel

Population Estimate Models . . . . . Kevin Bestgen

Colorado Pikeminnow

Upper Colorado River . . . . . Doug Osmundson, Ken Burnham

Green River Subbasin . . . . . Kevin Bestgen, John Hawkins, Mike Hudson, Ron Brunson, Tim Modde

San Juan River Subbasin . . . . . Dale Ryden

Basin-wide Estimates . . . . . Tom Nesler

Humpback Chub

Black Rocks . . . . . Chuck McAda

Westwater Canyon . . . . . Mike Hudson, Tom Chart, Melissa Trammell

Desolation/Gray Canyons . . . . . Mike Hudson, Tom Chart, Melissa Trammell

Yampa Canyon . . . . . Tim Modde, Bruce Haines

Cataract Canyon . . . . . Rich Valdez

Grand Canyon . . . . . Lew Coggins, Melissa Trammell

Other Estimates for Black Rocks and Westwater Canyon . . . . . Tom Nesler

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EXECUTIVE SUMMARY

The U.S. Fish and Wildlife Service (Service) released draft recovery goals for the four Colorado River endangered fishes for public review through a Notice of Availability in the Federal Register (66 FR 47033–47034) on September 10, 2001. These recovery goals provide site-specific management actions and objective, measurable criteria for downlisting and delisting the endangered humpback chub (*Gila cypha*), bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). Demographic criteria include numbers of populations and individuals necessary for recovery. Reliable, precise population estimates are needed to monitor population status and trends, to determine if downlisting and delisting demographic criteria are met, and to ensure demographic and genetic viability. The Service has determined that mark-recapture models provide the best available population estimates. Population estimates are being conducted or are planned for all wild populations of Colorado pikeminnow and humpback chub; razorback sucker and bonytail will be addressed at a later date.

Numbers of Colorado pikeminnow are being estimated in eight reaches of occupied habitat in the Upper Colorado River Basin: lower and upper reaches of the Upper Colorado River, lower Green River, middle Green River, White River, Yampa River, Desolation/Gray canyons, and San Juan River. Population estimates for the upper and lower reaches of the Upper Colorado River are available for 1992–1994 and 1998–2000. Data are available for estimates for the middle Green River, Yampa River, and White River for 2000 and 2001, and data are available for estimates for Desolation/Gray canyons and the lower Green River for 2001. Abundance of Colorado pikeminnow in the San Juan River was estimated in 1995, but numbers of wild fish are so low that subsequent estimates will not be possible until hatchery-produced fish have augmented the population. Abundance estimates for Colorado pikeminnow were also made for the Upper Colorado River and Green River subbasins for the period 1991–1997. These estimates are based on the sum of marked and unmarked fish handled under a number of sampling regimes. Although these estimates lack the precision of estimates from data collected under more rigorous mark-recapture sampling designs, these estimates provide insights into the status and trends of the Colorado pikeminnow populations in various river reaches.

Crew size and configuration vary considerably under current sampling protocols. The crew on the Upper Colorado River consists of two persons, whereas crews in the Green River subbasin consist of two electrofishing boats, each with two netters and a boat operator. Primary gears used are electrofishing and trammel nets, often used in combination in a "block and shock" method in enclosed backwaters and floodplains. Crews in the Green River subbasin also electrofish shorelines extensively. All sampling is conducted mid-April to June, during post ice-off and through runoff. Most crews have conducted three sampling occasions, spaced about 1 week apart. Four occasions were conducted in the upper reach of the upper Colorado River to assess effect of sampling occasions on precision; increased number of occasions increased probability of capture and reduced coefficient of variation. Two occasions were conducted in the lower Colorado River because of small numbers of fish.

Abundance of humpback chub is estimated in five reaches of the Upper Colorado River Basin and two in the Lower Colorado River Basin. The entire occupied range of the humpback chub is not currently sampled because of the presence of large, whitewater rapids that minimize access to sample sites and gear efficiency. Reaches being sampled include Black Rocks, Westwater Canyon, Desolation/Gray canyons, Yampa Canyon, Cataract Canyon, and the Little Colorado River (LCR) and mainstem Colorado River in Grand Canyon. Population estimates for Black Rocks and Westwater Canyon are available for 1998, 1999, and 2000. Estimates for Yampa Canyon are available for 2000, and data for estimates for Desolation/Gray canyons are available for 2001. Sampling for population estimates in Cataract Canyon will begin in 2002. Estimates for the LCR are available for autumn 2000, and spring and summer 2001; data collected for autumn 2001 have not been analyzed. Estimates for the Colorado River near the LCR inflow and in Middle Granite Gorge are available for 2000 and 2001.

Most habitats occupied by humpback chub appear to be under-sampled. Only 15% of Westwater Canyon and 7% of Desolation/Gray canyons are currently being sampled. Despite high fidelity of humpback chub for specific river reaches, it is believed that movement of fish between sampled and unsampled subreaches is leading to inaccurate and imprecise estimates. Sampling for humpback chub is generally being conducted in autumn (September–October) when water temperatures are cool to minimize stress to fish. Sampling in Desolation/Gray canyons in August 2001 raised concerns over stress to the fish from warm water temperatures.

Sampling in the LCR in Grand Canyon is conducted in October–November (autumn), May–June (spring), and August–September (summer), but no concerns have been raised over stressed fish. Sampling in the Colorado River in Grand Canyon is conducted in August, September, and December, with no concerns for stress to fish. Three occasions have been conducted in Black Rocks (except 4 in 1999), Westwater Canyon, Desolation/Gray canyons, Yampa Canyon, and the Colorado River in Grand Canyon. Only two sampling occasions were conducted in the LCR in Grand Canyon, in 2000 and 2001.

Population estimates for humpback chub, particularly in Black Rocks and Westwater Canyon, Desolation/Gray canyons, and Grand Canyon exhibit high variability, suggesting problems with sampling design and methodology. Concerns for over-handling fish in Black Rocks and Westwater Canyon appear unfounded because of the increasing percentage of recaptured fish, negating the hypothesis of selective mortality of tagged fish. Estimates in Westwater Canyon appear highly variable because only 15% of the occupied area in the canyon is being sampled, and it is believed that fish are leaving specific sample sites between sampling occasions. A similar problem seems to exist for Desolation/Gray canyons, where only 7% of the occupied area is being sampled. Low population size in Yampa Canyon may not allow for precise estimates, but the current estimate provides an approximation of population size. Length-frequency analysis and continued sampling will provide a robust design that will allow ongoing monitoring of the population and assessment of recruitment. The population of humpback chub in Cataract Canyon may be similar to that in Yampa Canyon. Estimates in the LCR in Grand Canyon are believed to be negatively biased (under estimates), based on proportion of recaptures suggesting that fish are attracted to the sampling gears. Abundance estimates for humpback chub were also made for the Black Rocks for 1994 and 1997, and for Westwater Canyon for 1993–1997. These estimates are based on the sum of marked and unmarked fish handled under a number of sampling regimes. Although these estimates lack the precision of estimates from data collected under more rigorous mark-recapture sampling designs, these estimates provide insights into the status and trends of these humpback chub populations.

Several issues and concerns have been identified for population estimates of Colorado pikeminnow and humpback chub. Estimates of Colorado pikeminnow in the Upper Colorado River and Green River subbasins appear to be close to target precision levels; possible

improvement has been identified for the Upper Colorado River by either adding to crew size or increasing sampling occasions. The estimate for the Upper Colorado River should be expanded to include the Gunnison River upstream of Redlands Diversion. Also, a 24-km reach in Westwater Canyon is not being sampled because of low numbers of Colorado pikeminnow; sampling for humpback chub in this canyon produces few Colorado pikeminnow and supports the sampling design to exclude this reach from sampling. More intensive sampling is recommended for the Upper Colorado River subbasin to improve precision and to ensure that subadults are being sampled for assessment of recruitment, especially in the lower reach. Numbers of wild Colorado pikeminnow in the San Juan River are currently low and population estimates are precluded. However, stocking of hatchery-reared fish is expected to bolster the population, such that a target of 1,000 subadults is expected to be present in the system by about 2005. Monitoring the San Juan River should be expanded and designed to account for survival and growth of stocked fish throughout the system. Monitoring of Colorado pikeminnow for downlisting is possible starting with the year 2001, assuming that the estimate for the Upper Colorado River subbasin exceeds 700 adults.

Precision, and perhaps accuracy, of population estimates for humpback chub appear to vary considerably. Effects of sampling methodology (i.e., gear types, sampling occasions, sampling intervals, etc.) and environmental factors (i.e., water temperature, river flow) need to be evaluated to determine if the current estimates are reliable. Over-handling of fish from repeated sampling occasions and stress from sampling in warm water temperatures have been identified as concerns. There seems to be agreement among biologists that humpback chub should be sampled during cool periods, preferably from mid-September through October, to reduce stress to the fish. Precision of estimates for humpback chub may not be the same as for Colorado pikeminnow. Monitoring of humpback chub for downlisting may be possible starting with year 2002, depending on the results of the evaluation of estimates. More intensive sampling is recommended for all humpback chub populations to improve precision and to ensure that subadults are being sampled for assessment of recruitment.

General Guidance and Action Items:

- Abundance estimates for Colorado pikeminnow and humpback chub should be based on mark-recapture models, and study designs should be consistent with assumptions of the

models with attention to bias, precision, and other considerations (e.g., the Green River Colorado pikeminnow estimates).

- Standards of length at age for Colorado pikeminnow and humpback chub should be adopted for the entire basin until further information indicates differences in growth rates and size at maturity among populations.
- The high variability in humpback chub population estimates should be scrutinized more closely regarding the design and methodology of the sampling effort.
- Expand sampling of humpback chub populations to include subadults to ensure accurate assessment of recruitment.
- Implement a standard protocol for identification of humpback chub in the field through application of standard meristic and morphometric measurements (i.e., “the art of seeing well”).
- Ensure that the periodicity of population point estimates satisfies requirements of the recovery goals.
- Stocking and facility-needs plans for Colorado pikeminnow in the San Juan River that are consistent with requirements of the recovery goals need to be finalized.

1.0 INTRODUCTION

The U.S. Fish and Wildlife Service (Service) released draft recovery goals for the four Colorado River endangered fishes for public review through a Notice of Availability in the Federal Register (66 FR 47033–47034) on September 10, 2001. These recovery goals provide site-specific management actions and objective, measurable criteria for downlisting and delisting the endangered humpback chub (*Gila cypha*), bonytail (*Gila elegans*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*; U.S. Fish and Wildlife Service 2001a, 2001b, 2001c, 2001d).

Demographic criteria include numbers of populations and individuals necessary for recovery. Reliable, precise population estimates are needed to monitor population status and trends, to determine if downlisting and delisting demographic criteria are met, and to ensure demographic and genetic viability. The Service has determined that mark-recapture models provide the best available population estimates.

A workshop was held in Fort Collins, Colorado, on December 6–7, 2001, to solicit input from experts on the statistical validity and precision of population estimates for Colorado pikeminnow and humpback chub. The workshop focused on available information for Colorado pikeminnow and humpback chub because there are extant wild populations; razorback sucker and bonytail will be addressed at a later date. The purpose of the workshop was to develop initial guidance to the Service in determining acceptable population estimates for Colorado pikeminnow and humpback chub. The objectives of the workshop were to bring together experts on population and recruitment estimates for a focused examination of the statistical validity of existing and future estimates, and to provide guidance on those estimates that should be accepted toward tracking population trends as required by the demographic criteria of the draft recovery goals.

The workshop was attended by 35 researchers, statisticians, and representatives of the Biology Committee of the Upper Colorado River Endangered Fish Recovery Program (UCRRP), Biology Committee of the San Juan River Basin Recovery Implementation Program (SJRRIP), and Grand Canyon Monitoring and Research Center (GCMRC). Presentations were made by individual researchers for respective regions of river where population estimates are being

conducted. Following the presentations, a moderator solicited input from the attendees, and all information was recorded on flip charts and electronically on a word processor.

Several issues were identified at the workshop that needed further investigation and reporting, and a subsequent meeting was held in Grand Junction, Colorado, on February 11–12, 2002, to further address and resolve these issues. The results of the workshop and meeting have been assimilated into this report that describes current protocols and makes recommendations to revise those protocols for more precise population and recruitment estimates. Summaries of sampling methodologies for Colorado pikeminnow and humpback chub are presented in Appendix Tables A-1 and A-2.

This report provides initial guidance to ensure statistical validity and precision of population and recruitment estimates for recovery of the Colorado River endangered fishes. Ongoing collaboration with researchers directly involved with these estimates is vital to the success of this process. The groups responsible for developing estimates for Colorado pikeminnow and humpback chub include the UCRRP, SJRRIP, and GCMRC. The UCRRP 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 while water development proceeds in compliance with State and Federal laws. The SJRRIP was established in 1991 to conserve populations of Colorado pikeminnow and razorback sucker in the San Juan River Basin while water development proceeds in compliance with State and Federal laws. The GCMRC is a research branch of the Glen Canyon Dam Adaptive Management Program (GCDAMP), established by the Secretary of the Interior in 1995 under the Federal Advisory Committee Act to provide oversight on the operation of Glen Canyon Dam to protect and/or enhance development of the Colorado River ecosystem through Grand Canyon. The GCDAMP consists of State and Federal agencies, water users, energy distributors, environmental groups, recreational interests, and Native American groups. Population estimates of humpback chub in Grand Canyon are the responsibility of the GCDAMP and GCMRC.

2.0 RECOVERY GOALS

2.1 Demographic Criteria

Demographic criteria in the draft recovery goals for Colorado pikeminnow and humpback chub contain three common elements:

- No net loss in current population sizes;
- Maintenance of self-sustaining populations; and
- Maintenance of demographic and genetic viability.

Demographic criteria for downlisting and delisting Colorado pikeminnow are summarized in Table 1. These criteria include numbers of individuals required in the Green River subbasin, Upper Colorado River subbasin, and San Juan River subbasin, as well as requirements for self-sustainability, and maintenance of demographic and genetic viability.

Table 1. Summary of demographic criteria for downlisting and delisting Colorado pikeminnow.

Downlisting (5 years; monitoring)	**Delisting (7 years beyond downlisting)**
• Maintain metapopulation • Green River and upper Colorado River populations maintained ("no net loss" + recruitment[a]); and • Green River subbasin population >2,600 adults (≥age 7; MVP); and • Upper Colorado River population >700 adults; and • San Juan River establish/maintain 1,000 age-5+ subadults	• Maintain metapopulation • Green River and upper Colorado River populations maintained ("no net loss" + recruitment[a]); and • Green River core population >2,600 adults (≥age 7); and • Upper Colorado River population >1,000 adults **OR** upper Colorado River population >700 adults and San Juan River population >800 adults

[a] Mean estimated recruitment of naturally produced subadults must equal or exceed mean annual adult mortality.

Demographic criteria for downlisting and delisting humpback chub are summarized in Table 2. These criteria include numbers of individuals required in each of the six populations, including Black Rocks, Westwater Canyon, Desolation/Gray canyons, Yampa Canyon, Cataract Canyon, and Grand Canyon.

Table 2. Summary of demographic criteria for downlisting and delisting humpback chub.

Downlisting (5 years; monitoring)	Delisting (3 years beyond downlisting)
• Each of the six populations maintained ("no net loss" + recruitment[a]); and • One core population in upper basin >2,100 adults (≥age 4; MVP); and • One core population in lower basin (Grand Canyon) >2,100 adults	• Each of the six populations maintained ("no net loss" + recruitment[a]); and • Two core populations in upper basin, each >2,100 adults (≥age 4); and • One core population in lower basin >2,100 adults

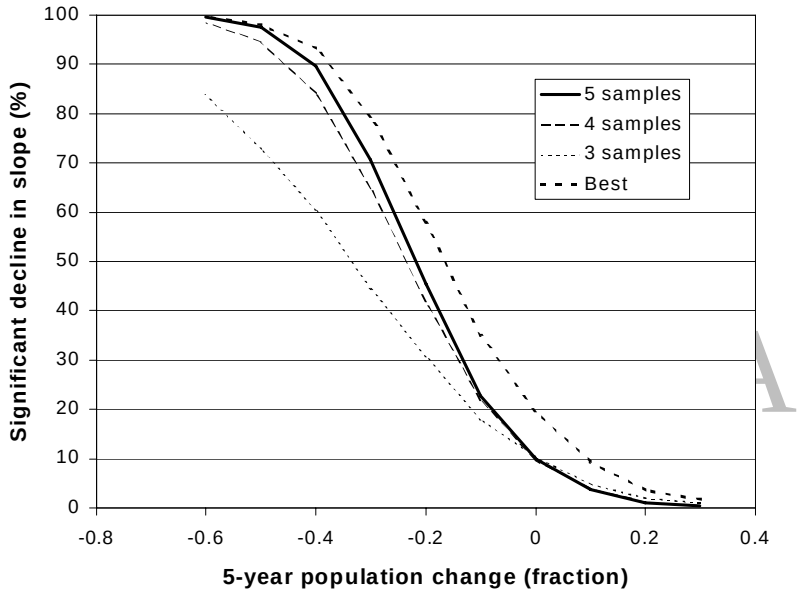
[a] Mean estimated recruitment of naturally produced subadults must equal or exceed mean annual adult mortality.

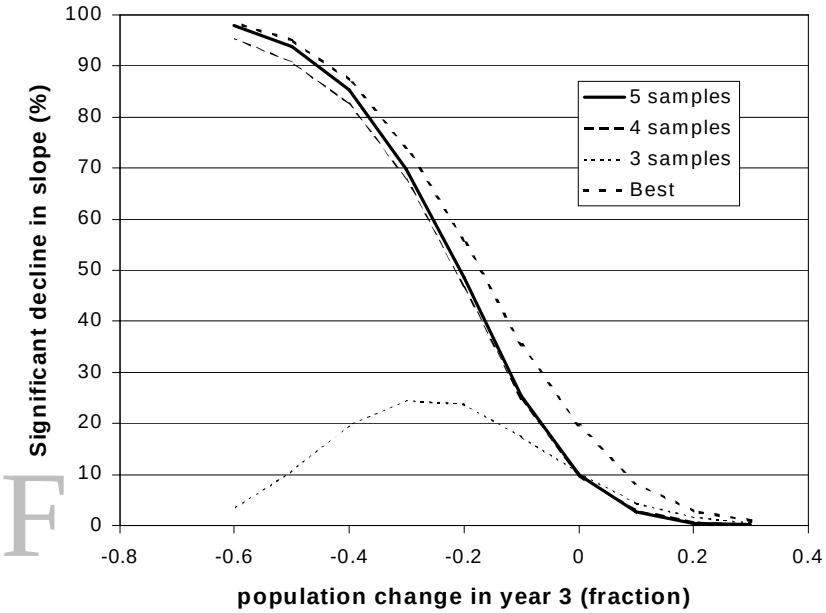
2.2 Monitoring

The monitoring period for Colorado pikeminnow is 12 years (i.e., one generation time), including 5 years for downlisting and 7 years for delisting. The monitoring period for humpback chub is 8 years (i.e., one generation time), including 5 years for downlisting and 3 years for delisting. At least three population point estimates are required (four are preferred) for the 5-year downlisting periods for each population of each species to assure a reasonable probability of detecting a significant population decline (Figure 1). At least five population point estimates are required during the 7-year delisting period for Colorado pikeminnow, and at least two estimates are required during the 3-year delisting period for humpback chub. All populations of a given species must be monitored during the downlisting and delisting periods, although point estimates for different populations may not necessarily occur in the same year.

2.3 Statistical Criteria

Reasonable statistical criteria are necessary to ensure that population estimates are sufficiently precise to accurately track fish abundance, recruitment, and significant increases or decreases in population sizes. Statistical criteria ensure adherence to the three common aspects of no net loss in current population sizes, maintenance of self-sustaining populations, and maintenance of demographic and genetic viability. No net loss in current population size is achieved when the slope of annual point estimates for a given population is not significantly less than zero ($P<0.10$). This regression analysis is applied to the 5-year downlisting period for each





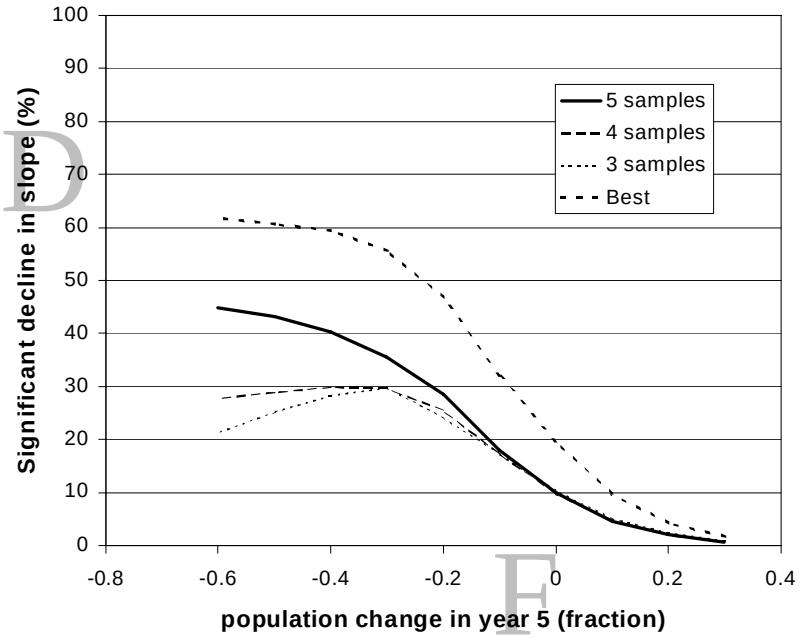


Figure 1. Probability of detecting a significant decline in slope with population change in all years (top left), in year 3 (top right), and in year 5 (left) with 3, 4, and 5 annual population point

estimates in a 5-year period.

population of Colorado pikeminnow and humpback chub, and for the combined downlisting and delisting periods for each population of each species. Hypothetical examples of this trend analysis are presented for each species in Figure 2.

Maintenance of a self-sustaining population is achieved when mean estimated recruitment of naturally-produced subadults equals or exceeds mean annual adult mortality. Estimated mean annual adult mortality is 15% for Colorado pikeminnow and 24% for humpback chub.

Maintenance of demographic and genetic viability is ensured when core populations exceed the minimum viable population (MVP; Figure 3). For Colorado pikeminnow, annual point estimates for the Green River subbasin must exceed 2,600 adults. For humpback chub, annual point estimates for each core population must exceed 2,100 adults; a core population of humpback chub may consist of one or more contiguous populations.

2.4 Size Criteria

2.4.1 Colorado Pikeminnow

The draft recovery goals define adult Colorado pikeminnow as fish that are age 7 or older, and recruitment is defined as subadults surviving to adults. To facilitate determination of adults and subadults for wild fish captured for population point estimates, it is necessary to determine length of fish at age 7 and length of subadults. Age to length relationships for Colorado pikeminnow are available from several investigations (Vanicek and Kramer 1969; Seethaler 1978; Musker 1981; Hawkins 1992; Osmundson 2001; Figure 4). 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 3) 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; of 34 fish examined between 428 and 503 mm TL, 76% 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

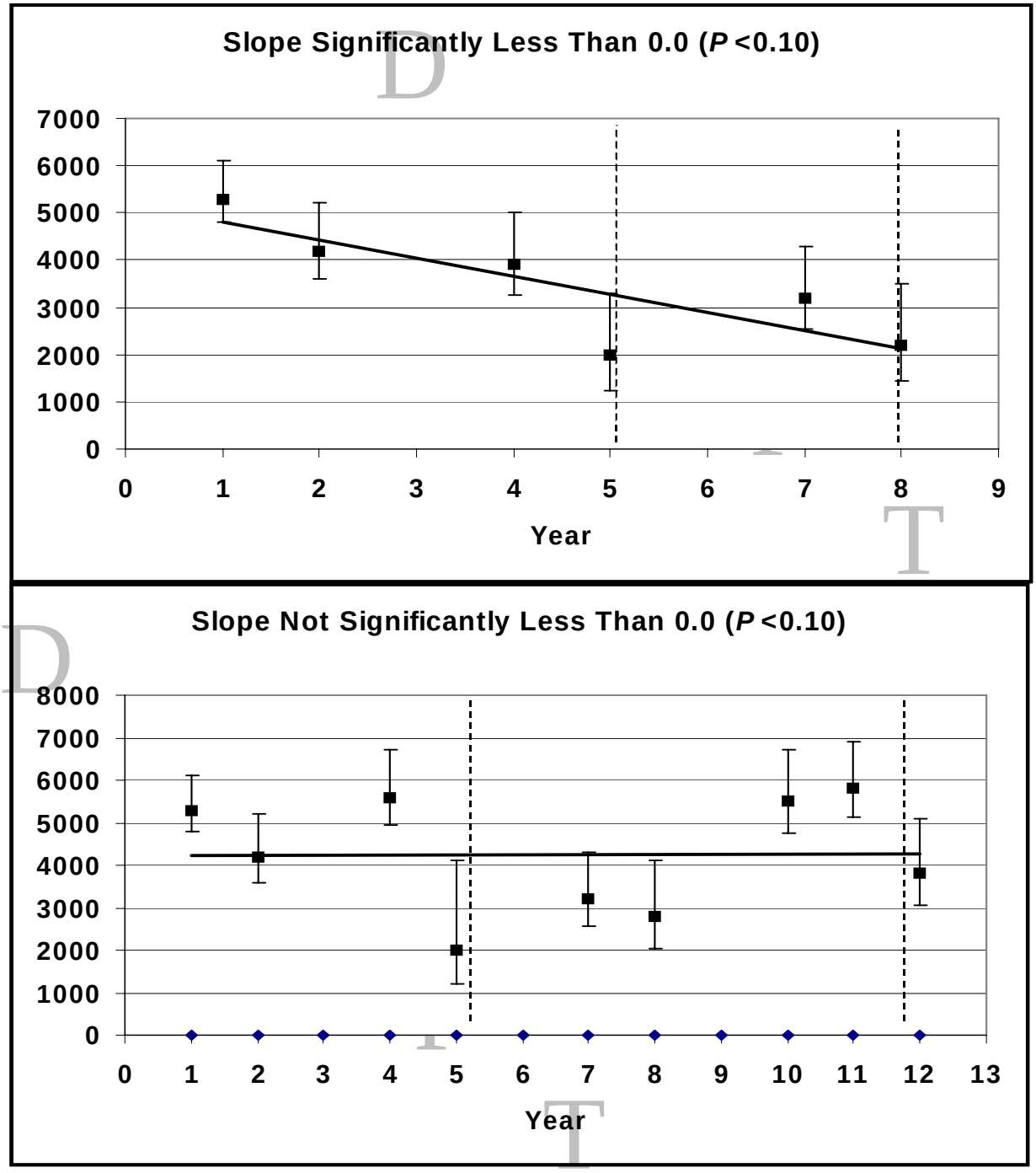
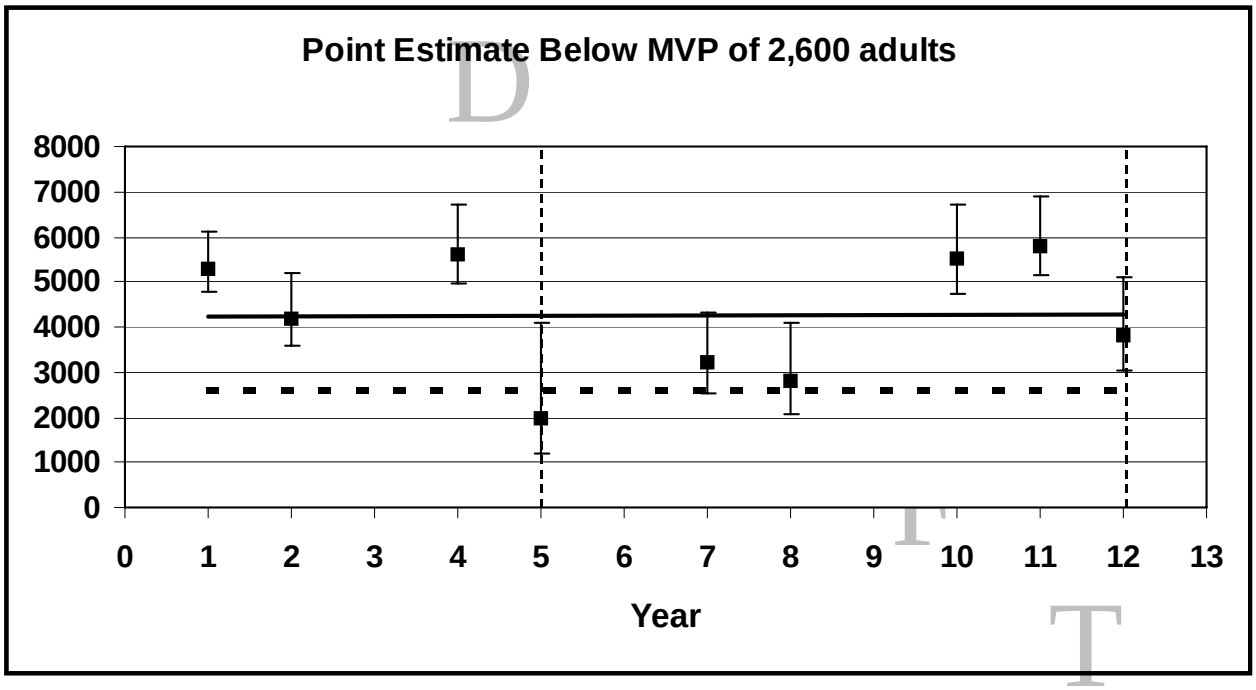


Figure 2. Hypothetical data for trend analysis with slope significantly less than 0.0 (P<0.10) for 8-year downlisting/delisting period of humpback chub (top), and slope not significantly less than 0.0 (P<0.10) for 12-year downlisting/delisting period of Colorado pikeminnow (bottom).



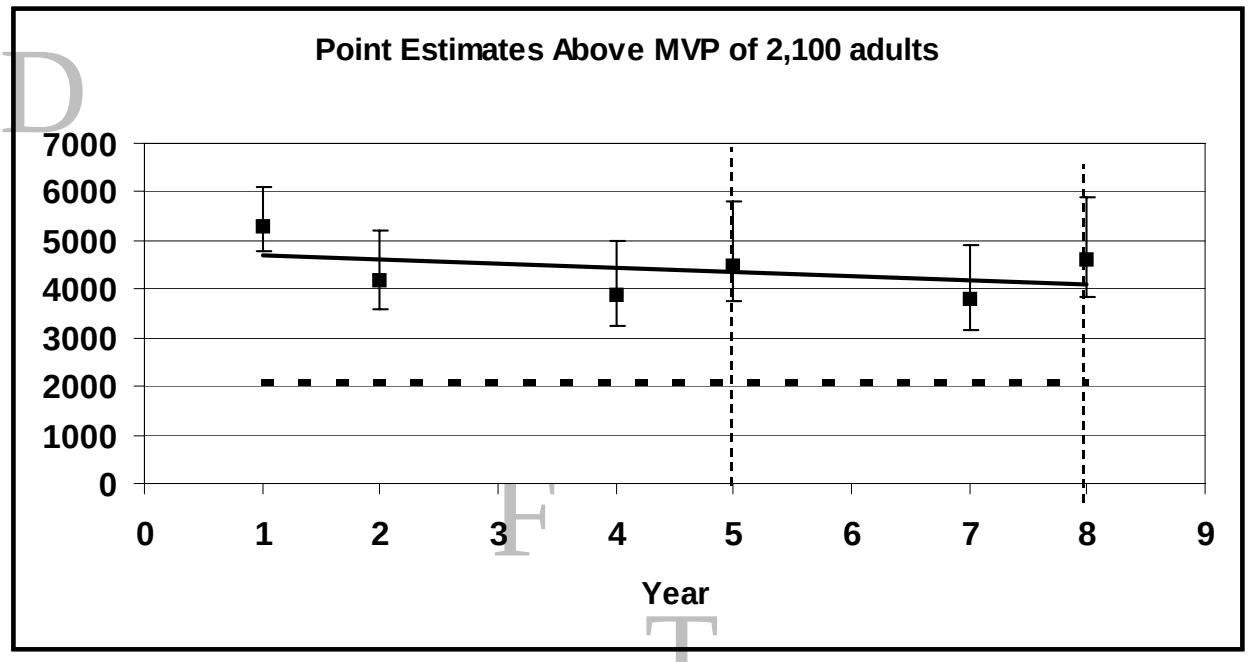


Figure 3. Hypothetical data for trend analysis and point estimates above minimum viable population (MVP) of 2,100 adults for 8-year downlisting/delisting period of humpback chub (top), and point estimate below minimum viable population (MVP) of 2,600 adults for 12-year downlisting/delisting period of Colorado pikeminnow (bottom).

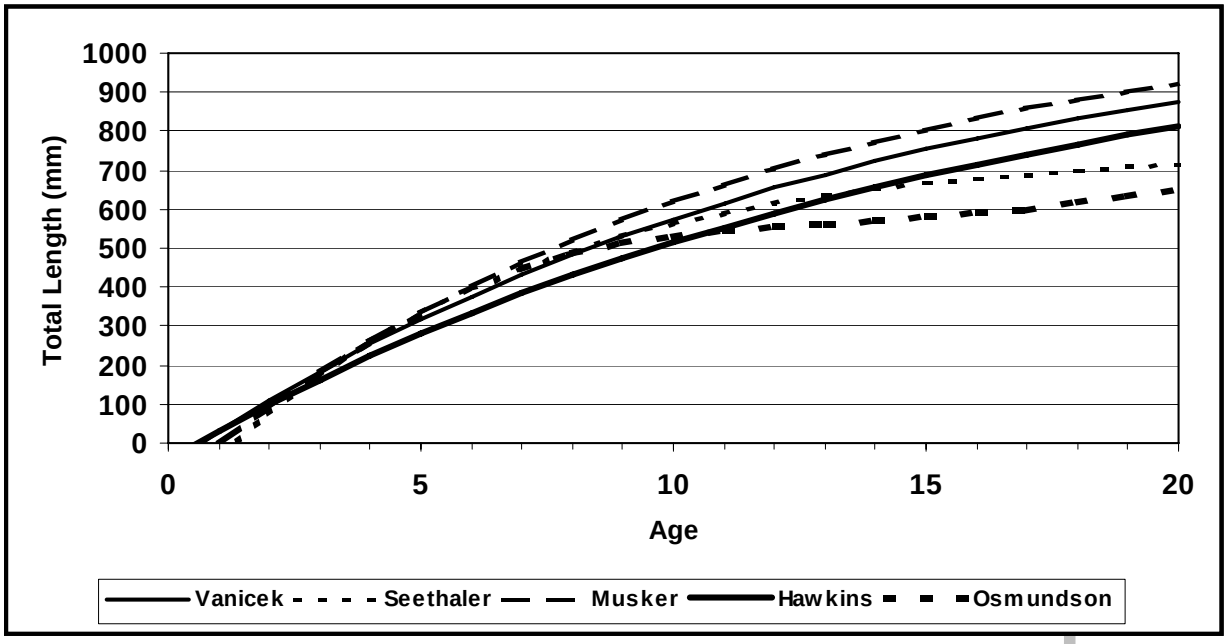


Figure 4. Predicted length at age for Colorado pikeminnow; computed from von Bertalanffy growth functions (Vanicek and Kramer [1969], Seethaler [1978], Musker [1981] as presented in Hawkins [1992]) and from growth-rate data (Osmundson 2001).

Table 3. 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)

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 (2001) were also used to develop the length to age relationship shown in Figure 4. 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.

Principal investigators at the December 6–7, 2001, workshop and the subsequent February 11–12, 2002, meeting agreed that age-7 fish average about 450 mm TL, but there was uncertainty regarding the size at which most Colorado pikeminnow reached sexual maturity. Tyus (1991) reported 14 ripe females on spawning grounds in the Green and Yampa rivers from 1981 to 1988 that averaged 654 mm TL and 194 ripe males that averaged 555 mm TL. Osmundson and Burnham (1998) defined subadults as fish that were 250–500 mm TL and adults as fish that were 450–900 mm TL; they used ≥500 mm TL for developing population estimates of adults in the Upper Colorado River. Based on the studies previously cited, subadults are defined as those fish that are 400–449 mm TL. This is based on an approximate length at age 6 (Table 3).

2.4.2 Humpback Chub

The draft recovery goals define adult humpback chub as fish that are age 4 or older. Age to length relationships for humpback chub are available from several investigations (Vanicek and Kramer 1969; Kaeding and Zimmerman 1983; Valdez 1990; Minckley 1992; Hendrickson 1993; Valdez and Ryel 1995; G.B. Haines (U.S. Fish and Wildlife Service, personal communication). Vanicek and Kramer (1969) determined average length of age-4 roundtail chub from the Green River at 218 mm TL, and average length of age-3 “Colorado chub” (*Gila* sp.) at 156 mm TL (based on scale back-calculations); roundtail chub can be used as a surrogate for humpback chub

because of similar growth rates and lengths. Valdez (1990) determined average length of age-4 humpback chub in Cataract Canyon at 200 mm TL, and length of age 3 at 144 mm TL. Using 30-day growth rates of humpback chub from the Little Colorado River in Grand Canyon (Minckley 1992), lengths at ages 3 and 4 were estimated at 170 and 200 mm TL, respectively. Hendrickson (1993) aged humpback chub from the Little Colorado River and the mainstem Colorado River in Grand Canyon; based on polynomial regression of average number of annuli from otoliths (lapillus and asteriscus) and opercles, age-3 fish were 157 mm TL and age-4 fish were 196 mm TL (Figure 5). Valdez and Ryel (1995) recorded size at first observed maturity (based on expression of gametes, presence of spawning tubercles) of humpback chub in Grand Canyon at 202 mm TL for males and 200 mm TL for females; average length of age-3 fish, based on scale back-calculations, was 186 mm TL. In Yampa Canyon, approximate length of age-4 roundtail chub from otolith age (G.B. Haines, U.S. Fish and Wildlife Service, personal communication) was 200 mm TL, and approximate length at age 3 was 150 mm TL. The previously cited investigations show that average length of age-4 humpback chub ranged from 196 to 218 mm TL, and length of a tracked cohort was 140–210 mm TL (Table 4). From this information on age at sexual maturity and age to length relationships, adult humpback chub are defined as fish that are 200 mm TL or larger. This is based on the conservative assumption that all age-4 fish are sexually mature, and the average length at age 4 is 200 mm TL. Based on the studies previously cited, subadults are defined as those fish that are 150–199 mm TL. This is based on an approximate length at age 3 (Table 4).

Size criteria for humpback chub may be refined as more data are available on age at maturity and age-length relationships. Observations of individual sizes of fish in each of the six populations indicate that different populations may have different growth rates and hence, different size at maturity.

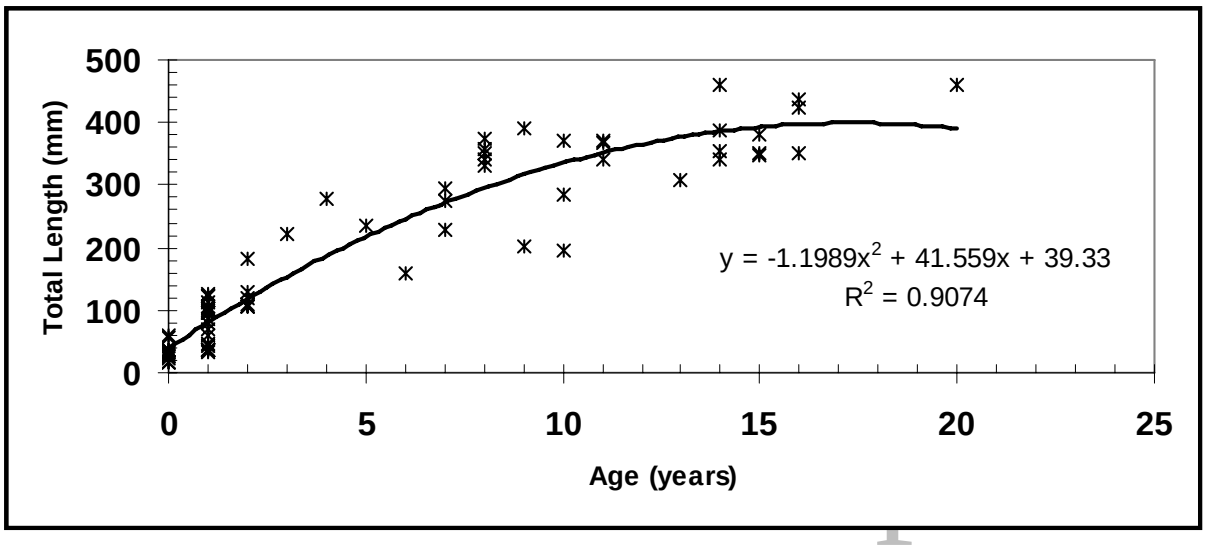


Figure 5. Total length to age relationship for humpback chub from Grand Canyon, based on average number of annuli from otoliths (lapillus and asteriscus) and opercles (Hendrickson 1993).

Table 4. Lengths of adult and subadult humpback chub as determined from scale back-calculations, otolith and opercle ages, and field observations.

Investigator	Area or Population	Adult		Subadult	
		Age	Total Length (mm)	Age	Total Length (mm)
Vanicek and Kramer (1969)	Dinosaur National Monument, Green River, Colorado and Utah	4	218[a]	3	156[b]
Valdez (1990)	Cataract Canyon, Colorado River, Utah	4	200	3	144
Minckley (1992)	Little Colorado River, Grand Canyon, Arizona	4	~200[c]	3	~170[c]
Hendrickson (1993)	Little Colorado River, Grand Canyon, Arizona	4	196	3	157
Valdez and Ryel (1995)	Colorado River, Grand Canyon, Arizona		Males: 202 Females: 200[d]	3	186
Chart and Lentsch (1999)	Westwater Canyon, Utah	4	140–210[e]	3	120–170[e]
Haines (pers. comm.)	Yampa River, Colorado[f]	4	200[a]	3	150[a]

[a]based on roundtail chub, *Gila robusta*
[b]based on "Colorado chub", *Gila* sp.
[c]based on 30-day growth rates
[d]based on size at first maturity from field observations
[e]based on length ranges of cohorts tracked with length-frequency
[f]based on otoliths

3.0 MARK-RECAPTURE POPULATION ESTIMATE MODELS

3.1 Mark-Recapture Models

Mark-recapture models are useful to estimate abundance (*N*-hat), survival rate (S), recruitment (R), and probability of capture (*P*-hat) of wild populations. Lambda (λ) reflects the change in population from one estimate to the next. Two basic model types are recognized, open models and closed models. Program CAPTURE (White et al. 1982) is recommended for identifying most suitable models and associated precision for each estimate.

Closed models have the following characteristics:

- Can only estimate *P*-hat and *N*-hat;
- Generally used for shorter-term studies;
- Allow for individual variation in probabilities of capture (time, behavior, heterogeneity);
- No immigration, emigration, mortality, or recruitment are allowed; and
- Inferences are to population at risk of capture, aspect of geographic closure.

Open Models have the following characteristics:

- Can estimate *P*-hat, *N*-hat, S, R, λ but not in first and last years;
- Generally used for longer-term studies, estimates require more sampling years and assumptions;
- Heterogeneity in probabilities of capture are not allowed;
- Allow immigration/recruitment and emigration/mortality to occur (estimated); and
- Geographic closure.

Sampling design and use of available empirical data over time enable development of a robust design for population estimates. A robust design includes aspects of sampling and analytical design, field methodologies, and use of acquired parameters in a manner that strengthens population estimates and precision. A robust design ensures that field sampling is consistent with mark-recapture models, and uses calculated survival and recruitment to refine model parameters. A robust design assists decisions on population estimates that are inconsistent

with trends or lack precision and reliability. It is important to maintain a robust design because a robust design:

- Can estimate *P*-hat, *N*-hat, S, R in all years;
- Allows heterogeneity in *P*-hats for both open and closed models;
- Estimates *N*-hat and S from different segments of data, and eliminates sampling covariance and correlations between estimates;
- Can test for functional relationships between parameters; and
- Assumes geographic closure.

Assumptions are associated with each mark-recapture population estimate model. Violation of any of these assumptions can reduce precision and possibly invalidate an estimate. Evaluation of assumption violations should be done at three stages:

1. During field sampling design;
2. During analyses, with goodness-of-fit tests and evaluation of specific assumptions to determine appropriate model to use; and
3. When assumptions are violated, effects must be evaluated and inferences adjusted accordingly.

3.2 Assumptions

Abundance estimation assumptions that apply to most mark-recapture models are:

- Geographic extent of population must be well-defined in order to give context to parameters;
- Similarity in sampling effort for populations at risk of capture across years are required for monitoring;
- Tag loss is assumed to be zero;
- Demographic closure is enhanced by closely-spaced secondary sampling events;
- Effects of immigration/emigration are limited to sampling prior to spawning;
- Large sampling area reduces effects of movements across boundaries, and it is possible to examine transition effects;
- Some heterogeneity in *P*-hats is possible due to sampling;
- Heterogeneity is reduced by restricting inference to adults of certain size;

- Data can be stratified by size to obtain separate estimates for identifiable size/age classes (R) if data are available;
- Heterogeneity effects are also reduced by even distribution of sampling effort, nearly all animals should be equally exposed to capture;
- Behavior effects are possible, but not evaluated with models; and
- Time effects are evident across occasions, and can usually be estimated.

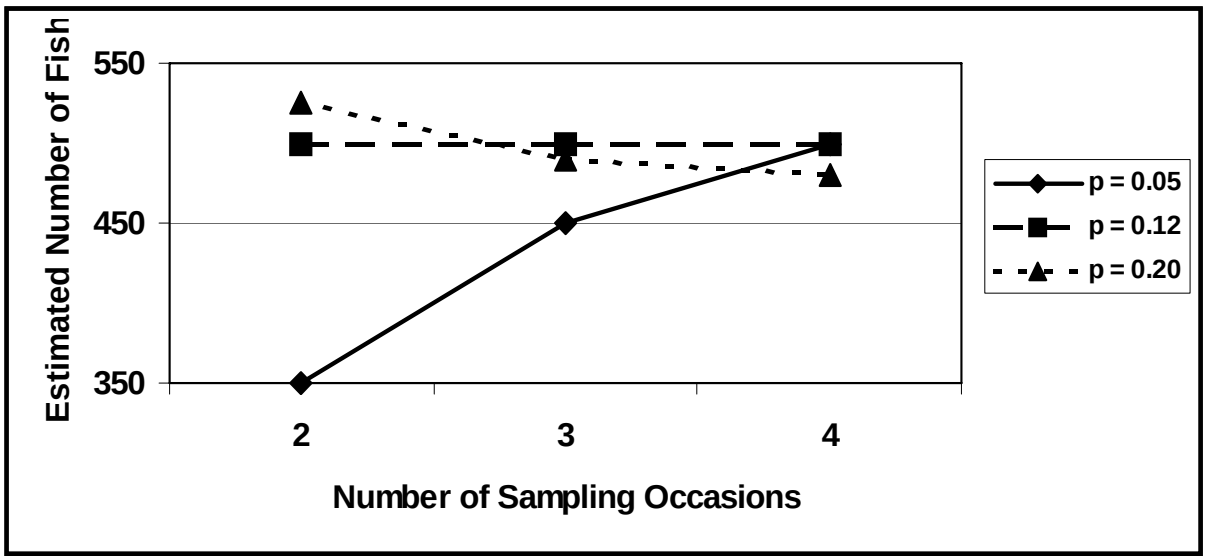
3.3 Bias and Precision

The precision of abundance estimates is an important consideration when ensuring that population abundance exceeds demographic criteria. The most reliable estimates of bias and precision are:

- Population size; large populations tend to yield more precise estimates;
- Probability of capture (*P*-hat); key is to increase capture probabilities; a high *P*-hat allows for fewer sampling occasions; a *P*-hat of ≥0.10 is a reasonable target.
- Coefficient of variation (*CV* = standard error divided by *N*-hat); a *CV* of ≤0.15 (0.10–0.20) is a reasonable target.
- Number of sampling occasions can affect *P*-hat and *CV*; the effect of sampling occasions on population estimates with different probabilities of capture (*P*-hat) is provided in Figure 6; and
- Lambda: reflects change in population from one estimate to next.

A measure of precision is important in determining the validity of a given abundance estimate and should be factored into demographic criteria. The effect of precision on detecting a change in population abundance is an important consideration. A random-effects analysis implemented in some of the more recent software will be helpful where there are 6–9 point estimates. Long term data allow use of other data analyses.

A measure of precision is an important consideration when an abundance estimate occurs that is lower than expected or below the current trend. An estimate with low precision (i.e., high *CV*) may lead to the decision to conduct another estimate in the subsequent year. A “rational analysis” is suggested that evaluates data and precision and accounts for aberrant estimates. The difficulty is determining the decision point when a single estimate occurs without benefit of



additional estimates.

Figure 6. Effect of number of population size, sampling occasions, and probability of capture (*P*) on coefficient of variation (*CV* for *P* = 0.05: 2 = 47, 3 = 41, 4 = 34; *CV* for *P* = 0.12: 2 = 31, 3 = 23, 4 = 15; *CV* for *P* = 0.20: 2 = 21, 3 = 10, 4 = 7).

3.4 Considerations

The following summarizes elements of mark-recapture population models that are important considerations:

- Define geographic context of sampled population;
- Ensure context is consistent across years;
- Meet assumption of closure based on geographics;
- Use design and model appropriate for data needs; closed for *N*-hat, open for *N*-hat, S, R, λ, or for robust design;
- Evaluate and reduce effects of assumptions in design phase;
- Simulate effects of different sampling schemes prior to implementing, choose desired level of precision *a priori*;
- Use information from sampling and biology to assist in model selection;
- Use simulations to evaluate other data effects of assumption violations on

inferences available from parameter estimations;

- Employ robust design — offers advantages of both model types; and
- Factor precision into population estimates to assess validity of estimate.

4.0 COLORADO PIKEMINNOW

[Note: Most of the population estimates that follow are preliminary and are included only to illustrate issues and concerns associated with statistical validity and precision.]

4.1 Upper Colorado River Subbasin

4.1.1 Current Protocol

Abundance of Colorado pikeminnow was monitored from 1991 to 2000 in the Upper Colorado River subbasin. Two multi-year data collection efforts were made: the first, from 1991 to 1994, and the second, from 1998 to 2000. The area of estimate included occupied habitat within the mainstem Colorado River from Price Stubb Diversion Dam at Palisade, Colorado, downstream to the confluence with the Green River, excluding Westwater Canyon. The upper reach, from Palisade to Westwater Wash, was sampled three times annually; the lower reach, from Cisco, Utah, to the Green River confluence, was sampled twice annually. More effort was placed in the upper reach because most adults occurred in the upper reach.

Sampling was conducted during a 6–8 week sampling window during runoff, from mid-April to mid-June. The analysis assumed population closure over the 6–8 week time period; i.e., recruitment, mortality, immigration and emigration were negligible. Time and manpower constraints limited the number of passes in each reach. A two-person crew covered 175 miles (282 km) of river. All large backwaters, flooded ponds and canyon mouths were first blocked with trammel nets and electrofished in a "block-and-shock" approach to capture as many Colorado pikeminnow as possible during each pass. Shorelines were electrofished in reaches where nettable habitats were scarce. The goal was to capture as many Colorado pikeminnow as possible and cover all areas so that all Colorado pikeminnow had some probability of being captured. Fish were measured and marked with uniquely coded Passive Integrated Transponder (PIT) tags.

Capture-recapture data were used to estimate abundance each year using closed-model methods with two or three sampling occasions (Program CAPTURE, White et al. 1982). Two

closed-population models were used to estimate abundance of Colorado pikeminnow in the Upper Colorado River subbasin. Model M_t was used for the upper reach; this model assumes constant probability of capture among individuals and among sampling occasions. Model M_o was used for the lower reach; this model assumes constant probability of capture among individuals but capture probability varies among sampling occasions. The two-pass regime mandated use of model M_o in the lower reach.

4.1.2 Current Estimates

Annual estimates of whole-river population size (all fish > 250 mm TL) averaged 613 during the early study period of 1991–1994 and 778 during the more recent study period of 1998–2000 (Table 5). Annual estimates of adults (> 500 mm TL) averaged 372 during the early study period and 534 during the recent period, representing a 44% increase in the adult population. However, differences between the two periods were not statistically significant. For the upper reach, estimated probability of capture (*P*-hat) averaged 0.12. When annual point estimates were regressed against year, a significant increase in both total fish and adults was indicated.

4.1.3 Issues and Concerns

Size at Maturity. — Estimates of adult Colorado pikeminnow in the upper Colorado River include all PIT-tagged fish (>about 150 mm TL). Based on size of recaptures, these estimates include about 9% of fish <450 mm TL; 450 mm TL is the defined size of fish at age 7 (Figure 4). Estimates need to be recalculated to reflect adult size (i.e., ≥450 mm TL).

Crew Size and Sampling Occasions. — Current crew size in the upper Colorado River is two people. This small crew size may be affecting probability of capture and possibly precision (i.e., coefficient of variation of estimate). Crew size should be sufficient to ensure maximum and equal probability of capture of all adult Colorado pikeminnow for each sampling occasion. The number of sampling occasions needs to be balanced with an acceptable level of precision, investment of time and funds, and over-handling of fish. There is currently little electrofishing along shorelines of the upper Colorado River. Two crews of three people each should be implemented to increase sampling effort.

Bias and Precision. — Precision of population estimates for Colorado pikeminnow in the Upper Colorado River subbasin could be improved either by additional sampling occasions or

with additional crews. However, the small size of the population, especially in the lower reach (confluence to lower Westwater Canyon) may preclude more precise estimates. Not including

Table 5. Area and year of estimate, estimator models, sampling occasions, population estimate (*N*-hat), 95% confidence intervals (C.I.), probability of capture (*P*-hat), and coefficient of variation (*CV*) for Colorado pikeminnow in the Upper Colorado River subbasin. Population estimates are based on all fish captured, which includes about <9% <450 mm TL; estimates do not include fish in the Gunnison River, Westwater Canyon, or Cataract Canyon.

Area of Estimate	Year	Model	Occasions	*N*-hat	95% C.I.	*P*-hat	*CV*
Upper Reach	1991	M_o	3	205	124–520	0.106	~0.25
	1992		3	311	179–1,204	0.074	
	1993		3	163	121–246	0.194	
	1994		3	332	223–728	0.103	
	1998	M_o	3	435	317–633	0.130	~0.25
	1999		3	367	278–513	0.156	
	2000		3	420	267–682	0.105	
Lower Reach	1992	M_t	2	224	81–806	0.09, 0.07	~0.25
	1993		2	512	247–1,225	0.10, 0.08	
	1994		2	297	152–695	0.16, 0.09	
	1998	M_t	2	330	190–665	0.09, 0.20	~0.25
	1999		2	401	165–1,158	0.10, 0.06	
	2000		2	381	170–979	0.09, 0.06	

the Gunnison River potentially violates the assumption of closure for population estimates because Colorado pikeminnow are known to pass through the Redlands fishway.

Mixing of Stocks. — Abundance estimates of Colorado pikeminnow in the Upper Colorado River subbasin assume a mixing of stocks in at least the two geographic reaches (Green River confluence to lower Westwater Canyon, upper Westwater Canyon to Palisade) where independent population estimates are conducted. Mixing of stocks within each of these two reaches is important for accurate and precise estimates. The 16.5-mile reach of Westwater Canyon is not included in the sampling because of the low numbers of Colorado pikeminnow usually found in that reach. Gunnison River fish are also not included in the estimate. Current estimates of Colorado pikeminnow for the Upper Colorado River subbasin include only the lower 2 miles of the Gunnison River, downstream of Redlands Diversion. The Redlands

fishway, installed at the Redlands Diversion in 1998, has allowed passage of over 50 adult Colorado pikeminnow into the Gunnison River. Numbers of adults in the Gunnison River upstream of the Redlands Diversion could be substantial and should be included in the estimate for the Upper Colorado River subbasin.

Immigration and Emigration. — Immigration and emigration from the two reaches are believed to be negligible during the annual sampling period, except for fish moving to and from the Gunnison River, which are monitored at the Redlands fishway. Estimates of recruitment for the Upper Colorado River subbasin are based on subadults in both lower and upper reaches. Since the young fish move to the lower reach and move back to the upper reach at maturity, accurate and precise estimates of subadults is important to assess recruitment.

4.1.4 Recommendations

- Estimates of adults will include fish ≥450 mm TL; subadults will include fish 400 to 449 mm TL.
- Greater effort needs to be expended with larger or multiple crews to increase precision, and shoreline electrofishing (in addition to block and shock) to increase capture probability; at least three sampling occasions need to be conducted each year in each of the two sub-reaches.
- The Gunnison River needs to be included in the estimate; it is not necessary to include Westwater Canyon and Cataract Canyon because of the low numbers of Colorado pikeminnow in those reaches.
- Conduct estimates in each of 3 consecutive years followed by 2 years off.

4.2 Green River Subbasin

4.2.1 Current Protocol

Mark-recapture population estimates of Colorado pikeminnow were conducted on the Green, White, and Yampa rivers in 2000 and 2001, which comprise the middle Green River. Reaches sampled included 332 miles of the Green River, 101 miles of the White River, and 70 miles of the Yampa River. Estimates were conducted in the lower Green River in 2001. The middle and lower Green River comprise the Green River subbasin population of Colorado

pikeminnow. Sampling was done cooperatively by the Service and Utah Division of Wildlife Resources on the Green River, the Service on the White River, and the Larval Fish Laboratory of Colorado State University on the Yampa River. Sampling was conducted during spring, starting after iceoff, using mostly electrofishing, with some trammel-net and hoop-nets sets in the Yampa River. A minimum of three sampling occasions were conducted in each reach. A combination of trammel-netting backwaters and electrofishing shorelines was used to capture as many Colorado pikeminnow as possible during each pass. All large backwaters, flooded ponds and canyon mouths were first blocked with trammel nets and electrofished in a "block-and-shock" approach. Fish were measured and marked with uniquely coded PIT tags. Multiple crews conducted sampling; each crew consisted of two netters and one operator on each of two electrofishing boats. A summary of effort and numbers of fish captured is provided in Table 6.

Capture-recapture data were used to estimate abundance each year using closed-model population estimators with three sampling occasions (Program CAPTURE, White et al. 1982). Two closed-population models (M_t and M_o) were used to estimate abundance of Colorado pikeminnow in the middle Green River. Model M_t assumes constant probability of capture among individuals and among sample occasions. Model M_o assumes constant probability of capture among individuals but capture probability varies among sample occasions.

Table 6. A summary of sampling effort, numbers of Colorado pikeminnow captured and recaptured, and probability of capture (*P*-hat) for Colorado pikeminnow in the Green River subbasin for 2000 and 2001. Data include all fish captured, which includes about 8% <450 mm TL. EF = electrofishing; FY = fyke netting.

Area – Reach	Year	Occasions	Effort	Number Captured (Recaptured)	(*P*-hat)
Entire Subbasin – 500 miles (includes lower GR)	Spring 2001	3–4	1,191 hr EF 294 hr FY	1,295 (148)	0.13
Middle Green River	Spring 2000	4	177 hr EF	639 (89)	0.13
Middle Green River	Spring 2001	4	253 hr EF	358 (37)	0.10
White River	Spring 2000	3	127 hr EF	289 (29)	0.09

White River	Spring 2001	3	204 hr EF	212 (28)	0.12
Yampa River	Spring 2000	4	61 hr EF	75 (6)	0.08
Yampa River	Spring 2001	4	177 hr EF	120 (22)	0.17
Desolation/Gray Canyons	Spring 2001	3	240 hr EF	256 (26)	0.10
Lower Green River	Spring 2001	3	317 hr EF	209 (34)	0.16

4.2.2 Current Estimates

Estimates for 2000 are available for the middle Green River, including the Yampa and White rivers (Table 7). Data collected in 2001 are available for the middle Green River (including Yampa River, White River, and Desolation/Gray canyons) and lower Green River, but have not been fully analyzed. Estimated numbers of Colorado pikeminnow for 2000 are about 2,100 adults in the middle Green River, 300 in the Yampa River, and 1,100 in the White River, for a total of about 3,500 adults. Probability of capture (*P*-hat) ranged from 0.08 to 0.16; coefficient of variation (*CV*) ranged from 0.09 to 0.36.

Table 7. Area and year of estimate, estimator models, sampling occasions, population estimate (*N*-hat), 95% confidence intervals (C.I.), probability of capture (*P*-hat), and coefficient of variation (*CV*) for Colorado pikeminnow in the Green River subbasin. Population estimates based on all fish captured, which includes about 8% <450 mm TL.

Area of Estimate	Year	Model	Occasions	*N*-hat	95% C.I.	*P*-hat	*CV*
Middle Reach	2000	M_t	4	2,037	1,23–2,55	0.08, 0.10, 0.13, 0.05	0.09
	2000	M_o	4	2,102	1,75–2,38	0.09	0.09
	2001	Data not analyzed				0.10	
Yampa River	2000	M_t	3	311	173–728	0.04, 0.07, 0.14	0.35
	2000	M_o	3	349	191–824	0.08	0.36
	2001	Data not analyzed				0.17	
White River	2000	M_t	3	1,115	833–1,578	0.10, 0.08, 010	0.16
	2000	M_o	3	1,120	837–1,585	0.10	0.16
	2001	Data not analyzed				0.12	

Deso/ Gray	2001	Data not analyzed	0.10	
Lower Reach	2001	Data not analyzed	0.16	

4.2.3 Issues and Concerns

Size at Maturity. — Estimates of adult Colorado pikeminnow in the middle Green River include all PIT-tagged fish (> about 150 mm TL). Based on size of recaptures, the estimates include about 8% of fish <450 mm TL; 450 mm TL is the size of fish at age 7 (Figure 4). Estimates need to be recalculated to reflect adult size (i.e., ≥450 mm TL).

Crew Size and Sampling Occasions. — The Green River subbasin is currently being sampled by multiple crews for population estimates. Each crew typically consists of one or two electrofishing boats, each with two netters and one boat operator. Crew size and effort in the middle and lower reaches of the Green River, White River, and Desolation/Gray canyons seems sufficient to produce precise and reliable population estimates, based on an average *P*-hat of about 8–16% and a *CV* of 9–16%. For the Yampa River, a *P*-hat of 4–14% and *CV* of 35–36% indicate a need to increase sampling efficiency, if possible. Sampling in the Yampa River is difficult logistically because of the narrow, rapid river flow during runoff, and a more precise estimate may not be possible.

Bias and Precision. — Population estimates for Colorado pikeminnow generally show good precision for the middle and lower Green River, Desolation/Gray canyons, and the White River. Probability of capture and coefficient of variation on the Yampa River indicate a need to improve precision in this river. However, the small size of the population, and the logistical difficulty of sampling this river may preclude more precise estimates.

Mixing of Stocks. — Abundance estimates of Colorado pikeminnow in the Green River subbasin assume a mixing of stocks within each of the five reaches where independent population estimates are conducted. Mixing of stocks within each of these five reaches is important for accurate and precise estimates.

Immigration and Emigration. — Immigration and emigration are believed to be negligible during the annual sampling period. Estimates of recruitment for the Green River subbasin are based on subadults in both lower and upper reaches. Since the young fish move to

the lower reach and move back to the upper reach at maturity, accurate and precise estimates of subadults is important to assess recruitment.

4.2.4 Recommendations

- Estimates of adults will include fish ≥450 mm TL; subadults will include fish 400 to 449 mm TL.
- Continue current effort to maintain precision.
- Conduct Yampa River, White River, and middle mainstem Green River estimates for a fourth consecutive year (i.e., 2003) to be consistent with the Desolation/Gray canyons and lower mainstem Green River estimates.
- Final populations estimate will be for the entire Green River subbasin.
- Conduct estimates in each of 3 consecutive years followed by 2 years off.

4.3 San Juan River Subbasin

4.3.1 Current Protocol

The number of wild Colorado pikeminnow in the San Juan River subbasin is considerably lower than in the Upper Colorado River or Green River subbasins. Only 17 adult Colorado pikeminnow were captured in the entire San Juan River between 1991 and 1995 as part of the fish community study and not as a designed mark-recapture population estimate. Fifteen sampling trips were conducted between June 1991 and October 1995 (three trips per calendar year) from river miles (RM) 136.6 (Stump Camp) to RM 119.2 (Four Corner's Bridge). The 17.4-mile reach was the only common section of the San Juan River sampled during all 15 trips, and only 15 adult Colorado pikeminnow were captured in this reach. Population estimates could not be conducted for later years because only one wild adult Colorado pikeminnow was captured in the San Juan River after October 1995. Radiotelemetry confirmed that these 15 fish were year-round residents of this river section. Of the 15 fish captured, 9 were recaptured (3 were recaptured twice).

A Schnabel multiple-census population estimate (Van Den Avyle 1993) was performed, based on marks and recaptures of adult Colorado pikeminnow in the San Juan River between 1991 and 1995. Associated confidence intervals were calculated using Poisson distribution

tables (Ricker 1975) to compensate for small numbers of captures and recaptures.

4.3.2 Current Estimates

The Schnabel population estimate yielded a value of 19 adult fish, with 95% confidence intervals of 10 to 42 adult fish (99% C.I. = 8–54 fish). A Petersen population estimate yielded estimates ranging from 9 to 20 fish for the 14 sampling intervals involved. The estimate models used assume a 0% mortality factor, although there was one confirmed mortality during the study and possibly more.

The almost complete lack of wild Colorado pikeminnow collections from 1996 to 2001 has precluded a more all-inclusive and up-to-date population estimate. Given that all but two adult Colorado pikeminnow were collected from RM 136.6–119.2 between June 1991 and October 1995, these estimates are extrapolated to the river as a whole. There were probably fewer than 40 adult Colorado pikeminnow in the entire San Juan River as of October 1995. The study from which these data were collected was not intended for population estimates, but rather as a fish community characterization study. The lack of repeated, riverwide sampling in all years (1991–1995) makes extrapolating this estimate to the river as a whole impossible. The small number of adult wild fish collected from 1991–2001 has precluded a more up-to-date population estimate from being performed; only 3 wild Colorado pikeminnow have been collected since October 1995; 2 juveniles (363 and 432 mm TL) near Lake Powell in 1996; 1 adult originally captured in April 1993, recaptured in 1998, 1999, and 2000 (all from RM 136.6–119.2).

4.3.3 Issues and Concerns

Stocking Implications. — Large numbers of larval and small juvenile hatchery fish have been released into the San Juan River, and more releases are planned for the future. A sampling design will need to be incorporated into the San Juan River program in order to estimate numbers of subadults (400–449 mm TL) and adults (≥450 mm TL). The recovery criteria call for a target of 1,000 subadults established by the end of the 5-year downlisting period, and 800 adults maintained during the 7-year delisting period (the delisting target is conditional on upper Colorado River target). When fish numbers are small, they are difficult to capture and an accurate population estimate is difficult to obtain.

Size at Maturity. — Adult size for population estimates of Colorado pikeminnow in the San Juan River subbasin should be consistent with the Green River and Upper Colorado River subbains at ≥450 mm TL.

Crew Size and Sampling Occasions. — Crew size should be sufficient to ensure maximum and equal probability of capture of all adult Colorado pikeminnow for each sampling occasion. The number of sampling occasions needs to be balanced with an acceptable level of precision, investment of time and funds, and over-handling of fish.

Bias and Precision. — Precision of population estimates for Colorado pikeminnow in the San Juan River subbasin cannot be currently assessed. Probability of capture and coefficient of variation should target about 0.10 and 0.15, respectively. The small size of the population in the San Juan River may preclude estimates that approach the target precision. Three radio-tagged Colorado pikeminnow were observed to actively avoid both electrofishing boats and trammel nets. Repeated sampling (especially electrofishing) may condition this species to avoid capture, and thus, bias population estimates.

Mixing of Stocks. — Abundance estimates of Colorado pikeminnow in the San Juan River subbasin should assume a mixing of stocks within each reach where independent population estimates are conducted. Mixing of stocks is important to accurate and precise estimates.

Immigration and Emigration. — Immigration and emigration should be negligible during annual sampling periods.

4.3.4 Recommendations

- Increase wild population of Colorado pikeminnow by augmenting with hatchery-produced fish.
- Begin population estimates when fish stocked in the first year of the approved stocking plan are age 5.
- Estimates of adults will include fish ≥450 mm TL; subadults will include fish 400 to 449 mm TL.
- Sampling protocols will be similar to those currently in use in the upper basin to minimize variability and maximize precision.
- Conduct population estimates throughout occupied range of stocked fish in San

Juan River subbasin.

- Conduct estimates in each of 3 consecutive years followed by 2 years off.

4.4 Basin-Wide Estimates

4.4.1 Current Protocol

Mark-recapture data for Colorado pikeminnow from all projects conducted from 1991 through 1997 in the Upper Colorado River Basin were assimilated, and estimates were made for the Upper Colorado/Gunnison rivers, Yampa/Little Snake rivers, White River, and Green/Duchesne/Price rivers (Nesler 2001). Data were assimilated for newly marked fish, recaptures, total captures, recaptures in the same year, time caught, and location captured. Fish were sampled in the Colorado River (RM: 47, 114,123, 170–176) during the months of March through October; in the Yampa River (RM: 34, 52–53) during the months of May through May, June, and July; in the White River (RM: 99, 100–105) during the months of May through May, June, August, October; and in the Green River (RM: 294, 319–366) during the months of March through November.

Population estimates were made from a compilation of all sampling efforts. It was assumed that sampling effort was more or less equal for each reach of river for each year. Exchange of marked fish between reaches occurred, but was assumed to be negligible (geographic closure). Demographic closure was not assumed; effects of mortality and recruitment were accounted for as knife-edge events (i.e., annual mortality was assumed to be 14%). Survival between marked and unmarked fish was assumed equal. Recruitment to the adult population was assumed to occur at the end of the capture season, with new recruits marked and added in the following year. Only PIT-tagged fish were included in population estimates, and spawning season data were eliminated from consideration. An annual adult survival rate of 0.86 was applied to marked fish from the previous year to account for mortality. Only the first capture in a season was used for individual fish, and only recapture events were used for resident fish. Newly-marked fish recaptured in the same season were omitted from the database.

The Chapman modification of the Petersen method was used to estimate population size, where: $N = (M+1)(C+1)/(R+1)$. Confidence intervals were based on Poisson frequency

distribution using the recapture number as a determining variable (Ricker 1975).

4.4.2 Current Estimates

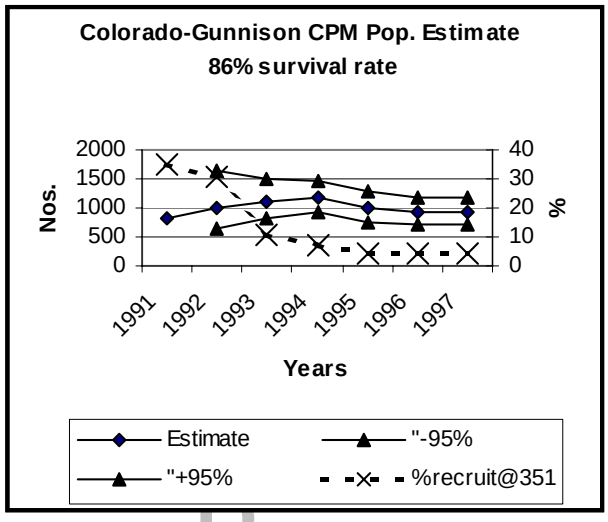
Population size was estimated for Colorado pikeminnow in the Upper Colorado-Gunnison rivers from 1991 through 1997, and from 1992 through 1997 for the Yampa-Little Snake, White, and Green rivers (Table 8; Figure 7). These population estimates included fish ≥350 mm TL. Estimates in the Upper Colorado-Gunnison rivers varied from 817 in 1991 to 1,167 in 1994. Estimates in the Yampa-Little Snake rivers varied from 120 in 1992 to 259 in 1995. Estimates in the White River varied from 182 in 1992 to 534 in 1997. Estimates in the Green-Duchesne-Price rivers varied from 2,035 in 1992 to 7,391 in 1997.

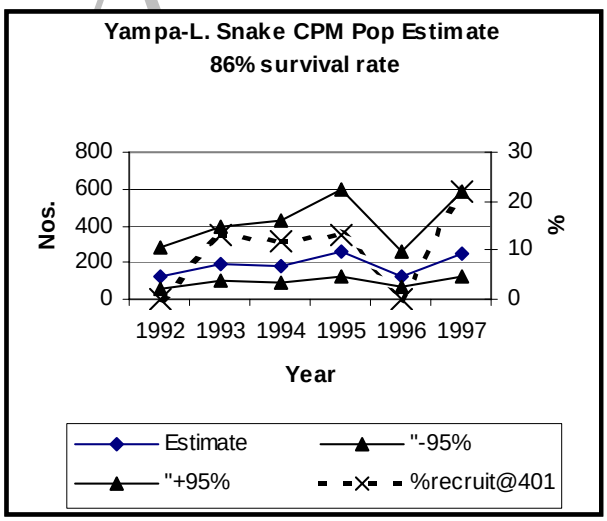
Table 8. Basin-wide population estimates for Colorado pikeminnow ≥350 mm TL at an assumed annual adult survival rate of 86% (Nesler 2000).

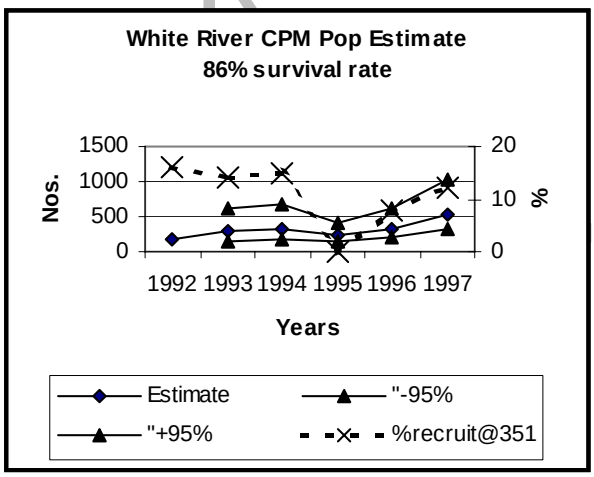
River	Year	Dates	River Miles	*N*-hat	95% C.I.		*P*-hat
					Lower	Upper	
Colorado & Gunnison Rivers	1990	4/18–6/15	135.1–181.8	0	—	—	—
	1991	4/16–9/11	16.5–208	817	—	—	0.016
	1992	3/04–10/09	11.9–207.3	1003	640	1656	0.107
	1993	4/06–8/02	Lake Powell–175.3	1095	818	1501	0.193
	1994	3/25–9/29	Lake Powell–175.3	1167	924	1475	0.270
	1995	5/04–10/17	50.5–163.7	985	760	1274	0.410
	1996	4/09–10/27	16.5–207.2	916	715	1171	0.436
	1997	4/17–9/11	53.3–175.6	922	720	1179	0.433
Yampa & Little Snake Rivers	1991	5/07–6/19	51.5–103.4	0	—	—	—
	1992	5/13–5/20	52.1–103.4	120	57	278	0.278
	1993	5/18–6/16	51.4–103.5	192	103	392	0.205
	1994	5/24–6/08	52.5–104.7	184	87	424	0.294
	1995	5/10–7/17	52.2–103.4	259	122	597	0.208
	1996	5/14–5/17	70.4–103.4	127	68	260	0.500
	1997	5/06–6/16	51.7–103.5	252	119	581	0.217
White River	1991	5/16–5/31	0.1–104.3	0	—	—	—
	1992	5/18–5/29	6–104.2	182	—	—	0.053
	1993	5/11–10/29	0–104.5	288	149	606	0.096
	1994	5/17–6/15	2.9–104.2	320	166	675	0.206
	1995	5/18–8/09	4.8–104.1	238	143	421	0.342
	1996	5/15–5/31	0.1–104.3	336	195	631	0.262
	1997	5/14–6/18	4.3–104.2	543	315	1018	0.183
Green, Duchesne, Price Rivers	1991	4/30–7/14	40.2–333.9	0	—	—	—
	1992	4/28–9/13	0–334	2035	908	5088	0.028
	1993	4/13–8/28	1–347	3927	1753	9819	0.033

Table 8 (continued)

River	Year	Dates	River Mile	*N*-hat	95% C.I.		*P*-hat
					Lower	Upper	
Green, Duchesne, Price Rivers	1995	3/23–11/08	25.7–363.2	5306	3737	7803	0.065
	1996	4/19–10/01	0.1–365.3	6686	4709	9832	0.093
	1997	4/22–10/17	1.5–333.5	7391	5383	10478	0.103







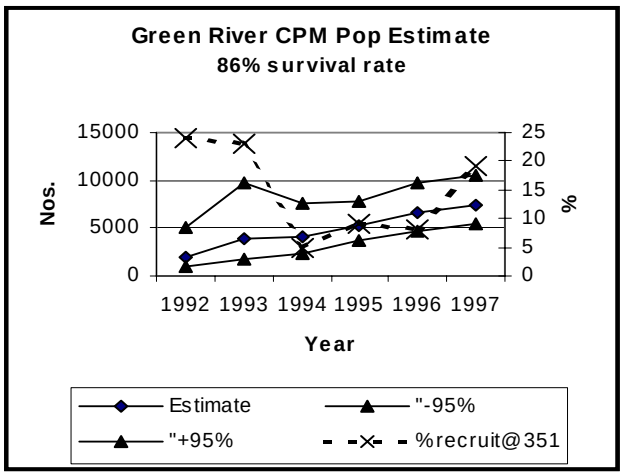


Figure 7. Trends in population estimates of Colorado pikeminnow ≥350 mm TL in the Upper Colorado-Gunnison rivers, Yampa-Little Snake rivers, White River, and Green River (See Table 8 for specific data).

4.4.3 Issues and Concerns

Size at Maturity. — Basin-wide estimates of adult Colorado pikeminnow include fish ≥350 mm TL. Estimates should be recalculated to reflect adult size (i.e., ≥450 mm TL).

Crew Size and Sampling Occasions. — Crew size and type of project to obtain basin-wide estimates varied greatly from 1991 through 1997. Varying crew size and effort likely affected capture efficiency and *P*-hat and *CV*. These basin-wide estimates are based on sampling occasions that were variously spaced during a given year.

Bias and Precision. — Estimates of coefficient of variation are not available for these population estimates. However, 95% lower confidence intervals (Table 8, Figure 7) range from about 65% to 80% of the estimate, and upper confidence intervals range from about 25% to 70% of the estimate. The precision of these estimates is a concern because of the varying intervals of time between sampling occasions. Data used for these estimates were gathered under a variety of sampling designs, most of which were not intended for mark-recapture population estimates. Intervals between sampling, sampling methods, gear types, sampling effort, and geographic areas sampled all varied among sampling efforts, leading to a high probability of violation of population estimator models and low precision and accuracy of estimates. An annual adult mortality rate was applied to all fish to account for variability in survival. This adult mortality rate may not be accurate for the period of time between samples. Sample occasions that are closely-spaced (i.e., 1–2 weeks) greatly reduce risks associated with assumptions of survival, emigration, and immigration.

Mixing of Stocks. — Abundance estimates of Colorado pikeminnow in the various reaches of the Upper Colorado River assume a mixing of stocks within each of the reaches where independent population estimates are conducted.

Immigration and Emigration. — Immigration and emigration could have been substantial during the period of these basin-wide estimates. Data for these estimates were collected from varying geographic reaches and during varying periods of time. Known spawning migration was considered for these estimates by discounting all fish during spawning periods. However, migration during the periods of estimates was unknown and could have been a factor.

4.4.4 Recommendations

- These estimates should not be used as downlisting and delisting criteria because the data were not collected under a mark-recapture sampling design, and the estimates lack precision. Basin-wide estimates for the period 1991 through 1997 provide valuable insight into trends of wild Colorado pikeminnow populations in the Green River and Upper Colorado River subbasins. Although these estimates lack precision and are based on data collected from sampling programs not intended for multiple mark-recapture population estimates, the estimates provide the magnitude of population abundance and the trend indicative of an increasing population. These estimates provide a longer period of record of population trend beyond one generation time.
- Recalculate population estimates to reflect adult size (i.e., ≥450 mm TL) and size of subadults (400–449 mm TL) for uniformity and comparison with other estimates.
- Assess level of recruitment with estimates of fish 400–449 mm TL and with length-frequency data, if possible.
- Continuation of this effort is not possible because data are no longer being collected in this manner.

5.0 HUMPBACK CHUB

[Note: Most of the population estimates that follow are preliminary and are included only to illustrate issues and concerns associated with statistical validity and precision.]

5.1 Black Rocks

5.1.1 Current Protocol

The Colorado River in Black Rocks was sampled in 1998, 1999, and 2000 to estimate size and structure of the humpback chub population. Sampling occurred in late summer and early autumn after water temperatures began to cool for the year. Three sampling trips were conducted in 1998 and 2000, four trips were made in 1999. Each sampling trip was 3 days long and trips were spaced one week apart. Sampling was primarily done with multi-filament

trammel nets (1-inch inner mesh), although *Gila* captures were supplemented with electrofishing and trap nets in 1998 and with angling in all years. Trammel nets were set in shoreline eddies in early morning and late afternoon. Nets were run at 1- to 2-hour intervals with a 2-hour set as a maximum interval (mean, 1.5 hour). All *Gila* were removed from the nets, placed in fresh water, and transported to a central processing point.

All *Gila* were identified as either humpback chub or roundtail chub, checked for a PIT tag, measured (total length, ± 1 mm), and weighed (± 1 g). Untagged fish were equipped with a PIT tag before release. After handling, *Gila* were placed in a 1.5% salt bath for 0.5–1 min, and released at the common location. About 10% of the total number handled were placed in a live cage and held overnight to assess initial mortality — no overnight mortalities occurred. All fish appeared healthy when released.

5.1.2 Current Estimates

Population estimates for humpback chub in Black Rocks were highly variable depending on the model selected to make the estimate. For example, estimates in 1998 ranged from 349 using Jackknife M_h to 1,495 using Chao M_h. Model M_o was selected as the 'best' estimator. Using the 'best' model, population estimates for humpback chub in Black Rocks were 948 (95% confidence interval, 603–1,573) in 1998, 921 (723–1,208) in 1999, and 539 (223–1,497) in 2000 (Table 9).

Catch rates declined markedly in 2000 compared with 1998 and 1999. A total of 184 humpback chub were handled in 1998 (number does not include within year recaptures), 293 in 1999 (four trips compared with three trips in other years), and 68 in 2000. Within-year recapture rates were about 10%, with overall recapture rates of 30 to 40% (includes multiple recaptures of the same fish during the same sampling trip, recaptures of fish tagged by other investigators, and fish tagged in previous years of this study). Recaptures included a total of 15 humpback chub that had originally been tagged in Westwater Canyon.

Length-frequency distributions of humpback chub were bimodal in all years. Modes were at 230–250 mm TL and 310–340 mm TL. Growth of recaptured fish averaged 7 mm per year. There was no significant difference in growth when humpback chub were partitioned into two size groups based on the length-frequency distribution. All humpback chub were sexed during the last sampling trip of 1999 when an experienced observer was available to sex the fish.

The sex ratio was not significantly different from 1:1.

Table 9. Area and year of estimate, estimator models, sampling occasions, fish size, population estimate (*N*-hat), 95% confidence intervals (C.I.), probability of capture (*P*-hat), and coefficient of variation (*CV*) for humpback chub in Black Rocks, Westwater Canyon, Desolation/Gray canyons, Yampa Canyon, Cataract Canyon, and Grand Canyon.

Area of Estimate	Year	Model	Occasions	Fish Size (mm TL)	*N*-hat	95% C.I.	*P*-hat	*CV*
Black Rocks	1998 1999 2000	M_o	3 4 3	≥ 180 ≥ 200 ≥ 200	948 921 539	603–1,573 723–1,208 223–1,497	0.07 0.09 0.04	0.25 0.13 0.54
Westwater Canyon	1998 1999 2000	M_o	3 3 3	≥ 190 ≥ 200 ≥ 160	5,171 2,261 1,704	3,299–8,287 1,349–3,942 1,095–2,758		
Desolation/Gray canyons	2001	Data not analyzed					0.03 0.27	
Yampa River	2000	M_o	3	≥ 125	242	101–717	0.021 0.043 0.088	0.57
	2000	M_h	3	≥ 125	442	147–1,578		0.70
Cataract Canyon	2002	Sampling will begin in 2002						
Little Colorado River-Grand Canyon	Autumn 2000	Chapman-Peterson	2	≥ 135	1,590	992–2,552	0.16	0.19
Little Colorado River-Grand Canyon	Spring 2001	Chapman-Peterson	2	≥ 150	2,082	1,600–2,550	0.12	0.12
Little Colorado River-Grand Canyon	Summer 2001	Chapman-Peterson	2	≥ 200	1,044	446–1,644	0.07	0.57
Little Colorado River-Grand Canyon	Autumn 2001	Data not analyzed						
Colorado River-Grand Canyon (Middle Granite Gorge)	Autumn 2000	Schnabel	3	≥ 150	143	83–349	0.18	

5.1.3 Issues and Concerns

Effects of Sampling and Handling. — The number of sampling occasions was increased from three in 1998 to four in 1999, and biologists expressed concern for over-handling fish. Yet, tagged fish held overnight for observation all survived in good health, and the number of recaptures increased with sampling occasion; this evidence goes counter to the issue of over-handling. Although the additional pass increased *P*-hat from 0.07 to 0.09, and decreased *CV* from 0.25 to 0.13, biologists felt that the additional pass was stressful on the fish. Reasons for a lower estimate of 539 in 2000 from 948 in 1998 (not signficant) may be related to unpredicted fish movements to other habitats not sampled, or dramatically different sampling conditions, such as flow.

Size at Maturity. — Although all fish PIT-tagged were used to generate an estimate, the majority (98% in 1998, 100% in 1999 and 2000) were ≥200 mm TL, which are defined as adults. Hence, current estimates account for virtually all adults.

Crew Size–Sample Effort. — Crew size and sample effort were constant from 1998 through 2000, and are not believed to be linked to reasons for decreased catches during that period of time.

Bias and Precision. — Precision of population estimates for humpback chub in Black Rocks varied among years. In 1998, three sampling occasions yielded a *P*-hat of 0.07 and a *CV* of 0.25; four occasions in 1999 yielded a *P*-hat of 0.09 and a *CV* of 0.13; and three occasions in 2000 yielded a *P*-hat of 0.04 and a *CV* of 0.54. The additional sampling occasions had a substantial effect on *CV*, but did not increase *P*-hat proportionally. Four sampling occasions may not be appropriate because of concern for over-handling of fish. Means for increasing precision may include added crew size and sampling during similar river flows, since flow stage seems to affect catchability of humpback chub.

Mixing of Stocks. — Mixing of stocks within Black Rocks (i.e., between sampling sites) is a reasonable assumption.

Immigration and Emigration. — Exchange of fish between Black Rocks and Westwater Canyon may affect population estimates. A total of 15 humpback chub from Westwater Canyon have been captured in Black Rocks for the period 1998–2000.

5.1.4 Recommendations

- Ensure sampling is conducted throughout occupied reach.
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL.
- Sampling will expand to capture subadults with electrofishing and hoop nets.
- Use key meristics/morphometrics to segregate *Gila cypha*, *Gila robusta*, and *Gila* sp. through application of "the art of seeing well" (Douglas et al. 1989, 1998).
- Conduct estimates in each of 3 consecutive years followed by 2 years off

5.2 Westwater Canyon

5.2.1 Current Protocol

The Colorado River through Westwater Canyon was sampled in 1998, 1999, and 2000 to estimate abundance of the humpback chub population. Three sites were sampled (Miner's Cabin, Cougar Bar, and Hades Bar). Sampling included about 0.5 miles at each site, or about 1.5 miles of the 10 miles of Westwater Canyon. Each site was sampled three times each year with 75-foot trammel nets (1-inch mesh), hoop nets, and electrofishing. A total of 275–300 2-hour net sets were made in the three sites for each of the three passes. All *Gila* sp. were identified and each fish 150 mm TL or larger received a PIT tag. Each fish was scanned for a pre-existing PIT tag, identifying it as a recapture.

A closed population model was used to estimate population size. It was assumed that the population was closed between sampling occasions, that marks were not lost, that all marks were correctly noted and recorded, and that each fish had a constant and equal probability of capture on each sampling occasion. Population estimator models M_o and M_t were used. Both models assume that all members of the population are equally at risk to capture, but the M_o model assumes that the probability of capture does not change from one sampling occasions to the next, while the M_t model assumes that the probability of capture changes from one sampling occasion to the next.

5.2.2 Current Estimates

Population estimates for the three sites in Westwater Canyon combined were 5,171 (95% C.I. = 3,299–8,287) in 1998; 2,261 (95% C.I. = 1,349–3,942) in 1999; and 1,704

(95% C.I. = 1,095–2,758) in 2000 (Table 9). The areas sampled in these sites represent only a total of about 15% of the river through Westwater Canyon.

5.2.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish during the warm summer months has been expressed for Westwater Canyon. Biologists feel that the fish are less stressed when handled during cool periods, when water temperature is below about 16°C; usually mid-September through October is the best time to sample. Fish are currently being held overnight (8–10 hours) in live pens for processing the following morning after capture; holding fish in crowded conditions may be imposing handling stress. Population estimates in Westwater Canyon have decreased from 5,171 in 1998, to 2,261 in 1999, and 1,704 in 2000 (decline significant from 1999 to 2000). Numbers of humpback chub captured has decreased from 488 in 1998, to 281 in 1999, and 279 in 2000, although numbers of recaptures have increased from 54 (11%) in 1998, to 65 (23%) in 1999, and 76 (27%) in 2000 (Table 10). The increase in numbers of recaptures is inconsistent with the hypothesis of over-handling and selective mortality of tagged fish. Reasons for decline in population estimates may be related to unpredicted fish movements to other habitats not sampled, or dramatically different sampling conditions, such as flow.

Size at Maturity. — Although all fish PIT-tagged were used to generate an estimate, the majority (99% in 1998, 100% in 1999, 98% in 2000) were ≥200 mm TL, which are defined as adults. Hence, current estimates account for virtually all adults.

Table 10. Numbers of humpback chub captured and recaptured in Westwater Canyon during 1998, 1999, and 2000.

Year	Minimum Fish Size (mm TL)	Total HB Captured	Total Recaptures (%)	Annual Recaptures
1998	190	488	54 (11%)	14
1999	200	281	65 (23%)	10
2000	160	279	76 (27%)	6
Total		1,048	195	30

Crew Size–Sample Effort. — Crew size and sample effort were constant from 1998 through 2000.

Bias and Precision. — Population estimates for humpback chub in Westwater Canyon appear to be highly variable and lacking precision. The efficacy of sampling in small subreaches of a population will need to be evaluated (i.e., only 15% of canyon is being sampled), but it appears that sampling will need to be extended to as many sites as possible in order to ensure that the estimate represents the population of humpback chub in Westwater Canyon.

Mixing of Stocks. — Sampling of humpback chub in Westwater Canyon during 1998, 1999, and 2000 was conducted within each of three distinct sampling sites (Miner's Cabin, Cougar Bar, Hades Rapid). The amount of mixing of individuals fishes within and among these sample sites has not been evaluated. Possibly marked and unmarked fish at a given site move outside of the effective sampling area and are not susceptible to capture on subsequent sampling occasions. This mixing and movement of fish outside of sampling areas needs to be investigated, and may explain apparent declines in fish numbers.

Immigration and Emigration. — Immigration and emigration of fish into and from Westwater Canyon are believed to be negligible during the annual sampling period, although exchange of small numbers of individuals has been documented with Black Rocks; this needs to be further evaluated.

5.2.4 Recommendations

- Expand sampling to include Miners Cabin, Cougar Bar to Little Hole, Hades Bar, and Big Hole; electrofish intervening reaches.
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL.
- Sampling will expand to capture subadults with electrofishing and hoop nets.
- Use key meristics/morphometrics to segregate *Gila cypha, Gila robusta,* and *Gila* sp. through application of "the art of seeing well" (Douglas et al. 1989, 1998).
- Conduct estimates in each of 3 consecutive years followed by 2 years off.
- Evaluate holding of fish overnight and consider shorter holding periods for processing of fish at the time of capture.

5.3 Other Estimates for Black Rocks and Westwater Canyon

5.3.1 Current Protocol

Mark-recapture data for humpback chub in the Upper Colorado River Basin were assimilated, and estimates were made for the Black Rocks and Westwater Canyon populations (Table 11; Nesler 2001). Data were assimilated for newly marked fish, recaptures, total captures, recaptures in the same year, time caught, and location captured for the period 1991 through 1997. Fish were sampled in Black Rocks (RM 127–136) for the period September 2–15 for the years 1994 and 1997. Fish were sampled in Westwater Canyon (RM 120–124) for the period April, July, September through September, and October for the years 1991 through 1997.

Population estimates were made from a compilation of all sampling efforts. It was assumed that sampling effort was more or less equal for each river reach for each year. Exchange of marked fish between was assumed to be negligible (geographic closure). Demographic closure was not assumed; effects of mortality and recruitment were accounted for as knife-edge events (i.e., annual adult mortality was assumed to be 24%). Survival between marked and unmarked fish was assumed equal. Recruitment to the adult population was assumed to occur at the end of the capture season, with new recruits marked and added in the following year. Only PIT-tagged fish were included in population estimates, and spawning season data were eliminated from consideration. An annual adult survival rate of 0.76 was applied to marked fish from the previous year to account for mortality. Only the first capture in a season was used for individual fish, and only recapture events were used for resident fish. Newly-marked fish recaptured in the same season were omitted from the database. All PIT-tagged fish were included in the estimate.

The Chapman modification of the Petersen method was used to estimate population size, where: $N = (M+1)(C+1)/(R+1)$. Confidence intervals were based on Poisson frequency distribution using the recapture number as a determining variable (Ricker 1975).

5.3.2 Current Estimates

Population size for humpback chub in Black Rocks for 1994 was 1,234 fish (95% C.I. = 451–3,085), and the estimate in 1997 was 1,159 (95% C.I. = 473–2,897) (Table 11).

Population size for humpback chub in Westwater Canyon for 1993 was 4,493 fish (95% C.I. = 1,834–11,233); the estimate in 1994 was 3,452 (95% C.I. = 2,001–6,473); the

Table 11. Other population estimates from Black Rocks and Westwater Canyon for humpback chub ≥150 mm TL at an assumed annual adult survival rate of 76% (Nesler 2000).

Area	Year	Dates	River Miles	*N*-hat	95% C.I.		*P*-hat
					Lower	Upper	
Black Rocks	1994	9/08–9/15	135.5–136.2	1234	451	3085	0.03
	1997	9/02–9/10	135.6–136.2	1159	473	2897	0.03
Westwater Canyon	1993	4/08–10/15	120–124.1	4493	1834	11233	0.03
	1994	7/13–9/16	120–124.1	3452	2001	6473	0.05
	1995	9/06–10/13	120–124.1	2893	1822	4822	0.10
	1996	7/24–9/13	120–124.1	2551	1743	3889	0.13
	1997	9/10–9/12	120–124.1	2039	1126	4077	0.17

estimate in 1995 was 2,893 (95% C.I. = 1,822–4,822); the estimate in 1996 was 2,551 (95% C.I. = 1,743–3,889); and the estimate in 1997 was 2,039 (95% C.I. = 1,126–4,077).

5.3.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish during the warm summer months has been expressed for all humpback chub populations. Biologists feel that the fish are less stressed when handled during cool periods, when water temperature is below about 16°C; usually mid-September through October is the best time to sample. Effects of sampling and handling on these estimates are not known.

Size at Maturity. — Size of adult humpback chub throughout the Colorado River Basin appears to be about 200 mm TL; subadults are defined as fish that are 150–199 mm TL.

Crew Size and Sample Effort. — Crew size to obtain these estimates for Black Rocks and Westwater Canyon varied greatly. Varying crew size and effort likely affected capture efficiency, *P*-hat, and *CV*. These basin-wide estimates are based on sampling occasions that were variously spaced during a given year.

Bias and Precision. — Population estimates for humpback chub based on historic data vary in precision. Some estimates are based on mark-recaptured data collected under very different sampling efforts among sampling occasions; this can affect probability of capture and

bias estimates. Also, some estimates are based on varying intervals of time between mark and recapture occasions; this can introduce errors into the estimate through varying mortality and migration of individuals. Different geographic reaches were sampled for different sampling occasions; this introduces bias into the estimates by not allowing all fish in the population equal capture probability. An annual adult mortality rate was applied to all fish to account for variability in survival of adults. This adult mortality rate may not be accurate for the period of time between samples. Sample occasions that are closely-spaced (i.e., 1–2 weeks) greatly reduce risks associated with assumptions of survival, emigration, and immigration.

Mixing of Stocks. — Mixing of stocks during the extended period of these population estimates, with variously spaced sampling occasions, is unknown.

Immigration and Emigration. — Immigration and emigration could have been substantial during the period of these basin-wide estimates. Data need to be reviewed for exchange of individuals between Black Rocks and Westwater Canyon. Migration during the periods of estimates was unknown and could have been a factor.

Precision and Accuracy. — Estimates of the coefficient of variation are not available for these estimates. However, 95% lower confidence intervals (Table 11, Figure 7) range from about 40% to 60% of the estimate, and upper confidence intervals range from about 40% to 70% of the estimate. The precision of these estimates is a concern because of the varying intervals of time between sampling occasions. Data used for these estimates were gathered under a variety of sampling designs, most of which were not intended for mark-recapture population estimates. Intervals between sampling, sampling methods, gear types, sampling effort, and geographic areas sampled all varied among sampling efforts, leading to a high probability of violation of population estimator models and low precision and accuracy of estimates.

5.3.4 Recommendations

- These estimates should not be used as downlisting and delisting criteria because of the lack of precision resulting from the various sampling methods used to collect the data. Estimates for Black Rocks for 1994 and 1997, and for Westwater Canyon for 1993–1997 provide valuable insight into trends of these humpback chub populations. Although these estimates lack precision and are based on data collected from sampling programs not intended for multiple mark-recapture population estimates, the estimates provide the

magnitude of population abundance and trend. These estimates provide a longer period of record of population trend beyond one generation time.

- Recalculate population estimates to reflect adult size (i.e., ≥200 mm TL) and size of subadults (150–199 mm TL) for uniformity and comparison with other estimates.
- Assess level of recruitment with estimates of fish 150–199 mm TL and with length-frequency data, if possible.
- Continuation of this effort is not possible because data are no longer being collected in this manner.

5.4 Desolation/Gray Canyons

5.4.1 Current Protocol

The Green River through Desolation/Gray canyons was sampled in 2001 to estimate abundance of the humpback chub population. Twelve sites were sampled between Sand Wash (RM 96) and Swasey's Rapid (RM 12), including Gold Hole, Cedar Ridge, Drippings Springs, Log Cabin, Rock Creek, Chandler Falls, Cow Swim, Florence Creek, Three Fords Canyon, Big Bend, Curry, and Coal Creek. Sampling included about 0.5 miles at each site, or about 6 miles of the 84 miles of Desolation/Gray canyons. Sites were sampled three times each year, although different sites were sampled on subsequent sampling occasions. Fish were sampled with 75-foot trammel nets (1-inch mesh; each set 2 hours), hoop nets, and electrofishing. All *Gila* sp. were identified and each fish 150 mm TL or larger received a PIT tag. Each fish was scanned for a pre-existing PIT tag to identify recaptures.

A closed population model was used to estimate population size. Currently, data collected are being analyzed using closed-population models available in the program CAPTURE (White et al. 1982). Assumptions of closed population models include: the population is closed, humpback chub do not lose their marks during the project, all marks are correctly noted and recorded at each capture occasion, and each animal has a constant and equal probability of capture on each trapping occasion.

Population estimator models M_o and M_t are being used. Both models assume that all members of the population are equally at risk to capture, but the M_o model assumes that the probability of capture does not change from one sampling occasions to the next, while the M_t

model assumes that the probability of capture changes from one sampling occasion to the next.

5.4.2 Current Estimates

Data collected in 2001 have not been analyzed and population estimates for Desolation/Gray canyons are not currently available.

5.4.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish during the warm summer months has been expressed for Desolation/Gray canyons. Biologists feel that the fish are less stressed when handled during cool periods, when water temperature is below about 16°C; usually mid-September through October is the best time to sample. Fish are currently being held overnight (8–10 hours) in live pens for processing the following morning after capture; holding fish in crowded conditions may be imposing handling stress. During 2001, numbers of humpback chub captured in Desolation/Gray canyons decreased from 204 on pass one, to 88 on pass two, and 33 on pass three (Table 12). Reasons for decline in numbers captured may be related to unpredicted fish movements to other habitats not sampled, or dramatically different sampling conditions, such as flow. Flow during the three sampling periods varied dramatically from 6,000 cfs on pass one, to 1,400 cfs on pass two, and 1,100 cfs on pass three. These differences in river flow could affect fish catchability dramatically.

Size at Maturity. — The majority (99%) of fish PIT-tagged were ≥200 mm TL, which is defined as an adult. Hence, current estimates should account for virtually all adults.

Crew Size–Sample Effort. — Crew size and sample effort will need to be adjusted and kept constant to ensure the best possible estimates. The principal investigator recommended electrofishing to be discontinued in Desolation/Gray canyons because of possible detrimental effects on spawning Colorado pikeminnow.

Bias and Precision. — Population estimates for humpback chub in Desolation/Gray canyons, like Westwater Canyon, appear to be highly variable and lacking precision. The efficacy of sampling in small subreaches of a population will need to be evaluated, but it appears that sampling will need to be extended to as many sites as possible in order to ensure mixing of marks and to minimize relocation of fish to areas outside of sample sites. All available gears will need to be used to ensure capture of subadults to evaluate recruitment.

Mixing of Stocks. — Sampling of humpback chub in Desolation/Gray canyons during

2001 was conducted at 12 sampling sites, each about 0.5 miles long. This represents only about

Table 12. Numbers of humpback chub captured and recaptured for each of three passes in Desolation/Gray canyons during 2001.

Pass	Total Chubs	Recaptures	Multiple Recaptures	CPUE	Flows (cfs)[a]
1	204			0.216	6,000
2	88	3		0.099	1,400
3	33	9	2	0.051	1,100
Total	325	12	2	0.124	

[a]Temperature increases as flows decrease.

7% (6 of 84 miles) of occupied habitat in Desolation/Gray canyons. The amount of mixing of individuals fishes within and among these sample sites has not been evaluated. Possibly marked and unmarked fish at a given site move outside of the effective sampling area and are not susceptible to capture on subsequent sampling occasions. This mixing and movement of fish outside of sampling areas needs to be investigated, and may explain apparent declines in fish numbers.

Immigration and Emigration. — Immigration and emigration of fish into and from Desolation/Gray canyons are believed to be negligible during the annual sampling period.

5.3.4 Recommendations

- Continue use of electrofishing in Desolation/Gray canyons. If spawning Colorado pikeminnow are present, electrofishing will be suspended for that area.
- Sample earlier in June to minimize effect of dropping water levels on sampling efficiency.
- Expand sampling to include 12 sites; electrofish intervening reaches.
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL.
- Sampling will expand to capture subadults with electrofishing and hoop nets.
- Implement two crews to sample simultaneously at different sites.
- Use key meristics/morphometrics to segregate *Gila cypha, Gila robusta,* and *Gila*

sp. through application of "the art of seeing well" (Douglas et al. 1989, 1998).

- Conduct estimates in each of 3 consecutive years followed by 2 years off.
- Evaluate holding of fish overnight and consider shorter holding periods for processing of fish at the time of capture.

5.5 Yampa Canyon

5.5.1 Current Protocol

The humpback chub population in the lower 60 km of the Yampa River (Yampa Canyon, Dinosaur National Monument) was monitored between 1998 and 2000 to determine size structure and estimate abundance. Angling, electrofishing, and trammel nets were used to capture fish. Two to three sampling trips were conducted per year. Electrofishing was limited to flows in excess of 1,000 cfs because of difficulty of accessing the canyon with electrofishing equipment at lower flows. All sampling was conducted on the descending limb of the hydrograph.

The density of fish in Yampa Canyon is relatively low (Karp and Tyus 1990), estimated at less than 8 fish/km (Nesler 2000). During the 3 years of monitoring, only 73 adults were captured and abundance could only be estimated during the last year of the study (2000). Using several estimator models, the population size of humpback chub in Yampa Canyon in 2000 was between approximately 100 and 2,000 individuals. Size structures of humpback chub between 1998 and 2000 indicate that individuals less than 250 mm TL were present in the population providing a source of recruitment. The size structure of humpback chub in lower Yampa River between 1998 and 2000 consisted of a greater percentage of smaller humpback chub than that observed in the Colorado River Fishery Project database consisting of collections between 1986 and 1997. The discrepancy in length frequency between the two data sets may be a function of sampling methodology. Approximately 80% of adult humpback chub captured between 1998 and 2000 were collected by electrofishing, whereas only 41% of fish collected previously were captured using electrofishing (the remainder were captured by angling or nets). Humpback chub were captured in most areas of the canyon sampled.

In 1998, 33 smaller suspected humpback chub were captured in seines. Identification of fish captured by seines was based on field examination (presence of 10 anal fin rays, mouth

terminus, and angle of caudal fin to anal fin) and was not conclusive, however, similar criteria used to identify juvenile humpback chub collected during 2000 in the laboratory were considered credible (D.E. Snyder, Larval Fish Laboratory, Colorado State University, personal communication). Most juvenile humpback chub collected by seines were sampled in the lower reaches of Yampa Canyon, however, these areas were more easily sampled with seines and may not represent distributional differences. Although not enumerated, it appeared that most year-classes of humpback chub were represented in Yampa Canyon.

5.5.2 Current Estimates

The humpback chub population in Yampa Canyon seems to be between approximately 100 and 2,000 adult individuals. A precise and accurate population estimate may difficult to obtain without additional effort. The size distribution of humpback chub in the lower Yampa River consisted of both adult and juvenile fish indicating some level of recruitment. Numbers of fish captured are presented in Table 13. Estimated population size of humpback chub (125+ mm TL) in Yampa Canyon for 2000 was 242 (95% C.I. = 101–717), using the preferred M_o model. Probability of capture ranged between about 2 and 9%, and *CV* was 57%. The estimate using the M_h model was 442 (95% C.I. = 147–1578). The population of humpback chub in Yampa Canyon is small, and a more precise estimate may not be possible. Nevertheless, these estimates provide insight into the magnitude of the population and together with catch information and length-frequency data provide insight into recruitment and self-sustainability.

5.5.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish during the warm summer months has been expressed for Yampa Canyon, as has been expressed for Westwater Canyon and Desolation/Gray canyons. Biologists feel that the fish are less stressed when handled during cool periods, when water temperature is below about 16°C; usually mid-September through October is the best time to sample. Sampling in Yampa Canyon is also limited by flows. Sampling with electrofishing cannot be conducted at flows of less than 1,000 cfs because of the difficulty of traversing the canyon with boats at that flow stage.

Size at Maturity. — Humpback chub captured and PIT-tagged in Yampa Canyon range in size from about 125 to 400 mm TL. Biologists report a shift to smaller fish in the latter sampling period (1998–2000), compared to the historical period (1985–1997). This shift may be

explained by use of different gear types and gear efficiency. Size of fish at maturity has not been evaluated

for Yampa Canyon, and it is assumed that subadults are fish 150–199 mm TL and adults are fish ≥200 mm TL.

Table 13. Numbers of adult humpback chub (≥125 mm TL) captured and recaptured in Yampa Canyon during 1998, 1999, and 2000. EF = electrofishing; CC = channel catfish.

Year	Date	Unmarked	Recaptured	Capture Gear
1998	7/9–12	7	0	1 EF raft, angling
	7/20–24	11	0	2 EF raft
1999	6/28–7/1	11	0	2 EF raft, angling
	7/12–14	8	1	1 EF raft, angling, recap from 1998
	7/20–8/11	4	0	Angling; CC removal
2000	6/8–9	9	0	1 EF raft
	6/19–21	16	2	2 EF raft; recap from previous trip
	6/26–28	17	0	2 EF raft

Crew Size–Sample Effort. — Crew size and sample effort will need to be adjusted and kept constant to ensure the best possible estimates.

Bias and Precision. — Population estimates for humpback chub in Yampa Canyon may not be possible. The population is currently small, and capture rates of marked and unmarked fish may be too low to generate reliable estimates.

Mixing of Stocks. — Humpback chub in Yampa Canyon are sampled throughout the canyon reach, but the amount of mixing within the canyon is unknown.

Immigration and Emigration. — Immigration and emigration of fish into and from Yampa Canyons are believed to be negligible during the annual sampling period. However, numerous young humpback chub have been captured downstream in Island Park, suggesting that the population extends into the Green River.

Population Size and Distribution – The population of humpback chub in Yampa Canyon may be too small for a reliable and precise estimate, (based on recommended targets of *P*-hat and *CV*). Numbers of individuals captured and recaptured on given sampling occasions may be too few to produce good estimates.

5.4.4 Recommendations

- Use total captures and catch rates to serve as an index of population size and trend, and length-frequency analysis and simulations to assess recruitment.
- Sample once per year, every year, instead of multiple mark-recapture approach
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL
- Sampling will expand to capture subadults with electrofishing and hoop nets
- Implement a standard protocol for identification of humpback chub in the field through application of "the art of seeing well" (Douglas et al. 1989, 1998).

5.6 Cataract Canyon

5.6.1 Current Protocol

Fish populations in Cataract Canyon have been sampled in 14 of the last 22 years, starting in 1979. Five investigative groups have conducted a total of 43 sampling trips, including the Service (1979–81; Colorado River Fishery Project; Valdez et al. [1982]); Ecosystem Research Institute and Bureau of Reclamation (1985; Valdez [1986]); Bio/West and Bureau of Reclamation (1986–1988; Valdez [1990]); Bio/West and Utah Division of Wildlife Resources (1989–92; Chart et al. [1990, 1991, 1992, 1993]); and Utah Division of Wildlife Resources (1995 Chart et al. [1996], 1998–99 [Trammel and Christopherson 1998, 1999]). Sampling has been done with medium-size rafts at various locales, generally between large rapids. Fish have been sampled with a variety of gears, including electrofishing, trammel nets, gill nets, seines, hoop nets, and angling. Sampling has been conducted to characterize the fish community and not to estimate population abundance.

All three species of Colorado River *Gila* live sympatrically in Cataract Canyon, including humpback chub, bonytail, and roundtail chub. Morphometric intergrades of these three species are common, and make it difficult to definitively identify some specimens. Specimens lacking

distinct species characteristics are classified as *Gila* sp. (chubs). A total of 138 humpback chub have been identified from Cataract Canyon (Table 14), including 54 adults. Eleven larvae have been identified from preserved specimens by the Larval Fish Laboratory, and 19 and 54 YOY and juveniles, respectively, have been identified in the field, based on anal and dorsal fin ray counts and the angle of the anal fin base. Of the 54 adults captured, 48 have been marked with

Table 14. Numbers of chubs (*Gila* sp.) captured in Cataract Canyon. USFWS = U.S. Fish and Wildlife Service; ERI = Environmental Research Institute; BOR = Bureau of Reclamation; BW = BIO/WEST; UDWR = Utah Division of Wildlife Resources.

Agency	Year	Trips	CH	BT	RT	HB	Total
USFWS	1979	2	-----	0	-----	0	0
USFWS	1980	1	-----	0	-----	1	1
USFWS	1981	1	-----	0	-----	0	0
ERI/BOR	1985	6	11	2	60	11	84
BW/BOR	1986	6	76	1	53	17	147
BW/BOR	1987	8	379	2	128	21	530
BW/BOR	1988	9	69	10	79	59	217
BW/UDWR	1989	3	46	0	2	3	51
BW/UDWR	1990	2	5	1	3	3	12
BW/UDWR	1991	1	4	0	2	6	12
BW/UDWR	1992	1	1	0	3	11	15
UDWR	1996	1	2	0	2	2	6
UDWR	1998	1	6	0	5	2	13
UDWR	1999	1	4	0	0	2	6
Totals:		43	603	16	337	138	1094

either medium red Carlin tags (28) or PIT tags (20) (Table 15). Only two of these 48 marked fish have been recaptured, including a Carlin-tagged fish that was at large from July 15, 1988 to April 12, 1989, but moved only 0.1 miles upstream; and a PIT-tagged fish that was at large only 9 hours on October 9, 1992, and moved 0.5 miles downstream. A Peterson estimate with the low

number of recaptures indicates a population of about 400–500 adults, although this is not a reliable estimate.

Table 15. Numbers of adult humpback chub captured, marked, and recaptured in Cataract Canyon. USFWS = U.S. Fish and Wildlife Service; ERI = Environmental Research Institute; BOR = Bureau of Reclamation; BW = Bio/West; UDWR = Utah Division of Wildlife Resources.

Agency	Year	Captured (>175 mm TL)	Marked	Recaptured	Tag
USFWS	1979	0	0	0	Carlin
USFWS	1980	1	1	0	Carlin
USFWS	1981	0	0	0	Carlin
ERI/BOR	1985	2	2	0	Carlin
BW/BOR	1986	3	3	0	Carlin
BW/BOR	1987	6	5	0	Carlin
BW/BOR	1988	15	15	0	Carlin
BW/UDWR	1989	3	2	1	Carlin
BW/UDWR	1990	3	0	0	Carlin
BW/UDWR	1991	6	6	0	PIT
BW/UDWR	1992	9	8	1	PIT
UDWR	1996	2	2	0	PIT
UDWR	1998	2	2	0	PIT
UDWR	1999	2	2	0	PIT
Totals:		54	48	2	PIT

5.6.2 Current Estimates

A mark-recapture population estimate for humpback chub is not possible with the current

data from Cataract Canyon. A mark-recapture effort is scheduled to begin in 2002. A pooled length-frequency histogram indicates four age groups and a supercohort of adults starting at about 190 mm TL. Age of maturity for humpback chub in Cataract Canyon is age 4, or about 200 mm TL.

5.6.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish during the warm summer months has been expressed for all humpback chub populations. Biologists feel that the fish are less stressed when handled during cool periods, when water temperature is below about 16°C; usually mid-September through October is the best time to sample. Cataract Canyon is one of the more difficult regions of the Colorado River Basin to sample. Large rapids prevent full access to the canyon from a few camp sites. Also, the population of humpback chub in Cataract Canyon is small and the fish are mixed with other *Gila* species and morphometric intergrades.

Size at Maturity. — Humpback chub captured and PIT-tagged in Cataract Canyon range in size from about 150 to 400 mm TL. Size of fish at maturity has not been evaluated for Cataract Canyon, but available data support the assumption that subadults 150–199 mm TL and adults are ≥200 mm TL.

Crew Size–Sample Effort. — Crew size and sample effort will need to be adjusted and kept constant to ensure the best possible estimates. Sampling Cataract Canyon will require biologists familiar with the canyon, the distribution and habits of the fish, and safe passage through the rapids.

Bias and Precision. — Population estimates for humpback chub in Cataract Canyon will be attempted in 2002. The population is currently small, and capture rates of marked and unmarked fish are likely to be low, and hence, precision may be low.

Mixing of Stocks. — Humpback chub in Cataract Canyon are sampled at four or five sites each with access to about 0.5-mile reaches between severe rapids. Mixing of stocks throughout the canyon is unknown.

Immigration and Emigration. — Immigration and emigration of fish into and from

Cataract Canyons are believed to be negligible during the annual sampling period.

5.6.4 Recommendations

- Attempt mark-recapture estimates in 2002, and determine if it will be necessary to sample each year for total captures and catch rates to serve as an index of population size and trend, and length-frequency analysis and simulations to assess recruitment (similar to Yampa Canyon).
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL.
- Sampling will include electrofishing and hoop nets to capture subadults to assess recruitment.
- Implement a standard protocol for identification of humpback chub in the field through application of "the art of seeing well" (Douglas et al. 1989, 1998).

5.7 Grand Canyon

5.7.1 Current Protocol

The largest aggregation of humpback chub in Grand Canyon is centered in the lower 14.9 km of the Little Colorado River (LCR) and in a 13.5-km reach of the mainstem Colorado River (MCR) near the confluence (~RM 57–68). Eight other small aggregations of humpback chub occur in Grand Canyon, totaling fewer than 300 adults. All life stages of humpback chub are collected in the LCR, while predominantly adults are encountered in the mainstem. Adult humpback chub ascend the LCR in spring to spawn and return to the mainstem for the remainder of the year. Additionally, there is some small but unknown proportion of adults that appear to be resident in the LCR. Juveniles may remain in the LCR for months or years, but many emigrate to the mainstem during late summer and fall rainstorm freshets. Historic abundance estimates employed a variety of methods and addressed different size classes and portions of the population. The best abundance estimate in the LCR is 4,508 > 150 mm TL in May 1992 (Marsh and Douglas 1996). Valdez and Ryel (1995) estimated an average abundance of 3,482 fish >200mm TL during 1991–1993 in the mainstem. It is a likely that the LCR and mainstem estimates overlap such that some fish are counted twice. No subsequent estimates were made until the present program of population estimation in the LCR began in autumn 2000.

In 2000 and 2001, three abundance estimates were made in series: autumn 2000 LCR, spring 2001 LCR, and summer 2001 mainstem. A autumn 2001 estimate will also be constructed following completion of data entry. Spring LCR estimates are to obtain spawning abundance. Autumn estimates are to obtain age-1 abundance from preceding year's spawn. The summer mainstem estimate is to obtain abundance of mainstem residents. Summer mainstem and autumn LCR estimates are assumed to be additive, with no movement occurring between estimates, and will give total abundance. For each estimate, two-pass (Chapman-Petersen) estimates were made to estimate abundance of fish >100 mm TL (smallest taggable size fish). However, the estimates are only valid for fish $\geq$ 135, 150, and 200 mm TL (smallest recapture) for autumn 2000, spring 2001, and summer 2001, respectively. Within the LCR, fish were sampled with hoop nets deployed at approximately 100-m intervals throughout the lower 14.2 km. Each hoop net was fished for 4–24 hours. Each 1.6-km section within the LCR inflow reach was fished for 2 days. Within the mainstem, fish were sampled with trammel and hoop nets set within a 19-km reach around the LCR inflow.

5.7.2 Current Estimates

The abundance estimates for each effort are as follows: 1) autumn 2000 LCR for HBC > 135 mm, N=1,590 (992–2,552), *CV*=0.19; 2) spring 2001 for > 100mm, N=3,553 (3,000–4,110), *CV*=0.08, and for fish >150mm, N=2,082 (1,600–2,550), *CV*=0.12; and 3) summer 2001 MCR for HBC > 200 mm, N=1,044 (446–1,644), *CV*=0.57.

There is some evidence based on comparing observed and expected mark-rate between estimation efforts that the LCR abundance estimates may be negatively biased. This is most likely due to incomplete mixing of marked and unmarked fish or behavioral differences among fish (i.e. trap-happy fish) within the LCR. Also, the mark-rate observed in the mainstem of fish marked in the LCR may have been reduced due to mixing with unmarked fish in the mainstem.

5.7.3 Issues and Concerns

Effects of Sampling and Handling. — Concern for handling fish in the Little Colorado River during the warm summer months has been expressed. During 1990–1995, humpback chub were captured and handled regularly from about March through July, but the effects of this handling was not evaluated. Since before 1990, a suite of federal, state, university, and private entities have conducted research on humpback chub in Grand Canyon. Though these efforts

have fostered an increased understanding of the life history and ecology of this species, it has been difficult to integrate the data collected during these efforts to provide a comprehensive stock assessment of humpback chub in Grand Canyon.

Size at Maturity. — Size of adult humpback chub in Grand Canyon is about 200 mm TL; subadults are defined as fish that are 150–199 mm TL.

Crew Size–Sample Effort. — Crew size and sample effort will need to be adjusted and kept constant to ensure the best possible estimates.

Bias and Precision. — Sampling design for population estimates for humpback chub in Grand Canyon may need to be modified to ensure accurate and reliable estimates. Currently, sampling in Grand Canyon is designed to characterize the aquatic community. One important aspect of this design will need to be precise population and recruitment estimates.

Mixing of Stocks. — Humpback chub in Grand Canyon are sampled at several sites in the mainstem and LCR, and mixing of stocks within each sampling reach is assumed.

Immigration and Emigration. — Humpback chub in Grand Canyon migrate annually to the LCR to spawn. Fish from the mainstem aggregate locally in large eddy complexes and swim upstream into the LCR to spawning sites. These fish return to holding sites in the mainstem after spawning. Young fish also emigrate from the LCR to the mainstem with rain freshets in late summer or when they reach sexual maturity. These movements must be accounted in estimating population size in Grand Canyon. Downstream dispersal of age 0 and juvenile humpback chub from the LCR supplement aggregations downstream of the LCR; however, there is no documented movement back to the LCR, except for fish in the LCR inflow aggregation.

5.7.4 Recommendations

- Expand sampling in the LCR to include a third sampling occasions for more precise mark-recapture estimate.
- Estimates of adults will include fish ≥200 mm TL; subadults will include fish 150 to 199 mm TL.
- Sampling will expand to capture subadults with hoop nets.
- Maintain sampling in the mainstem to include a third sampling occasion.
- Estimate size of aggregations at 30-mile, LCR inflow, Middle Granite Gorge.
- Implement a standard protocol for identification of humpback chub in the field

through application of “the art of seeing well” (Douglas et al. 1989, 1998).

6.0 TENTATIVE SAMPLING SCHEDULES

Tentative sampling schedules for population estimates are provided for Colorado pikeminnow (Table 16) and humpback chub (Table 17). The schedule for a given population may be modified if a need is identified for an additional estimate because of a highly variable estimate caused by unsuitable sampling conditions.

The sampling schedules for Colorado pikeminnow and humpback chub are based on a system of 3 consecutive years of annual estimates followed by 2 years without estimates. This schedule provides the most robust schedule possible in balance with minimizing risks of over-handling fish. A 3-year robust schedule allows for calculation of annual population estimates (*N*-hat), survival rate (S), recruitment (R), probability of capture (*P*-hat) for each sample occasion, and lambda (λ), or the change in population from one estimate to the next. This schedule will also meet the requirements of the draft recovery goals of at least three annual population estimates during the 5-year downlisting period for both species, and at least two additional annual estimates during the 3-year delisting period for humpback chub, and at least five additional annual estimates during the 7-year delistng period for Colorado pikeminnow.

Table 16. Tentative population estimate schedule for Colorado pikeminnow.

Area (Reach)	Agency[a]	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Upper Colorado River Subbasin																	
Upper Colorado River (Price-Stubbs Dam to Green River confluence)	USFWS	XC[b]	XC	XC			X	X	X			X	X	X			X
Green River Subbasin																	
Middle Green River (Split Mtn to Sand Wash)	UDWR, USFWS			XC	XC	X	X			X	X	X			X	X	X
Yampa River (Deer Lodge to Echo Park)	LFL/CSU			XC	XC	X	X			X	X	X			X	X	X
White River (White River Dam to Green River)	USFWS			XC	XC	X	X			X	X	X			X	X	X
Desolation/Gray Canyons (Sand Wash to Green River City)	UDWR, USFWS				XC	X	X			X	X	X			X	X	X
Lower Green River (Green River City to Colorado River confluence)	UDWR, USFWS				XC	X	X			X	X	X			X	X	X
San Juan River Subbasin																	
San Juan River	USFWS, UDWR									X	X	X			X	X	X

[a] USFWS=U.S. Fish and Wildlife Service, UDWR=Utah Division of Wildlife Resources, LFL/CSU=Larval Fish Laboratory/Colorado State University

[b]XC=estimate conducted, X=estimate planned

Table 17. Tentative population estimate schedule for humpback chub.

Area (Reach)	Agency[a]	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Upper Colorado River Basin													
Black Rocks	USFWS	XC[b]	XC	XC			X	X	X			X	X
Westwater Canyon	UDWR	XC	XC	XC			X	X	X			X	X
Desolation/Gray Canyons	UDWR				XC	X	X	X			X	X	X
Yampa River	USFWS			XC	XC		X	X	X	X	X	X	X
Cataract Canyon	UDWR					X	X	X	?[c]	?	X	X	X
Lower Colorado River Basin													
Grand Canyon	GCMRC, USFWS			XC	XC	X	X	X			X	X	X

[a] USFWS=U.S. Fish and Wildlife Service, UDWR=Utah Division of Wildlife Resources, GCMRC=Grand Canyon Monitoring and Research Center

[b]XC=estimate conducted, X=estimate planned

[c]?=maybe needed if protocol becomes similar to Yampa Canyon

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APPENDIX A

SUMMARY OF CURRENT POPULATION-ESTIMATE PROTOCOLS FOR COLORADO PIKEMINNOW AND HUMPBACK CHUB IN THE COLORADO RIVER BASIN

Table A-1. Summary of current population-estimate protocols for Colorado pikeminnow. USFWS=U.S. Fish and Wildlife Service, UDWR=Utah Division of Wildlife Resources, LFL/CSU=Larval Fish Laboratory/Colorado State University

Area	Agency	Reach	Years of Estimate	Crew	Gears – Primary Methods	Time of Estimate	Sample Occasions	Sample Interval	Issues and Concerns
Upper Colorado River Subbasin									
Upper Colorado River	USFWS	Price-Stubbs Dam to upper Westwater Canyon (Upper) – 100 km	1991–94 1998–00	2 persons	EF, TN "block and shock"	mid-April to mid-June	3 3	1 week	Does not include Gunnison River above Redlands Diversion
		Confluence to lower Westwater Canyon (Lower) – 181 km	1992–94 1998–00	2 persons	EF, TN "block and shock"	mid-April to mid-June	2 3	1 week	Does not include Cataract Canyon
Green River Subbasin									
Middle Green River	UDWR, USFWS	Split Mtn to Sand Wash – 169 km	2000 2001	multiple crews	EF, TN "block and shock", shoreline EF	mid-April to mid-June	4 3	1 week	
Yampa River	LFL/CSU	Deer Lodge to Echo Park – 113 km	2000 2001	multiple crews	EF, TN "block and shock", shoreline EF	mid-April to mid-June	3 3	1 week	Electrofishing limited to >1,000 cfs
White River	USFWS	White River Dam to Green River – 163 km	2000 2001	multiple crews	EF, TN "block and shock", shoreline EF	mid-April to mid-June	3 3	1 week	
Desolation/ Gray Canyons	UDWR, USFWS	Sand Wash to Green River City – 153 km	2001	multiple crews	EF, TN "block and shock", shoreline EF	mid-April to mid-June	3	1 week	
Lower Green River	UDWR, USFWS	Green River City to Colorado River confluence – 193 km	2001	multiple crews	EF, TN "block and shock", shoreline EF	mid-April to mid-June	3	1 week	
San Juan River Subbasin									

San Juan River	USFWS, UDWR	Stump Camp to Four Corners Bridge – 28 km	1995	multiple crews	EF, TN	June to October	3	1 month	Fish avoid EF; Small numbers of wild fish

Table A-2. Summary of current population-estimate protocols for humpback chub. USFWS=U.S. Fish and Wildlife Service, UDWR=Utah Division of Wildlife Resources, GCMRC=Grand Canyon Monitoring and Research Center.

Area	Agency – Principal	Reach	Years of Estimate	Crew	Gears – Primary Methods	Time of Estimate	Sample Occasions	Time Between Occasions	Concerns
Upper Colorado River Basin									
Black Rocks	USFWS	Moore Bottom – 1.6 km	1998 1999 2000	multiple crews	TN, EF, HN	mid-Sept-October	3 4 3	1–2 weeks	Concerns for over-handling of fish; flow may affect catch efficiency
Westwater Canyon	UDWR	Miner's Cabin – 0.8 km Cougar Bar – 0.8 km Hades Rapid – 0.8 km	1998 1999 2000	5-person crew	TN, HN	mid-Sept-October	3 3 3	1–2 weeks	Area of estimate covers only 1.5 of 15 mile canyon
Desolation/ Gray Canyons	UDWR	12 sites, each ~0.5 km – 6 km	2001	2x3-person crews	TN, EF, HN	July–August	3	1–2 week	Fish stress when handled in warm water temperatures; Flow may affect catch efficiency
Yampa River	USFWS	Deer Lodge to Echo Park – 113 km	2000 2001	multiple crews	EF, TN, HN	June–August	3	1 week	Low numbers of wild fish; electrofishing limited to >1,000 cfs
Cataract Canyon	UDWR	Colorado River confluence to Lake Powell – 19 km	2002	2x3-person crews	EF, TN, HN	mid-Sept–October	3	1 week	Low numbers of wild fish
Grand Canyon	GCMRC, USFWS	LCR – 15 km Colorado River – 11 km	2000 2001	multiple crews	LCR – HN, TN MCR – TN, HN, EF	spring, fall	3	1 week	Individuals migrate to spawn in LCR