EVALUATION OF POPULATION ESTIMATES FOR COLORADO PIKEMINNOW AND HUMPBACK CHUB IN THE UPPER COLORADO RIVER BASIN

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Final Report

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PREFACE

This report was prepared by the Program Director's Office of the Upper Colorado River Endangered Fish Recovery Program (UCRRP) for the U.S. Fish and Wildlife Service (Service). The report synthesizes the proceedings of two workshops held in 2001 and 2004 by the UCRRP to improve the reliability and precision of population estimates for the federally endangered Colorado pikeminnow (*Ptychocheilus lucius*) and humpback chub (*Gila cypha*). Reliable and precise population estimates are required by the Service in species recovery goals when considering downlisting and delisting of these species.

Population estimates provided in this report are preliminary and should not be used as final estimates until evaluated by the Service. Refinement of population estimates is an ongoing process and these estimates may be revised with new information and better insight into analytical methods. This report was prepared from unpublished information presented by researchers at two workshops and is subject to revision.

ACKNOWLEDGMENTS

The following individuals attended one or both workshops convened by the Upper Colorado River Endangered Fish Recovery Program on December 6–7, 2001, in Fort Collins, Colorado; and August 24–25, 2004, in Grand Junction, Colorado. Several field sampling issues were identified at the first workshop and a subsequent meeting was held in Grand Junction, Colorado, on February 11–12, 2002, to address and resolve those issues. In addition, a Population Estimates *Ad Hoc* Committee was convened following the second workshop to provide responses to questions on the various population estimates and to review this report. We thank all participants and reviewers for their contributions to increasing scientific validity of population estimates for Colorado pikeminnow and humpback chub in the Upper Colorado River Basin. Some individuals represented various stakeholder interests, or their affiliation changed, and only their affiliation at the time of the second workshop is provided. Members of the Population Estimates *Ad Hoc* Committee are indicated by ** next to their names.

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Gary Burton	Western Area Power Administration
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EXECUTIVE SUMMARY

The Upper Colorado River Endangered Fish Recovery Program (UCRRP) coordinates population estimates for the endangered Colorado pikeminnow (*Ptychocheilus lucius*) and humpback chub (*Gila cypha*) in the Colorado River Basin. Reliable and precise estimates are needed by the U.S. Fish and Wildlife Service as part of recovery and demographic criteria provided in species recovery goals approved in August 2002. Population estimates are being conducted in eight regions of the Upper Colorado River Basin by state and federal agencies with assistance from universities and private individuals. Mark-recapture estimates are being obtained from field sampling of populations in each region for 3 consecutive years with 2 years off to minimize over-handling of fish. Estimates of Colorado pikeminnow began in 1992 in the Upper Colorado River Subbasin and in 2000 in the Green River Subbasin. Numbers of wild fish in the San Juan River Subbasin are currently too low for formal mark-recapture estimates, and hatchery augmentation is expected to increase population size for estimates by about 2006. Estimates of humpback chub began in 1998 in Black Rocks and Westwater Canyon; 2000 in Yampa Canyon; 2001 in Desolation/Gray Canyons; and 2003 in Cataract Canyon. Annual reports are submitted by respective researchers for each of the population estimates to the UCRRP and the San Juan River Basin Recovery Implementation Program, and findings are presented and discussed at the Annual Upper Basin Researchers Meeting. Two workshops of species experts and statisticians have been convened by the UCRRP to improve reliability and precision of population estimates, and an *ad hoc* committee of species experts and researchers has been established to ensure ongoing communication and evaluation of field sampling protocols and analytical methods. Precision criteria of capture probability (P-hat $\geq$0.10) and coefficient of variation ($CV \leq$0.15) are not being consistently met in all estimates. Researchers are refining field sampling protocols and analytical methods to improve precision but environmental variables, particularly flow, are uncontrolled and affect capture efficiency and hence, precision. Estimates will continue to be evaluated, but maximum achievable precision may be reflected in current estimates.

1.0 INTRODUCTION

1.1 Background

This report was prepared by the Program Director's Office of the Upper Colorado River Endangered Fish Recovery Program (UCRRP) for the U.S. Fish and Wildlife Service (Service). The purpose of this report is to assimilate, synthesize, and evaluate population estimates for Colorado pikeminnow (*Ptychocheilus lucius*) and humpback chub (*Gila cypha*) in the Upper Colorado River Basin. The Service requires reliable and precise population estimates when considering downlisting and delisting of these endangered species. Population estimates are being conducted in eight regions of the Upper Colorado River Basin (Figure 1-1); razorback sucker (*Xyrauchen texanus*) and bonytail (*Gila elegans*) are not sufficiently numerous in the wild for population estimates at this time.

Recovery goals were approved for the four Colorado River endangered fish species on August 1, 2002. These recovery goals amend and supplement prior recovery plans and provide guidance on species recovery. These recovery goals identify site-specific management actions and objective, measurable criteria for downlisting and delisting the endangered humpback chub, bonytail, Colorado pikeminnow, and razorback sucker (U.S. Fish and Wildlife Service 2002a, 2002b, 2002c, 2002d). Objective, measurable recovery criteria include recovery factor criteria and demographic criteria for consideration in downlisting and delisting. Demographic criteria are numbers of populations, trends in annual population point estimates, mean annual recruitment rates, and numbers of core populations that meet minimum viable population size. Reliable and precise population estimates are needed to monitor species status and trends and to help determine if downlisting and delisting criteria are being met. The Service has determined that mark-recapture models provide the most precise population estimates for these big river fish.

Region 6 (Mountain-Prairie Region) of the Service is responsible for recovery of the four big river fishes. All population estimation activities are coordinated by the UCRRP, and data collection and analysis are the responsibility of specific state and/or federal agencies, often with assistance from universities or private individuals (Table 1-1). Population estimates and supporting documentation are reported annually to the UCRRP and the San Juan River Recovery Implementation Program (SJRIP), and presented at the Annual Upper Basin Researchers Meeting (http://coloradoriver recovery.fws.gov/).

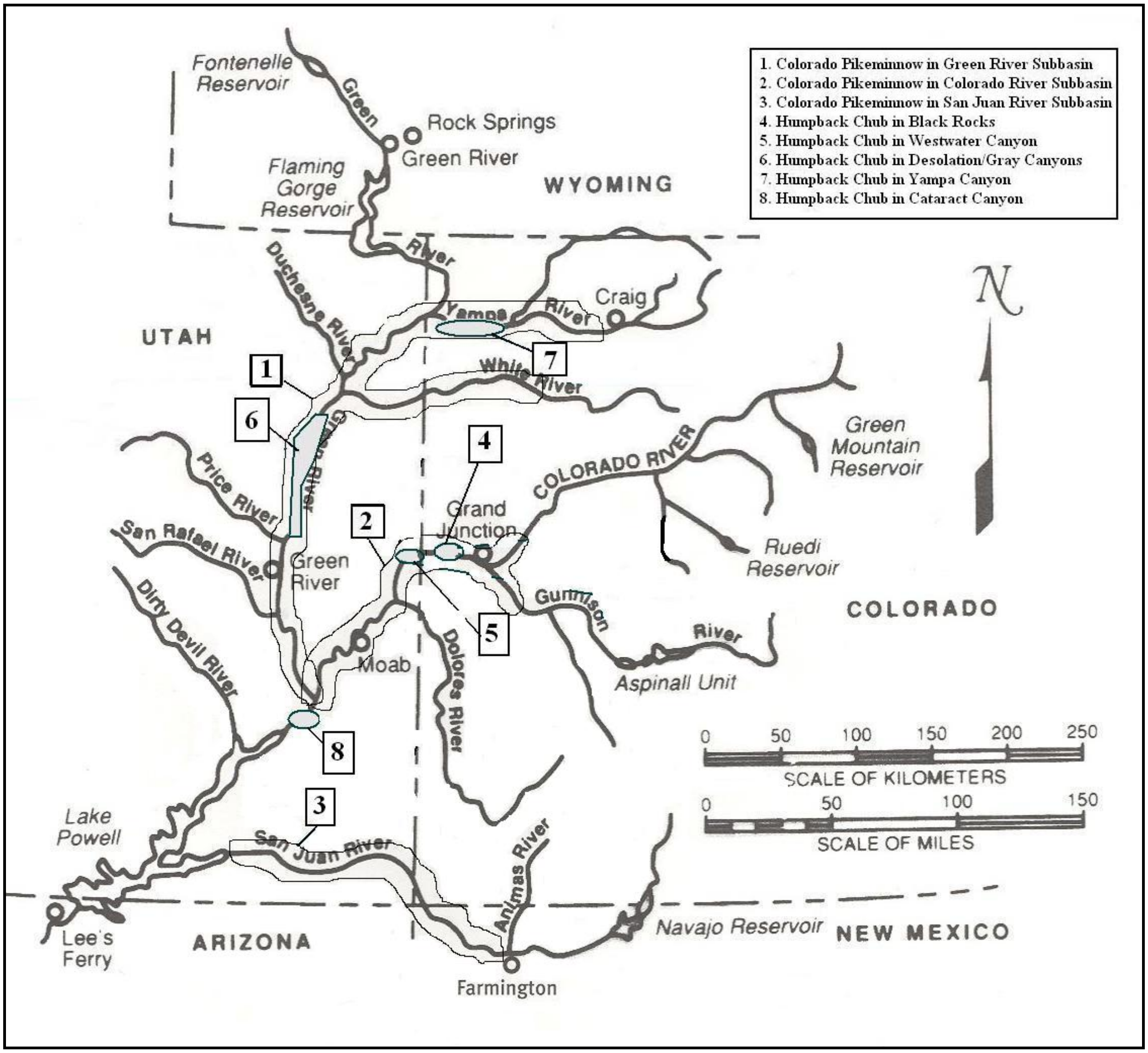

Figure 1-1. The Upper Colorado River Basin with eight regions sampled for population estimates of Colorado pikeminnow (CPM; regions outlined) and humpback chub (HBC; regions shaded gray).

Table 1-1. Regions of the Colorado River Basin in which mark-recapture population estimates are being conducted for Colorado pikeminnow and humpback chub, with responsible agencies, principal researchers, and primary field and/or statistical assistance. See Figure 1-1 for locations of Regions 1–8.

River Region	Period of Available Estimates	Responsible Agencies	Principal Researcher(s) — present and past	Primary Field and/or Statistical Assistance
Colorado Pikeminnow				
1. Green River Subbasin	2000–2003	Utah Division of Wildlife Resources—Vernal, UT; U.S. Fish and Wildlife Service—Vernal, UT	Kevin Christopherson, Ron Brunson, Mike Hudson (UDWR); Tim Modde (USFWS)	Kevin Bestgen, John Hawkins—Colorado State University, Fort Collins
2. Upper Colorado River Subbasin	1992–1994 1998–2000 2003–2004	U.S. Fish and Wildlife Service—Grand Junction, CO	Doug Osmundson	Ken Burnham—Colorado State University, Fort Collins Ron Ryel—Utah State University, Logan
3. San Juan River Subbasin	1991–1995 (survey) 1996–2003 (survey)	U.S. Fish and Wildlife Service—Albuquerque, NM	Dale Ryden, Jim Brooks	
Humpback Chub				
4. Black Rocks	1998–2000 2003	U.S. Fish and Wildlife Service—Grand Junction, CO	Chuck McAda	Ron Ryel—Utah State University, Logan Kevin Bestgen—Colorado State University, Fort Collins
5. Westwater Canyon	1998–2000 2003	Utah Division of Wildlife Resources—Moab, UT	Julie Jackson, Mike Hudson, Tom Chart, Melissa Trammell	
6. Desolation/Gray Canyons	2001–2003	Utah Division of Wildlife Resources—Moab, UT	Julie Jackson, Mike Hudson, Tom Chart, Melissa Trammell	
7. Yampa Canyon	2000 2003	U.S. Fish and Wildlife Service—Vernal, UT	Tim Modde, Bruce Haines, Sam Finney	
8. Cataract Canyon	2003	Utah Division of Wildlife Resources—Moab, UT	Paul Badame	Rich Valdez—SWCA, Logan, UT

1.2 Population Estimates Workshops

Two workshops were convened by the UCRRP to reach consensus among researchers for reliable and precise population estimates for Colorado pikeminnow and humpback chub. Workshop I was held in Fort Collins, Colorado, on December 6–7, 2001, to develop initial guidance for determining acceptable population and recruitment estimates. Workshop II was held in Grand Junction, Colorado, on August 24–25, 2004, to review and evaluate point estimates developed to date. These workshops brought together researchers, species experts, statisticians and population ecologists familiar with population and recruitment estimation methods, as well as Service personnel for a focused examination of the statistical validity of existing estimates and improved precision of future estimates. These workshops promoted exchange of ideas; recommended refinements in field sampling protocols; and increased awareness of analytical techniques available to researchers. Researchers at the second workshop presented population estimates for their respective regions and were asked to recommend point estimates that the Service may use in considering downlisting and delisting.

The workshops were attended by 57 individuals representing five basin states; four federal agencies; two national environmental organizations; two universities; and four private entities (see Acknowledgements). The UCRRP Staff helped to coordinate the workshops and members of the biology committees of the UCRRP and SJRRIP were in attendance. Researchers at each workshop were asked to describe field sampling methods, analytical methods, and population estimates for their respective river region (see Table 1-1 for region of population estimates and agency responsibility). Following the presentations, a moderator solicited input from the attendees and all information was recorded. Proceedings of the first workshop were assimilated in a draft report (Upper Colorado River Endangered Fish Recovery Program 2002) that included preliminary population estimates. These estimates were used to illustrate issues and concerns associated with statistical precision and not as final estimates.

1.3 Population Estimates *Ad Hoc* Committee

A Population Estimates *Ad Hoc* Committee was formed and convened by the UCRRP on August 24, 2004, following the second workshop. This committee consists of nine researchers and species experts that were asked to respond to 10 questions regarding the reliability and precision of each population estimate for Colorado pikeminnow and humpback chub (see section 4.0). Further evaluation of population estimates was made at the Annual Upper Basin Researchers Meeting on January 19–20, 2005, in Grand Junction, Colorado. A panel consisting of four members of the *Ad Hoc* Committee was convened to summarize the *Ad Hoc* Committee's Summary Report on Population Estimates from the 2004 Population Estimates Workshop II; to provide researchers with the opportunity to evaluate and discuss population estimates; and to identify the direction of research and future population estimates. The primary purpose of the workshops and the responsibility of the *ad hoc* committee were to evaluate reliability and precision of estimates. Status and trends of populations were discussed, but will be further evaluated by the UCRRP.

2.0 ESTIMATORS AND STATISTICAL GUIDELINES

2.1 Genesis of Population Estimates

Studies of Colorado pikeminnow and humpback chub in the upper basin began nearly 40 years ago and initially focused on taxonomy and fundamental species demography (e.g., Vanicek and Kramer 1969; Holden and Stalnaker 1970), distributions and basic life history (e.g., Holden and Stalnaker 1975; Seethaler 1978; see Muth et al. 2000), and habitat and flow requirements (U.S. Fish and Wildlife Service 1982). The first organized upper basin effort at quantifying numbers of fish began in 1986 with the Interagency Standardized Monitoring Program (ISMP; e.g., McAda et al. 1994; McAda 2002a), as part of the coordination process that helped to form the UCRRP. The ISMP involved sampling age-0 Colorado pikeminnow in the fall, adult Colorado pikeminnow in the spring, and fall sampling for humpback chub in Westwater Canyon and Black Rocks. Other monitoring efforts (e.g., overwinter age-0 Colorado pikeminnow, Desolation/Gray Canyons humpback chub) were separately funded and technically not part of ISMP. The ISMP used prior distribution data to establish river reaches for catch rate estimates of age-0, subadult, and adult Colorado pikeminnow and adult humpback chub. This was later expanded to include larval sampling for Colorado pikeminnow and razorback sucker (e.g., Bestgen 1997; Muth et al. 1997, 1998) and over-winter survival of age-0 Colorado pikeminnow (e.g., Haines et al. 1998; Converse et al. 1999; McAda and Ryel 1999). These efforts yielded estimates of relative abundance but with no clear relationship to actual population size.

The need for precise estimates of abundance was clear, but there was uncertainty among researchers as to the feasibility of basin-wide estimates of population size for any of the endangered fish species. In 1992, the number of adult Colorado pikeminnow in the Upper Colorado River Subbasin was successfully estimated with a mark-recapture sampling design

(Osmundson and Burnham 1998; Osmundson 2002). Simultaneous, but independent mark-recapture estimates for adult and subadult Colorado pikeminnow were implemented in the Green River Subbasin in 2000 (Bestgen et al. 2005). Consecutive mark-recapture population estimates for humpback chub began in 1998 in Black Rocks (McAda 2002b) and Westwater Canyon (Chart and Lentsch 1999); in 2000 in Yampa Canyon (Haines and Modde 2002); in 2001 in Desolation/Gray Canyons (Jackson and Hudson 2005); and in 2003 in Cataract Canyon (Utah Division of Wildlife Resources 2004).

Researchers are in general agreement that population estimates for Colorado pikeminnow should be conducted for 3 consecutive years with 2 years off to minimize over-handling of fish and because of limited qualified personnel and funds. For humpback chub, the initial estimates should be 3 years on and 2 years off, followed by 2 and 2. Researchers are currently working on refining these estimates with improved field sampling techniques and analytical methods. The feasibility of linking these estimates to prior and ongoing trend data (e.g., ISMP, larval drift, overwinter survival) is also being investigated, evaluated, and implemented through more robust analytical designs. Analyses of Colorado pikeminnow data in the Green River Subbasin show possible linkages between catch rates of age-0 and subadults with more recent mark-recapture estimates of adults and subadults (Bestgen et al. 2005). These robust analyses provide valuable insight into past and current population size and trends, and may be possible with other populations, given the availability of suitable data.

The two population estimates workshops served to identify and refine the most suitable population estimators and develop guidelines for statistical precision. Refinement in population estimates is an ongoing process in which researchers continue to refine field sampling techniques best suited to data needs of appropriate estimators and use the most suitable analytical techniques. The following sections of this report provide an overview of mark-recapture estimators and statistical guidelines developed from these workshops. The methodologies continue to be refined as data are collected, analyzed, and integrated with estimates of prior years. Researchers recognize that all population estimators are constrained by necessary assumptions that may not be entirely satisfied given the logistical difficulties of sampling the Colorado River, and hence, desired levels of statistical precision may not be achievable. The ongoing process of annual population estimates, periodic workshops, and annual researcher meetings helps researchers better understand achievable levels of precision.

2.2 Mark-Recapture Models

Mark-recapture models are used to estimate abundance (*N*-hat), survival rate (S), recruitment (R), and probability of capture (*P*-hat) of wild populations of Colorado pikeminnow and humpback chub in the upper basin. A change in population from one estimate to the next can be assessed with lambda (λ), where $\lambda > 1$ indicates an increasing population, and $\lambda < 1$ indicates a decreasing population. Two basic estimator model types are recognized; closed population estimates (e.g., Lincoln-Peterson index [Schnabel 1938; LeCren 1965; Otis et al. 1978]) and open population estimates (e.g., Jolly-Seber models [Jolly 1965, 1982; Seber 1965, 1982]). Programs CAPTURE (Otis et al. 1978; White et al. 1978, 1982; Burnham et al. 1987; Rexstad and Burnham 1991) and MARK (White 2003) are recommended for identifying the most suitable model(s) and associated precision for each estimate.

Commonly used models are:

- Estimator Null M_o –The simplest of all models, M_o assumes all members of the population are equally at risk of capture on every trapping occasion. Parameters estimated are population size and a single probability of capture (see Otis et al. 1978).
- Estimator Chao M_t –Model M_t assumes capture probabilities vary with time. Parameters estimated are population size and probability of capture for each occasion, as described in Chao (1989). When probabilities of capture are small, this estimator performs well.

Closed models have the following characteristics:

- Estimate only *N*-hat and *P*-hat;
- Generally applied to short-term studies;
- Allow for individual variation in probabilities of capture, or heterogeneity (e.g., time, behavior, susceptibility to capture);
- Do not allow for immigration, emigration, mortality, or recruitment; and
- Require geographic closure for subject population.

Open Models have the following characteristics:

- Estimate *P*-hat, *N*-hat, S, R, and λ but not in first and last years;
- Generally used for long-term studies and estimates require more sampling years and assumptions;
- Do not allow for heterogeneity in probability of capture; and
- Account for immigration, emigration, mortality, or recruitment.

Sampling design and use of available empirical data over time allow for 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.

A robust design is important to maintain because:

- Can estimate *P*-hat, *N*-hat, S, and R in all years;
- Allows for 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
- Allows for assumption of 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.

2.3 Assumptions

Abundance estimation assumptions and considerations 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 is required (i.e., homogeneity in *P*-hat), although some heterogeneity in *P*-hats is possible due to sampling;
- Tag loss is assumed to be zero;

- Demographic closure is enhanced by closely-spaced secondary sampling events;
- Effects of immigration and emigration are limited by strategic spatial and temporal sampling;
- Large sampling area reduces effects of movements across boundaries, and it is possible to examine transition effects;
- 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);
- 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.

2.4 Precision and Bias

The precision of estimates is an important consideration to ensure that population estimates are reliable and satisfy demographic criteria. The most reliable estimates of bias and precision are:

- **Population size (*N*-hat)**: large populations tend to yield more precise estimates.
- **Probability of capture (*P*-hat)**: *P*-hat of ≥ 0.10 is a reasonable target; a high *P*-hat allows for fewer sampling occasions.
- **Coefficient of variation (*CV*)**: a *CV* of ≤ 0.15 (0.10–0.20) is a reasonable target; *CV* = standard error divided by *N*-hat.

The criteria provided above for *P*-hat and *CV* are targets and not requirements. Number of sampling occasions can also affect precision by affecting *P*-hat and *CV*. The effect of sampling occasions on population estimates with different probabilities of capture (*P*-hat) is provided in Figure 2-1. A critical decision faced by researchers is determining the number of sampling occasions necessary to achieve a desired level of precision (i.e., *N*-hat, *P*-hat, *CV*) without over-handling the fish and achievable within a given budget, labor, and time frame.

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 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 in this type of analysis is determining the decision point when a single estimate occurs without benefit of additional estimates.

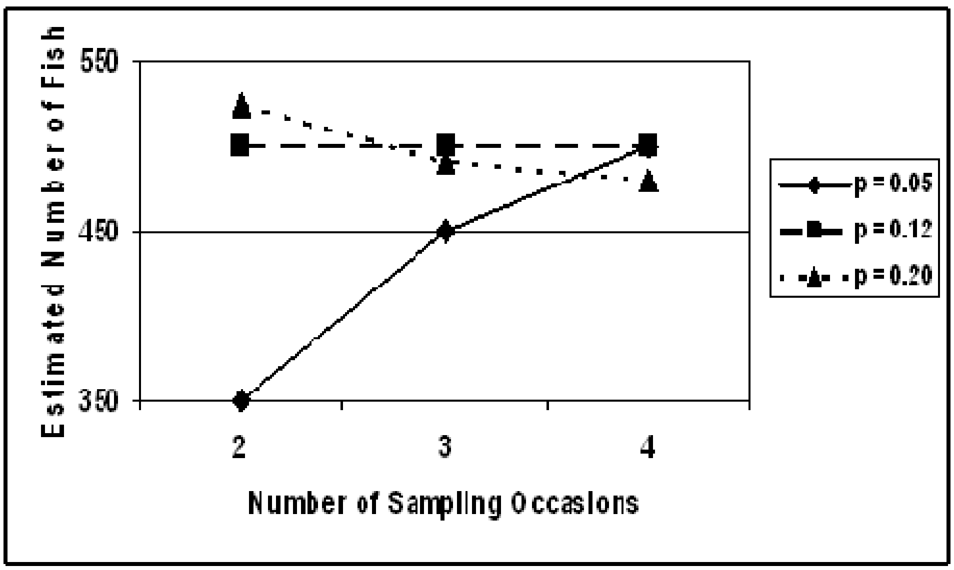

Figure 2-1. Effect of number of population size, sampling occasions, and probability of capture (P) on coefficient of variation (*CV* for P = 0.05: 2 = 47, 3 = 41, 4 = 34; *CV* for P = 0.12: 2 = 31, 3 = 23, 4 = 15; *CV* for P = 0.20: 2 = 21, 3 = 10, 4 = 7).

2.5 Considerations

The following summarizes **important considerations of mark-recapture population estimators**:

- Define geographic context of sampled population;
- Ensure that geographic and sampling context are consistent across years;
- Meet assumption of geographic closure;
- Use design and model type appropriate for data needs; i.e., 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 implementation, choose desired level of precision *a priori*;
- Use prior information from sampling and life history to assist model selection;
- Use simulations to evaluate effects of assumption violations;
- Employ robust design, when possible, to offer advantages of both model types; and
- Factor precision into population estimates to assess validity of estimate.

3.0 POPULATION ESTIMATES

Populations of Colorado pikeminnow and humpback chub are being monitored in eight regions of the Upper Colorado River Basin (Figure 1-1). Population size is being estimated with mark/recapture techniques in all but region 3 because the number of wild fish in the San Juan River is currently too low for these types of estimates. The following summarizes sampling design, analytical methods, and population estimates, and provides a discussion for each of the eight regions. Summaries provided for each region are current to 2003 or 2004, depending on the latest available information provided by the respective researcher. The eight regions and associated fish species are:

1. Colorado Pikeminnow in the Green River Subbasin.
2. Colorado Pikeminnow in the Colorado River Subbasin.
3. Colorado Pikeminnow in the San Juan River.
4. Humpback Chub in Black Rocks.
5. Humpback Chub in Westwater Canyon.
6. Humpback Chub in Desolation/Gray Canyons.
7. Humpback Chub in Yampa Canyon.
8. Humpback Chub in Cataract Canyon.

3.1 Colorado Pikeminnow

3.1.1 Green River Subbasin

Sampling Design.—Population estimates for Colorado pikeminnow in the Green River Subbasin encompass a total of 817 river kilometers (RK; 508 miles) in five reaches of three major rivers, including 534 RK (332 miles) of the Green River as three reaches (middle Green, Desolation/Gray, and lower Green); 163 RK (101 miles) of the White River; and 121 RK (75 miles) of the Yampa River (Bestgen et al. 2005; Figure 3-1). Independent estimates for the middle Green, White, and Yampa rivers are available from 2000 through 2003, and estimates for the Desolation/Gray and lower Green reaches are available from 2001 through 2003. Altogether, about 19,300 km (12,000 miles) of shoreline have been sampled with 3,723 hours of electrofishing, and a total of 3,108 juvenile and adult Colorado pikeminnow have been captured.

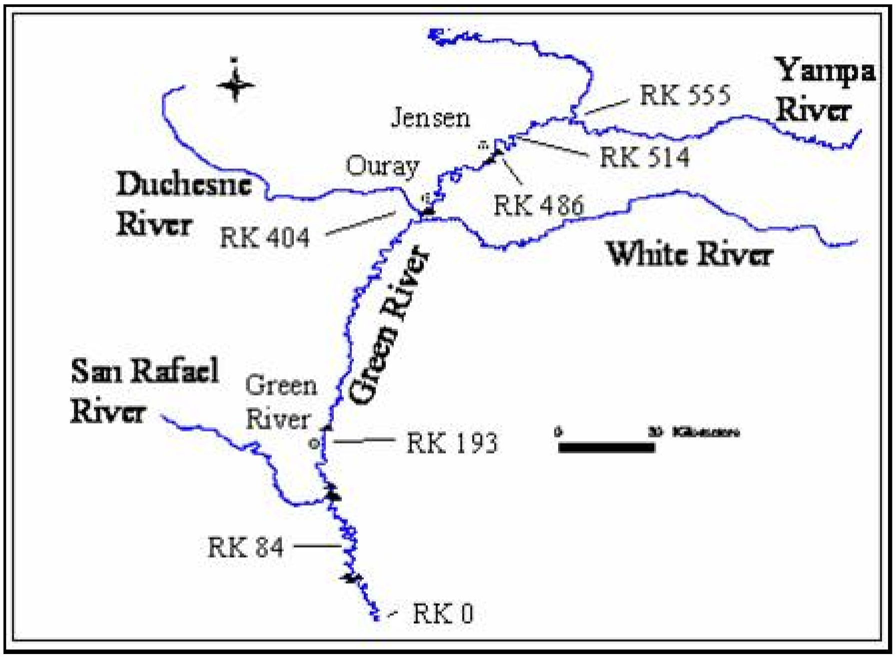

Figure 3-1. The five population estimates reaches of the Green River Subbasin. Figure from Bestgen et al. (2005). The five reaches are the middle Green River, lower Green River, Desolation/Gray Canyons, Yampa River, and White River.

Colorado pikeminnow are sampled during high flows in spring between the periods of post-ice-off and post-runoff (usually April 1–June 15). A minimum of three sampling occasions (passes), spaced 2–4 weeks apart, are conducted in each reach with some focus on areas of fish concentrations, such as large backwaters and flooded tributary mouths. Sampling is mostly by electrofishing with some trammel nets and hoop nets set in backwaters. All Colorado pikeminnow are scanned for a PIT tag (Passive Integrated Transponder); marked fish are recorded as recaptures and unmarked fish are marked with a PIT tag. Adults are considered as fish ≥ 450 mm TL and recruit-size fish are 400–449 mm TL.

Care is taken to ensure that the sampling design meets the assumptions of mark-recapture models. The assumption of demographic closure is addressed through: (a) sampling of nearly the entire range of the Colorado pikeminnow in the Green River Subbasin, and (b) short intra-annual sampling periods in which mortality, recruitment, and movements are limited. The assumption of homogeneity was further addressed through incorporation of a covariate total length in estimates of capture probabilities to account for the effect of fish size (i.e., big fish are rare and harder to capture). The assumed mixing of marked and unmarked fish is ensured through sampling of habitats where fish concentrate annually during spring runoff and by providing complete sampling coverage of available habitats where most of the fish occur. It is also assumed that the PIT tags are reliably detected, tag loss is low, and that there is no differential mortality of marked fish. Sampling in spring is sufficiently in advance of spawning-related movements and no behavior effects have been detected that affect or bias sampling or fish capture.

Analytical Methods.—The Huggins robust design multi-strata model (Huggins 1989, 1991; Bestgen et al. 2005) was used to evaluate robustness of sample design and estimates of Colorado pikeminnow. This model accounts for individual heterogeneity in the data and allows individual covariates to be used for estimating the initial capture (*P*-hat) and recapture (*c*) probabilities of the closed capture model. The Huggins model allowed for the covariate total length because animals not captured were factored out of the likelihood. A robust design was logical and allowed for mostly closed model estimates of *N* in all years, and open model estimates of S between years with total length (quadratic and cubic effects) as the covariate. The Huggins model also showed that multi-strata (reach) differences were supported, and that the effect of the total length covariate applied to every year, reach, and sampling occasion. Annual transition rates for Colorado pikeminnow moving between reaches were also estimated with total length as a covariate.

Pradel's lambda (Pradel 1996) was used to estimate rate of population change as a function of survival and recruitment. The Pradel (1996) model estimates both seniority and apparent survival from the encounter histories and is a parameterization of the Jolly-Seber model. A lambda (λ) > 1 indicates an increasing population, and a $\lambda < 1$ indicates a declining population. Data from ISMP for 1992–2003 were used to compute lambda with the assumption that data were collected from fixed reaches over time.

Population Estimates.—Annual population estimates were computed for adults and recruits of Colorado pikeminnow in each of five reaches of the Green River Subbasin, including the middle Green River, lower Green River, Desolation/Gray Canyons, Yampa River, and White

River (Figure 3-2; Table 3-1; Bestgen et al. 2005). These estimates show an apparent decline in adults, but no significant difference among estimates within reaches, except between 2000 and 2003 for the middle Green River and White River. These reaches support highest numbers of Colorado pikeminnow in the subbasin. Reductions in abundance were less apparent in the Yampa River, Desolation/Gray Canyons, and lower Green River.

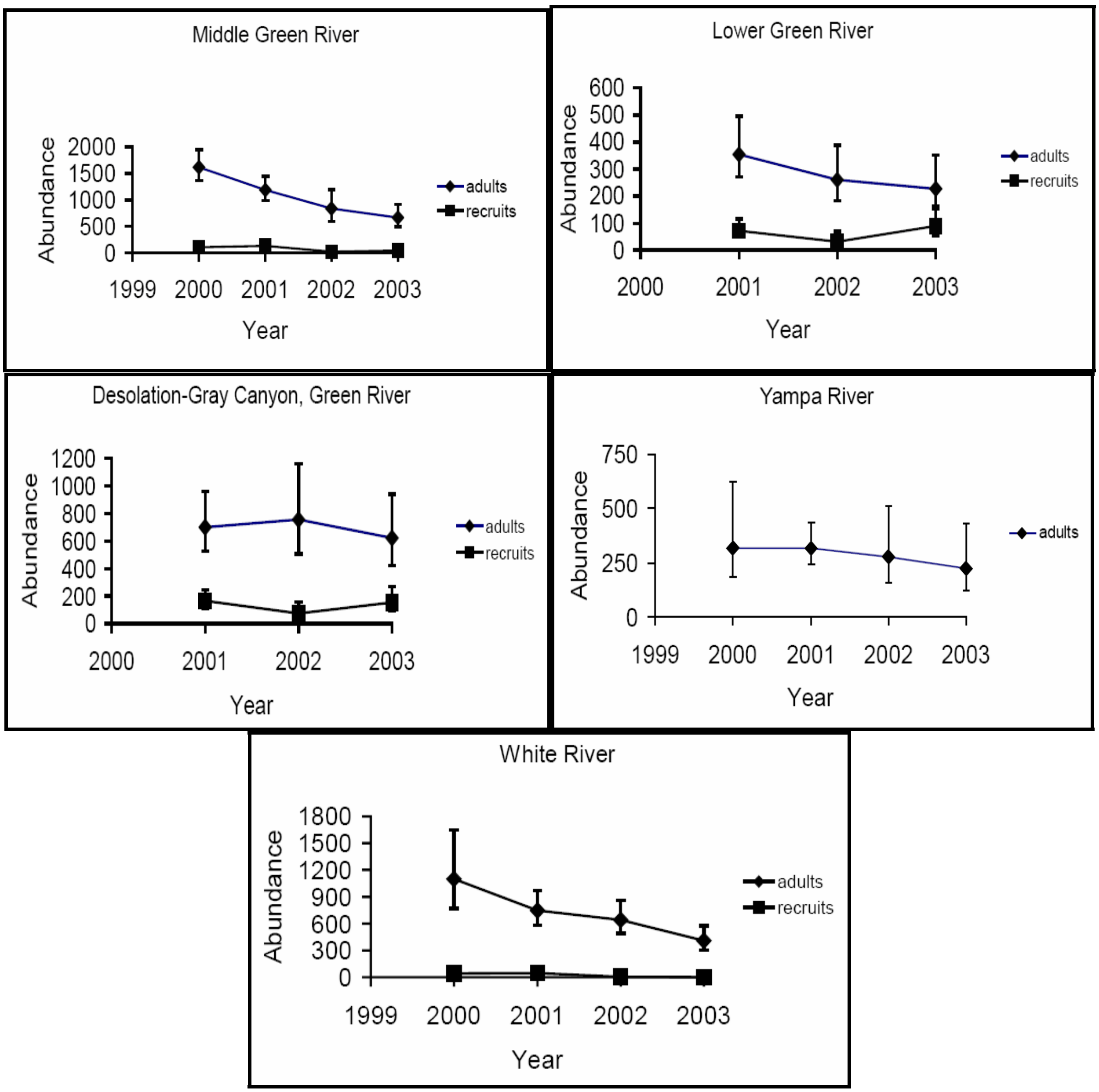

Figure 3-2. Annual population estimates (95% confidence intervals) for adults and juveniles (recruits) of Colorado pikeminnow in five reaches of the Green River Subbasin. Figures from Bestgen et al. (2005).

Table 3-1. Number captured, abundance estimates, standard error (SE), 95% confidence intervals (CI), and coefficients of variation (%*CV*) for adult (> 450 mm TL) and recruit-size (400–449 mm TL) Colorado pikeminnow in five reaches of the Green River Subbasin, 2000–2003. Percent recruits = estimates of recruits/adults in the same year times 100. Numbers of fish captured (recaptured) are shown separately, or sum of captures and recaptures. Data to create this table were taken from Bestgen et al. (2005).

Life Stage	Year	No. Captured (recaptured)	Abundance	SE	95% CI	*CV* (%)
Middle						
Adults	2000	738 (254)	1,613	149	1,359–1,948	9
	2001	394 (36)	1,184	115	986–1,441	10
	2002	110	834	151	593–1,192	18
	2003	155	663	107	491–918	16
Recruits	2000		107	20	76–158	19
	2001		133	26	93–199	20
	2002		22	15	7–78	70
	2003		43	16	22–91	38
Lower						
Adults	2001	238 (28)	355	56	270–496	16
	2002	215	261	51	184–388	19
	2003	59	227	49	154–352	22
Recruits	2001		71	16	48–116	23
	2002		31	13	16–69	41
	2003		89	27	53–162	30
Desolatio						
Adults	2001	282 (26)	699	109	527–963	16
	2002	137	757	165	504–1,166	22
	2003	117	621	129	423–942	21
Recruits	2001		163	33	114–247	20
	2002		72	28	36–154	39
	2003		152	44	90–269	29
Yampa						
Adults	2000	93 (41)	317	105	184–623	33
	2001	140 (20)	320	48	245–438	15
	2002	33	277	87	157–512	31
	2003	33	224	75	123–434	34
White						
Adults	2000	320 (91)	1,100	220	762–1,653	20
	2001	236 (24)	746	98	586–973	13
	2002	185	643	94	491–864	15
	2003	119	407	68	300–573	17
Recruits	2000		43	15	24–87	35
	2001		45	14	26–84	31
	2002		5	4	2–24	90
	2003		0	0	0–0	

Annual estimates for each of the five reaches of the Green River Subbasin were summed for 2000–2003 (Figure 3-3; Table 3-2; Bestgen et al. 2005). Based on the non-overlapping confidence limits, 2000 estimates for the White River were different from 2003; and for the middle Green River, the 2000 estimate was different from both the 2002 and 2003 estimates. Further, the difference between the basin-wide estimates in 2001 and 2003 are also different. Abundance estimates from 2001 to 2003 resulted in a 35% decline of Colorado pikeminnow in the Green River Subbasin (3,303 to 2,142).

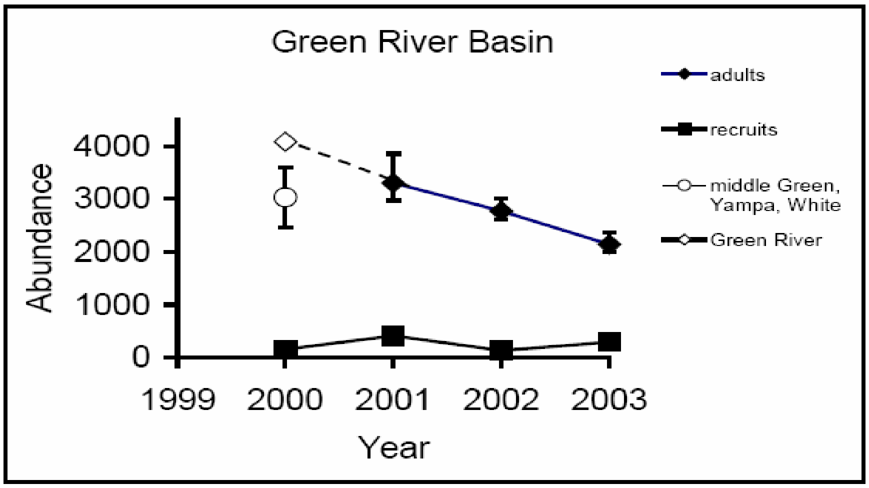

Figure 3-3. Colorado pikeminnow population estimates and 95% confidence intervals for adults (≥450 mm TL) and recruits (400–449 mm TL) in the Green River Subbasin. Abundance estimates and statistics are shown in Table 3-2. From Bestgen et al. (2005).

Table 3-2. Number captured, abundance estimates, standard error (SE), 95% confidence intervals (CI), and coefficients of variation (*CV* as %) for adult (> 450 mm TL) and recruit-sized (400 to 449 mm TL) Colorado pikeminnow in the Green River Subbasin, 2000 to 2003. Percent recruits = estimates of recruits/adults in the same year times 100. Numbers of fish captured (recaptured) are shown separately, or sum of captures and recaptures. Data to create this table were taken from Bestgen et al. (2005).

Life Stage	Year	No. Captured (recaptured)	Abundance	SE	95% CI	*CV*	% Recruits
Adults	2000*	1,151 (386)	3,030	286.8	2,467–3,592	9	
	2001	1,290 (134)	3,303	206.1	2,900–3,707	6	
	2002	680	2,771	282.7	2,216–3,325	10	
	2003	483	2,142	232.7	1,686–2,598	11	
Recruits	2000		150	26.3	98–201	18	4.9%
	2001		412	51.1	312–512	12	12.5%
	2002		130	35.5	61–200	27	4.7%
	2003		284	55.8	175–393	20	13.3%

*Year 2000 estimates include only the Middle Green River, Yampa River, and White River reaches.

Abundance of recruit-size fish (i.e., 400–449 mm TL) during 2000–2003 represented 4.9 to 13.3% of the estimated abundance of adult Colorado pikeminnow (Table 3-2). The number of recruit-size fish, taken as a percentage of adults, must equal or exceed mean annual adult mortality (i.e., 1-survival) as a demographic criterion of recovery goals. Survival rate for adult Colorado pikeminnow for 2000–2003 was 0.65 (95% CI, 0.586–0.708; Table 3-3) and was lower than the 0.82 (95% CI, 0.709–0.891) survival rate estimated for Colorado pikeminnow from ISMP data collected from 1991 to 1999 (McAda 2002a); additional prior annual survival estimates were similar at 0.81 (Gilpin 1993) and 0.85 (Osmundson et al. 1997). When compared to the corresponding years (Table 3-3), percent recruits were consistently below mean annual adult mortality. This indicates that declines in abundance of adult Colorado pikeminnow in 2000–2003 were caused by a combination of low adult survival and low recruitment. Low adult survival may be related to extended drought in the Colorado River Basin. Low recruitment is attributed to weak year classes from low survival of age-0 fish caused by poor, drought-related conditions of nursery backwaters in the middle and lower Green River (see Discussion below). Low recruitment and survival may also be related to proliferation of nonnative fish during drought conditions. There was no support for the hypothesis that reduced survival of adult Colorado pikeminnow was due to sampling mortality.

Table 3-3. Apparent survival rates (S), recruitment, and capture probabilities (*P*-hat) for Colorado pikeminnow in the Green River Subbasin. Data to create this table were taken from Bestgen et al. (2005).

Years	Mean Survival (S) (range)	Mean Mortality (1-S)	Mean Capture (*P*-hat) (range)
1991–1999	0.82 (0.709–0.891)	0.18	0.053 (0.038–0.074)
2000–2003	0.65 (0.586–0.708)	0.35	0.090 (0.054–0.119)

Percent of recruit-size fish (i.e., 400–449 mm TL) from 1991 to 2003 was variable, but equaled or exceeded average annual adult mortality of 18% (1991–1999) in 4 of 13 years (i.e., 1992–1994, 1998; Figure 3-4 top) and 35% in only 2 of 13 years (i.e., 1992, 1993, 1998). For 1991 to 1999, recruit-sized fish averaged 24.7% (range, 8%–59%) of adults captured in ISMP samples, and for 2000–2003, recruits averaged 3.3% (range, 0%–6.6%). An average of 8.8% recruits was estimated from abundance estimates for 2000–2003.

Comparison of age-0 and recruit-size Colorado pikeminnow in the Green River Subbasin indicates possible linkages. Although males first mature at age-4 and females at age-5, age-growth analyses (Hawkins 1992) show that recruit-size fish (400–450 mm TL) may be 5–7 years old. Percent recruits may be linked to year-class strength as indicated by age-0 ISMP data (Figure 3-4 bottom). The large numbers of age-0 fish in particularly the middle Green River during 1987–1989 appear to account for the high percentage of recruits 5–7 years later during 1992–1994. Similarly, a spike in numbers of age-0 fish in 1993 appears to account for the spike in percentage of recruits in 1998.

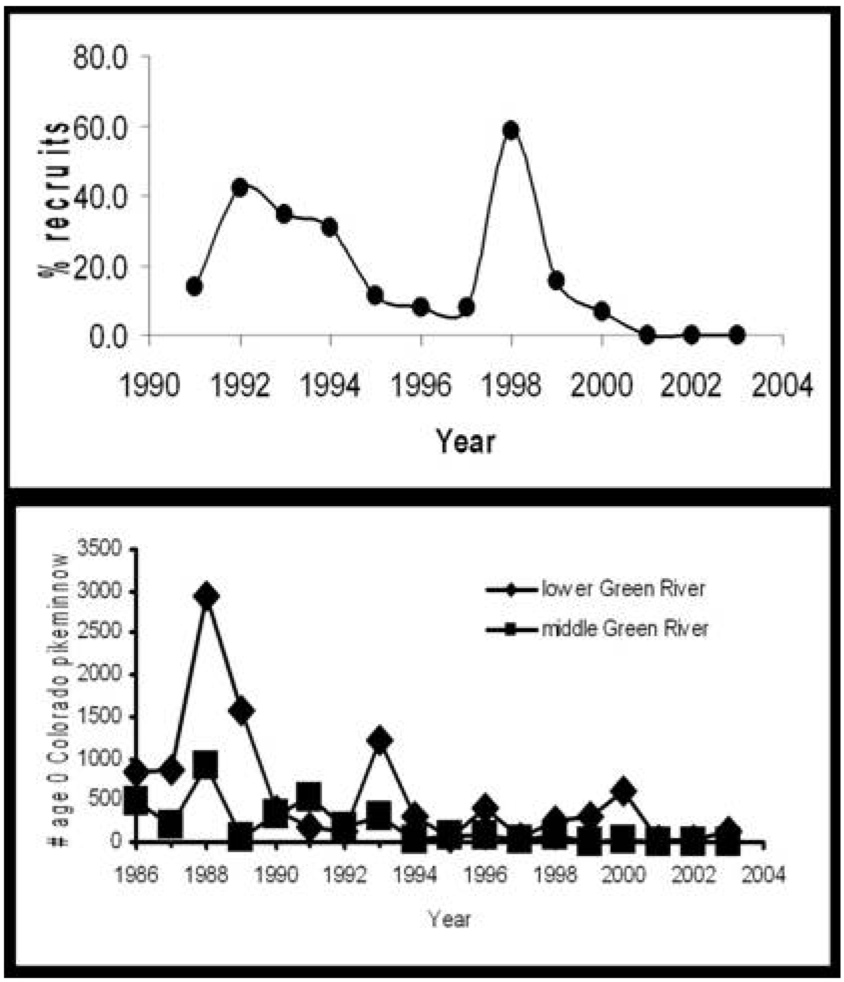

Figure 3-4. Percent recruits for Colorado pikeminnow in the Green River Subbasin, 1991–2003 (top) and number of age-0 in the lower and middle Green River from ISMP (bottom). From Bestgen et al. (2005).

Rate of population change for Colorado pikeminnow in the Green River Subbasin was evaluated using Pradel's lambda, which estimates rate of population change as a function of survival and recruitment and not estimated abundance. Pradel's lambda value of > 1 indicates an expanding population and a value of < 1 indicates a declining population. Pradel's lambda indicates that from 1992 through 2000, the population of Colorado pikeminnow was stable or increasing in all years but one (i.e., 1997; Figure 3-5). The lambda values indicate that a population decline occurred between 2000 and 2001, and that a declining population is indicated for 2001–2003.

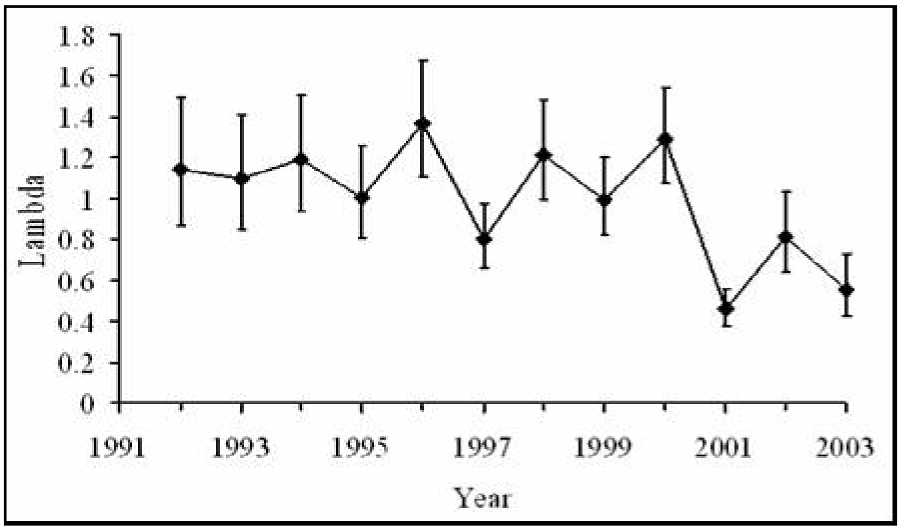

Figure 3-5. Estimated finite rate of population change (λi) for ISMP data collected in the Green River Basin, Utah and Colorado, at 10 sites from 1991 to 2003. Error bars are 95% confidence limits, λ > 1 represents an expanding population, λ< 1 represents a declining population, λ = 1 represents a stable population. From Bestgen et al. (2005).

Discussion.—Sampling effort and number of recaptures in the Green River Subbasin are sufficient to support a complex and robust population estimator model, although estimates for reaches with small populations were less precise. Based on the non-overlapping confidence limits, 2000 estimates for the White River were different from 2003; and for the middle Green River, the 2000 estimate was different from both the 2002 and 2003 estimates. Further, the difference between the basin-wide estimates in 2001 and 2003 are also different. Abundance estimates from 2001 to 2003 resulted in a 35% decline of Colorado pikeminnow in the Green River Subbasin. No significant differences are indicated, although precision of river-wide estimates varies; i.e., *CV* = 0.06–0.11. Largest declines were in the middle Green River and White River where the populations are largest.

The apparent abundance decline is due in part to reduced survival of adults, although survival rates also were not significantly different. Survival rates of adult Colorado pikeminnow were lower in 2000–2003 than in 1991–1999. The apparent decline is also due in part to reduced recruitment, where recruitment is not sufficient to offset adult mortality. Recruitment rates of Colorado pikeminnow were also lower in 2000–2003 than in 1991–1999. Reduced recruitment appears to be linked to weak year-classes of age-0 Colorado pikeminnow in the lower Green River and middle Green River. Weak year classes are evident since the early 1990's and appear to be associated with low flow regimes. Reduced survival of adults since 2000 also appears to be related to low summer base flows and may be caused by stress from drought; i.e., 2002 was the second lowest flow year on record in the middle Green River. Low recruitment and survival may also be related to proliferation of nonnative fish during drought conditions. There was no evidence of increased mortality due to sampling. Additional analyses are needed to better understand the relationship of environmental correlates to year-class strength and recruitment.

3.1.2 Upper Colorado River Subbasin

Sampling Design.—Population estimates of Colorado pikeminnow in the Upper Colorado River Subbasin have been conducted from 1991 to 2004 (Osmundson and Burnham 1998; Osmundson 2002, 2004). These estimates encompass a total of 282 RK (177 miles) that include the Upper Colorado River from Price Stubb Diversion Dam near Palisade, Colorado, downstream to the confluence with the Green River, excluding Westwater Canyon (Figure 3-6). Three multi-year data collection efforts include: (1) 1991–1994, (2) 1998–2000, and (3) 2003–2004. The 1991–1994 and 1998–2000 sample efforts were conducted with one 2-person crew. Three passes were conducted in the upper reach (i.e., upstream of Westwater Canyon) where adults were more abundant, and two passes were conducted in the lower reach (i.e., lower Westwater Canyon to Green River confluence). Sampling was conducted during a 10-week period coinciding with spring runoff (mid-April to mid-June). All large backwaters, flooded bottomlands, 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 netable habitat was scarce. The goal was to cover all areas so that all Colorado pikeminnow had some probability of capture.

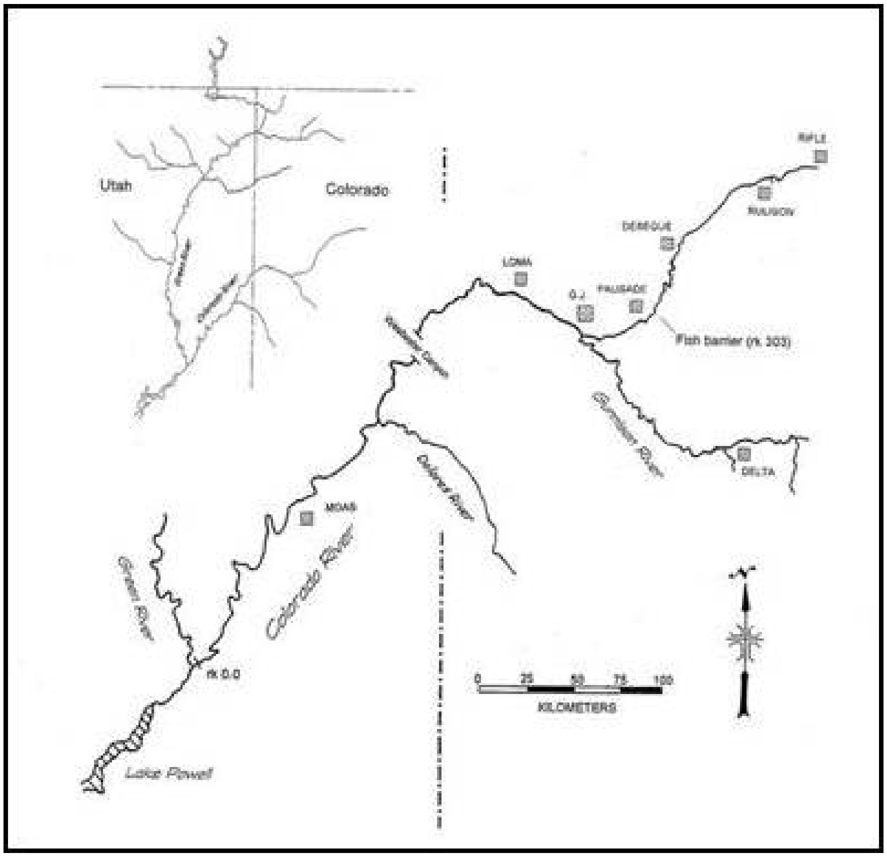

Figure 3-6. The two population estimates reaches of the Upper Colorado River Subbasin. Figure from Osmundson (2004). The two reaches are the Price-Stubb Diversion to Westwater Canyon and Westwater Canyon to the Green River confluence.

The 2003–2004 sampling was conducted with four 2-person crews using the same techniques as in prior years. Two crews sampled the lower reach and two crews sampled the upper reach. There were four river-wide passes in 2003 and three in 2004. Spring runoff was abbreviated in both years and sampling started prior to runoff, but ended when Colorado pikeminnow began moving to spawning sites. Sampling lasted 12 weeks in 2003 and 9 weeks in 2004, and each complete pass averaged 11 days. Most sampling in 2003 and 2004 was done using shoreline electrofishing because there were few backwaters. All Colorado pikeminnow were measured and marked with uniquely coded PIT tags.

Analytical Methods.—Capture-recapture data were used to estimate abundance each year using closed-model estimators with two to four sampling occasions (Program CAPTURE, White et al. 1982). For the 1991–1994 and 1998–2000 estimates, number of passes varied between upper and lower reaches and necessitated separate estimates for each reach; i.e., Model M_o was selected for the upper reach with three passes, and model M_t was used for the lower reach with two passes. These separate estimates were summed to derive a total estimate of adult Colorado pikeminnow for the Upper Colorado River. For the most recent estimates of 2003–2004, there was an equal number of passes in each reach that allowed construction of one capture history matrix for the entire study area, and model M_o was used.

Population Estimates.—Annual estimates of whole-river population size (all fish > 250 mm TL) averaged 613 during the period of 1991–1994 and 778 during the period of 1998–2000 (Figure 3-7; Table 3-4). Annual estimates of adults (> 500 mm TL) averaged 372 during 1991–1994 and 534 during 1998–2000, 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, significant increases in total fish and adults were indicated. Estimates of adult Colorado pikeminnow in the upper Colorado River for the periods 1991–1994 and 1998–2000 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. Estimates in Figure 3-7 were recalculated to reflect adult size of ≥ 450 mm TL.

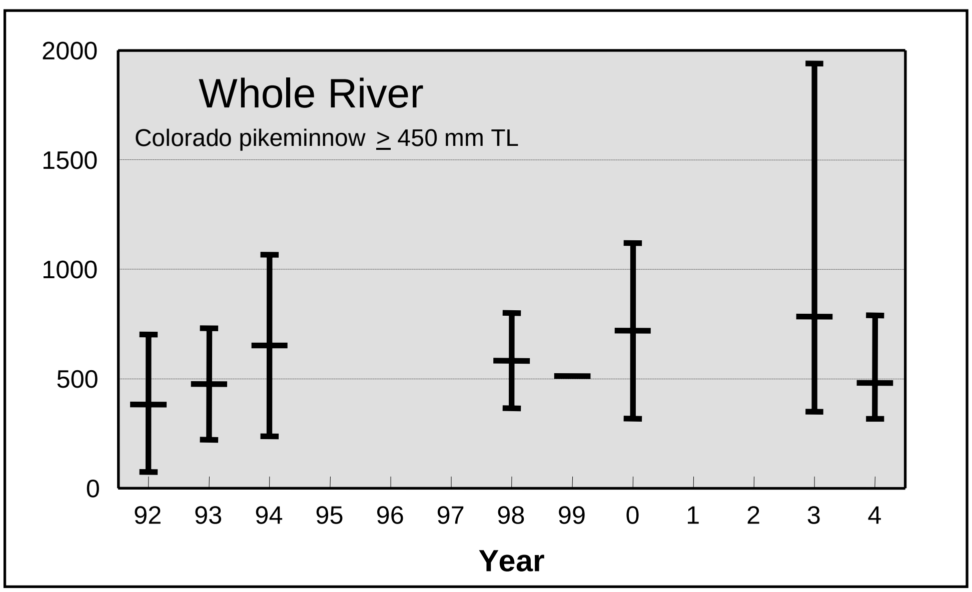

Figure 3-7. Annual population estimates (95% confidence intervals) for Colorado pikeminnow adults in the Upper Colorado River Subbasin. From Osmundson (2004).

Table 3-4. 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. Estimates for 2003 and 2004 are for fish ≥450 mm TL. Data to create this table were taken from Osmundson and Burnham (1998) and Osmundson (2002, 2004).

Area of Estimate	Year	Model	Occasions	No. Captured (recaptured)	*N*-hat	95% C.I.	*P*-hat	%*CV*
Upper Reach	1991	M_o	3	59	205	124–520	0.106	~25%
	1992		3	65	311	179–1,204	0.074	
	1993		3	78	163	121–246	0.194	
	1994		3	93	332	223–728	0.103	
	1998	M_o	3	–	435	317–633	0.130	~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	~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	~25%
	1999		2	–	401	165–1,158	0.10, 0.06	
	2000		2	–	381	170–979	0.09, 0.06	
Entire Region	2003	M_o	3	89	784	350–1,904	0.03	47%
	2004	M_o	3	127	481	317–789	0.10	24%

Discussion.—Modifications in sampling effort were implemented as a result of recommendations from the first population estimates workshop. Crew size was increased from one 2- person crew in 1991–1994 and 1998–2000 to four 2-person crews in 2003–2004. Increase in crew size and shoreline electrofishing were implemented to increase precision by increasing the number of sampling occasions and fish captures. Despite the increased effort in 2003, precision of the population estimate was low and attributed to low water conditions that reduced backwater trammel-netting, a technique that yielded high numbers of Colorado pikeminnow in past years. The 2004 recaptures were also low, but additional sampling in July for another study increased sample size to the point where precision roughly met guidelines for *P*-hat and *CV*.

There were insufficient recaptures to use Program CAPTURE to estimate abundance of Colorado pikeminnow 400–449 mm TL in 2003. Estimates of recruits were calculated using the proportion of recruit-sized fish to adult-sized fish from the length-frequency of all captures and the population estimate of adult-size fish. This assumed that length-frequency of captured fish was representative of the population and the point estimate of adults was accurate. For 2003, 89 captured fish were of adult size (> 450 mm) and 23 were recruit-size fish (400–449 mm), or 26% of adult total. Model M_o estimated 784 adults in the population, and based on the 26% ratio of subadults to adults, there were 203 recruit-size fish in the population in 2003. To replace 15% mortality of adults, only 118 recruits were needed. For 2004, 127 captured fish were of adult size; 29 were of recruits, or 23% of adult total. Model M_o estimated 481 adults in the population, and based on the 23% subadult/adult ratio, there were 110 recruit-size fish. Only 72 were needed to replace 15% adult mortality.

3.1.3 San Juan River Subbasin

Sampling Design.—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 (U.S. Fish and Wildlife Service 2004). Only 17 wild adult Colorado pikeminnow were captured in the entire San Juan River between 1991 and 1995 as part of a fish community study and not as a designed mark-recapture population estimate (Ryden 1997, 2000, 2003; Ryden and McAda 2004; Holden 1999). 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 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).

Analytical Methods.—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 (Ryden 1997, 2000, 2003). Associated confidence intervals were calculated using Poisson distribution tables (Ricker 1975) to compensate for small numbers of captures and recaptures.

Population Estimates.—The Schnabel population estimator yielded an estimate of 19 adult Colorado pikeminnow (95% CI = 10–42) in the San Juan River. A Petersen population estimator yielded estimates ranging from 9 to 20 adults for the 14 sampling intervals. The estimator models used assumed a 0% mortality factor, although there was one confirmed mortality during the study and possibly more.

Discussion.—It is surmised that there were probably fewer than 40 adult Colorado pikeminnow in the entire San Juan River as of October 1995. The low numbers of wild fish from 1996 to 2001 precluded a robust population estimate, and the estimated number is less than 20 fish. Only 3 wild Colorado pikeminnow have been collected since October 1995; 2 juveniles (363 and 432 mm TL) near Lake Powell in 1996; and 1 adult originally captured in April 1993, recaptured in 1998, 1999, and 2000 (all from RM 136.6–119.2). Given that all but two adult Colorado pikeminnow were collected from RM 136.6–119.2 between June 1991 and October 1995, the estimate of less than 20 fish is applied to the entire San Juan River.

The wild population of Colorado pikeminnow in the San Juan River is currently being increased through hatchery augmentation (Table 3-5; Ryden and McAda 2004). As long as numbers of fish are low, precise population estimates will be difficult to obtain. Population estimates should begin when fish stocked in the first year of the approved stocking plan are age-5. Sampling protocols should be similar to those currently in use in the upper basin to minimize variability and maximize precision. Population estimates should be conducted throughout occupied range of stocked fish in the San Juan River Subbasin.

Table 3-5. Numbers of hatchery Colorado pikeminnow stocked in the San Juan River, 1996–2003. This table was taken from a presentation by Dale Ryden, U.S. Fish and Wildlife Service.

Year	Number of Fish Stocked	Life-Stage(s) Stocked
1996	100,000	Age-0
1997	116,927 (49 were adults)	Age-0/Adults
1998	10,571	Larvae
1999	500,000	Larvae
2000	105,000	Larvae
2001	148	Adults
2002	210,418	Age-0
2003	176,933 (1,005 were age-1)	Age-0/Age-1
Total	~1,220,000	

3.2 Humpback Chub

Population estimates are available for all five upper basin populations of humpback chub, including Black Rocks, Westwater Canyon, Desolation/Gray Canyons, Yampa Canyon, and Cataract Canyon (Table 3-6). The following sections describe estimates for each population.

Table 3-6. Area and year of estimate, estimator models, sampling occasions, fish size, number of fish captured, 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, and Cataract Canyon. Data to create this table were taken from McAda (2004), Jackson (2004a, 2004b), Finney et al. (2004) and Utah Division of Wildlife Resources (2004).

Area of Estimate	Year	Model	Occasions	Fish Size (mm TL)	No. Captured	*N*-hat	95% C.I.	*P*-hat	*CV*
	1998		3	180	184	948	603–1,573	0.07	0.25
Black Rocks	1999	M_o	4	200	293	921	723–1,208	0.09	0.13
	2000		3	200	68	539	223–1,497	0.04	0.54
	2003		4	200	69	478	221–1,176	0.04	0.46
	1998		3	190	488	5,171	3,299–8,287	--	--
Westwater Canyon	1999	M_o	3	200	281	2,261	1,349–3,942	--	--
	2000		3	160	279	1,704	1,095–2,758	--	--
	2003		3	200	298	2,413	1,500–4,396	--	--
	2001		3	200	270	1,998	1,479–6,291	0.045	0.26
Desolation/Gray canyons	2002	M_o	3	200	246	2,193	1,435–9,548	0.057	0.35
	2003		3	200	233	945	737–1,960	0.083	0.20
	2000	M_o	3	>150	44	391	180–2,750	0.03	0.57
Yampa River	2000	M_h	3	>150	9	442	147–1,578	--	0.70
	2003		3	>150	8	391	180–2,750	--	--
Cataract Canyon	2003	M_o	3	200	32	150	71–407	0.084	0.50

3.2.1 Black Rocks

Sampling Design.—Humpback chub were first reported in Black Rocks in 1977 (Kidd 1977). Population estimates of humpback chub in Black Rocks have been conducted from 1998 to 2000, and 2003 (McAda 2004). These estimates encompass a total of 1.4 RK (0.9 miles) that include the Upper Colorado River from RM 135.5 to RM 136.4. Sampling occurs in late summer and early autumn after water temperatures begin to cool for the year. Three sampling trips were conducted each in 1998 and 2000, and four trips each were made in 1999 and 2003. 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 trap nets were also used in 1998 and electrofishing was used 1998, 2003, and 2004 in an attempt to catch smaller fish; angling was used in all years. Trammel nets were set in shoreline eddies in early morning and late afternoon for 1- to 2-hour intervals (mean, 1.0 hour). All *Gila* were removed from the nets, placed in fresh water, and transported to a central processing point.

All *Gila* were field identified as either humpback chub or roundtail chub (Douglas et al. 1989, 1998), 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 an oxygenated 1.5% salt bath with "Stress Coat" for 0.5–1 min, and released at a common location. About 10% of all fish handled were placed in a live cage and held overnight to assess short-term latent mortality. No overnight mortalities occurred, and all fish appeared healthy when released.

Analytical Methods.—A closed model was used to estimate population size. Population estimator models used included M_o, Jackknife M_h, and Chao M_h. All three 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, and the M_h model assumes that different individuals have different capture probabilities.

Population Estimates.—Population estimates for humpback chub in Black Rocks were highly variable depending on the estimator model selected. Estimates in 1998 ranged from 349 using Jackknife M_h to 1,495 using Chao M_h. Using the 'best' model (Model M_o), population estimates for humpback chub in Black Rocks were 948 (95% CI, 603–1,573) in 1998, 921 (723–1,208) in 1999, 539 (223–1,497) in 2000, and 478 (221–1,176) in 2003 (Table 3-6; Figure 3-8).

Catch rates declined markedly in 2000 and 2003, 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), 68 in 2000, and 69 in 2003. 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.

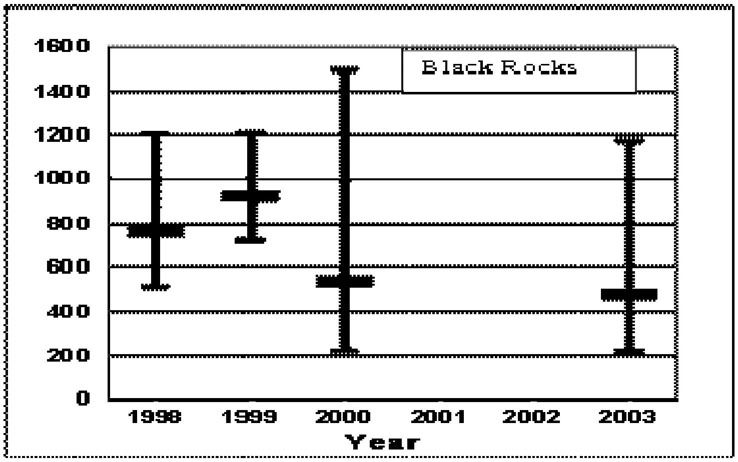

Figure 3-8. Point estimates for adult humpback chub in Black Rocks (McAda 2004).

Discussion.—The number of sampling occasions was increased from three in 1998 to four in 1999, and biologists expressed concern for over-handling fish. 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 in 1999 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 to the fish and the additional effort was not warranted. Reasons for a lower estimate of 539 in 2000 from 948 in 1998 (not significant) may be related to unpredicted fish movements to other habitats not sampled, or dramatically different sampling conditions, such as flow. A lower estimate of 478 was also seen in 2003.

Although all PIT-tagged fish were used to generate an estimate, the majority (98% in 1998, 100% in 1999, 2000, and 2003) were ≥200 mm TL, which are defined as adults. Hence, current estimates account for virtually all adults. Crew size and sample effort were constant from 1998 through 2000, and are not believed to be linked to reasons for decreased catches.

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; three occasions in 2000 yielded a *P*-hat of 0.04 and a *CV* of 0.54; and four occasions in 2003 yielded a *P*-hat of 0.04 and a *CV* of 0.46. The additional sampling occasions reduced *CV* in 1999, but not in 2003. 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.

3.2.2 Westwater Canyon

Sampling Design.—Humpback chub were first reported in Westwater Canyon in 1979 (Valdez et al. 1982). Population size of humpback chub in Westwater Canyon was estimated during 1998–2000 and 2003 (Chart and Lentsch 1999; Jackson 2004a). Three sites were sampled in 1998–2000 (i.e., 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 occupied habitat in Westwater Canyon. In 2003, sampling was expanded to include Miners Cabin, Cougar Bar to Little Hole, Hades Bar, and Big Hole by electrofishing intervening reaches. 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 was injected with a PIT tag. Each fish was scanned for a pre-existing PIT tag, identifying it as a recapture.

Analytical Methods.—A closed model was used to estimate population size with the assumptions that: (1) the population was closed between sampling occasions, (2) marks were not lost, (3) all marks were correctly noted and recorded, and (4) 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.

Population 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 (1,349–3,942) in 1999; and 1,704 (1,095–2,758) in 2000 (Table 3-6). The areas sampled in these sites represent only about 15% of occupied habitat in Westwater Canyon. Additional sites were sampled in 2003 to increase coverage to about 20% of occupied habitat, and the combined estimate of adults was 2,413 (95% C.I. = 1,500–4,396). The precision of these estimates was not provided by the researcher, but the wide confidence intervals indicate rather low precision (Figure 3-9).

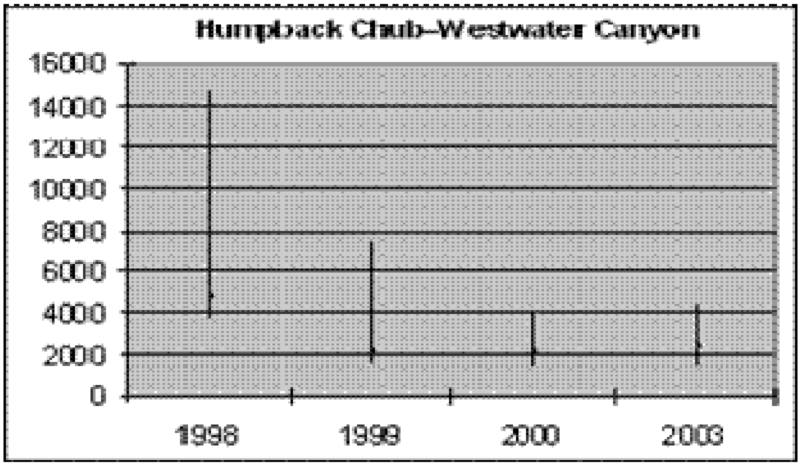

Figure 3-9. Point estimates for adult humpback chub in Westwater Canyon (Jackson 2004a).

Discussion.—Population estimates in Westwater Canyon decreased from 5,171 in 1998, to 2,261 in 1999, and 1,704 in 2000 (67% decrease from 1998 to 2000); the estimate in 2003 was 2,413. Numbers of humpback chub captured also decreased from 488 in 1998, to 281 in 1999, and 279 in 2000 (43% decrease from 1998 to 2000); total number captured in 2003 was 298. Total numbers of recaptures (including all prior years) increased from 54 (11%) in 1998, to 65 (23%) in 1999, and 76 (27%) in 2000; numbers of recaptures in 2003 was 50 (17%) (Table 3-7). 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 size may be related to model violations of closure (i.e., fish move from and to sample areas between occasions), or to dramatically different flow conditions during sampling.

Table 3-7. Numbers of humpback chub captured and recaptured in Westwater Canyon during 1998, 1999, 2000, and 2003. Data to create this table were taken from Jackson (2004b).

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
2003	200	298	50 (17%)	12
Total		1,346	245	42

Population estimates for humpback chub in Westwater Canyon appear to be highly variable and lacking precision. 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) representing about 15% of the canyon area. This effort was expanded in 2003 to include Miners Cabin, Cougar Bar to Little Hole, Hades Bar, and Big Hole with electrofishing in intervening reaches. Expanding the area of sampling apparently did not increase precision or capture probability, although additional sampling in 2004 and 2005 are necessary to more fully evaluate the effect of the expanded sampling effort. 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 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.

Although all PIT-tagged fish were used to generate population estimates, the majority (99% in 1998, 100% in 1999, 98% in 2000, and 98% in 2003) were ≥200 mm TL, which are defined as adults. Hence, current estimates account for virtually all adults. However, capture efficiency of subadult humpback chub (150–199 mm TL) in Westwater Canyon is low and estimated recruitment is difficult to assess.

3.2.3 Desolation/Gray Canyons

Sampling Design.—Humpback chub were first reported in Desolation/Gray Canyons in 1967 (Holden and Stalnaker 1970). The Green River through Desolation/Gray Canyons was sampled in 2001–2003 to estimate abundance of humpback chub (Jackson 2004b). 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 (Figure 3-10). Sampling included about 0.5 miles at each site, or about 6 miles of the 84 miles (7%) 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 received a PIT tag. Each fish was scanned for a pre-existing PIT tag to identify recaptures.

Analytical Methods.—Population estimator models M_o and M_t were used to estimate population size of humpback chub in Desolation/Gray Canyons. 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.

Population Estimates.—Population estimates for humpback chub in Desolation/Gray Canyons were 1,998 (95% CI = 1,479–6,291) in 2001; 2,193 (1,434–9,548) in 2002; and 945 (737–1,960) in 2003 (Table 3-6; Figure 3-11; Jackson 2004a). Capture probabilities (*P*-hat) were 0.045, 0.057, and 0.083; and coefficients of variation (*CV*) were 0.26, 0.35, and 0.20.

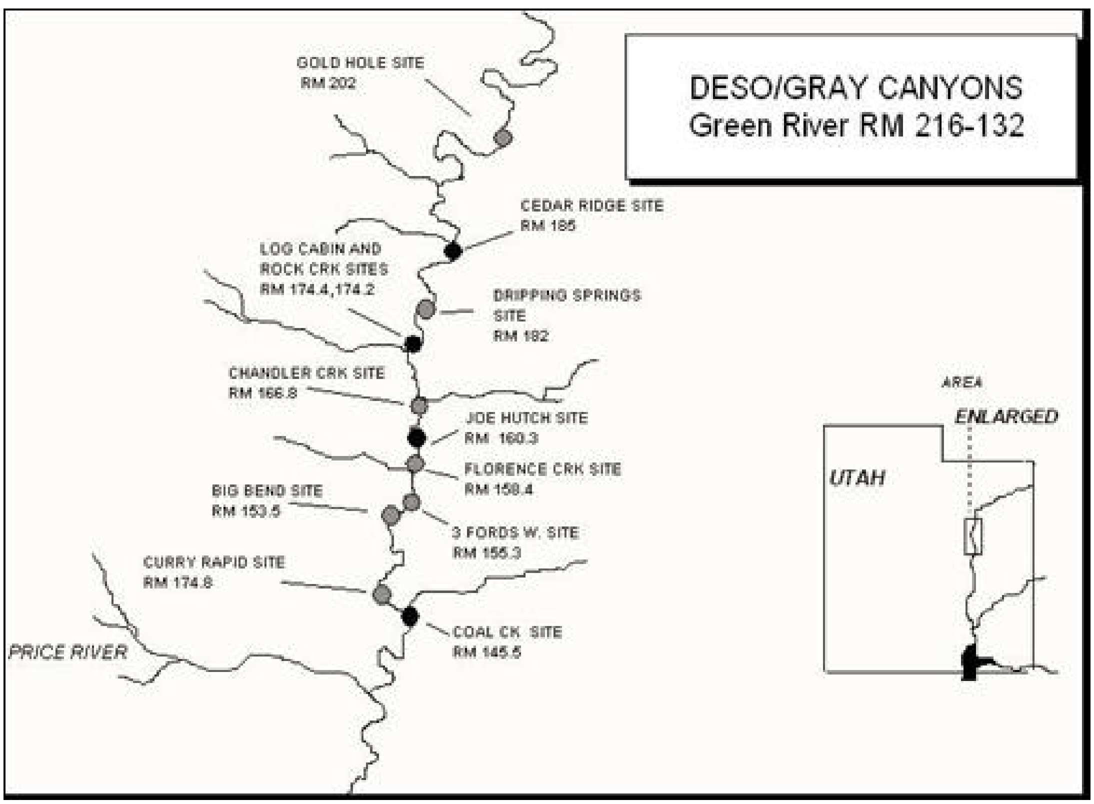

Figure 3-10. Desolation/Gray Canyons of the Green River and sample locations for humpback chub population estimates. Figure from Jackson (2004b).

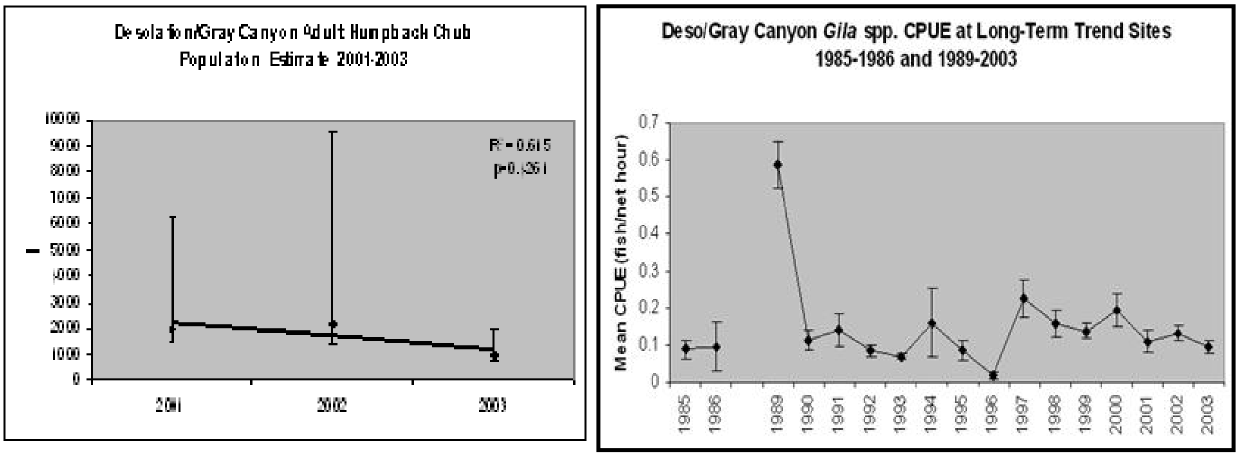

Figure 3-11. Point estimates for adult humpback chub in Desolation/Gray Canyons (left). ISMP trammel net monitoring, 1998–2000 (right). Figures from Jackson (2004b).

Discussion.—The population of humpback chub in Desolation/Gray Canyons declined from 1,998 in 2001 to 945 in 2003 (53% decrease), and the total numbers of fish captured declined from 270 in 2001 to 233 in 2003 (14% decrease). Reasons for these declines may be related to fish movements to and from habitats not sampled, or dramatically different flow conditions between and within years. Flows during the three sample periods in 2001 were 6,000 cfs on pass one; 1,400 cfs on pass two; and 1,100 cfs on pass three, in which 204, 88, and 33 humpback chub were captured, respectively.

Several factors possibly contributed to decline in point estimates of humpback chub in Desolation/Gray Canyons, including sample time of year, low water conditions, a watershed fire that delivered large amounts of ash into the river 2002, and increased numbers of smallmouth bass. Sampling in 2001 and 2002 was conducted during varying flows in summer, whereas sampling in 2003 was conducted in fall at more stable, but lower flows. Fish may have been more confined and more readily recaptured in 2003. Also, a large fire in the watershed (Rattle Complex fire) occurred in July 2002 with a reported fish kill in September 2002 from heavy sediments in rainstorm runoff that probably depleted the humpback chub population. An increased number of smallmouth bass is reported in Desolation/Gray Canyons that is a recognized fish predator.

The ISMP data were used to link past catch rate data to population estimates in order to assess long-term population trends. Several environmental factors (e.g., flow) were probably acting on catch rates and ultimately trends, especially in years of single pass sampling. Pulses of recruitment that translated to subsequent higher catch rates appear to follow high water years.

The majority (99%) of PIT-tagged humpback chub was ≥200 mm TL, which is defined as an adult, and current estimates account for virtually all adults. Population estimates for humpback chub in Desolation/Gray Canyons, like Westwater Canyon, appear highly variable and lack precision. Hence, refinements in field sampling protocol in Desolation/Gray Canyons were recommended at the first workshop in 2001 and implemented. Crew size and sample effort were expanded to increase fish captures, and spring electrofishing was discontinued to avoid detrimental effects on spawning Colorado pikeminnow. Sampling was extended to as many sites as possible in order to ensure mixing of marks and to minimize movement of fish to areas outside of sample sites. All available gears were used to ensure capture of subadults to evaluate recruitment. Sampling of humpback chub in Desolation/Gray Canyons during 2001 was conducted at 12 sampling sites, each about 0.5 miles long, or about 7% (6 of 84 miles) of occupied habitat. Increased sample sites have expanded coverage to about 10% of occupied habitat. Recommendations for future sampling include substituting Big Bend Site with Surprise Site; increase the number of passes from three to four to decrease *CV*; and use 0.5-inch mesh trammel nets in addition to 1-inch mesh to increase number of juveniles captured.

3.2.4 Yampa Canyon

Sampling Methods.—Humpback chub were first reported from the Yampa River in 1948 (Tyus 1998). The humpback chub population in the lower Yampa River (RK 76–17; Yampa Canyon, Dinosaur National Monument) was monitored from 1998 to 2000 to determine size structure and estimate abundance (Haines and Modde 2002; Finney et al. 2004). Two to three sampling trips were conducted annually during this period. Angling, electrofishing, and trammel nets were used to capture fish. Electrofishing was limited to flows in excess of 1,000 cfs because of difficulty of accessing the canyon with electrofishing boats at lower flows. All sampling was conducted on the descending limb of the hydrograph prior to mid-June or the first of July.

Sampling area was expanded in 2003–2004 to include the Yampa River from Deerlodge (RK 76) downstream to the confluence with the Green River (RK 0); and the Green River through Whirlpool Canyon, Split Mountain Canyon, and Lodore Canyon (Figure 3-12). Area of sampling was extending following recommendations from the first population estimates workshop because researchers believed that the greater Yampa Canyon population extends into the three adjoining canyons.

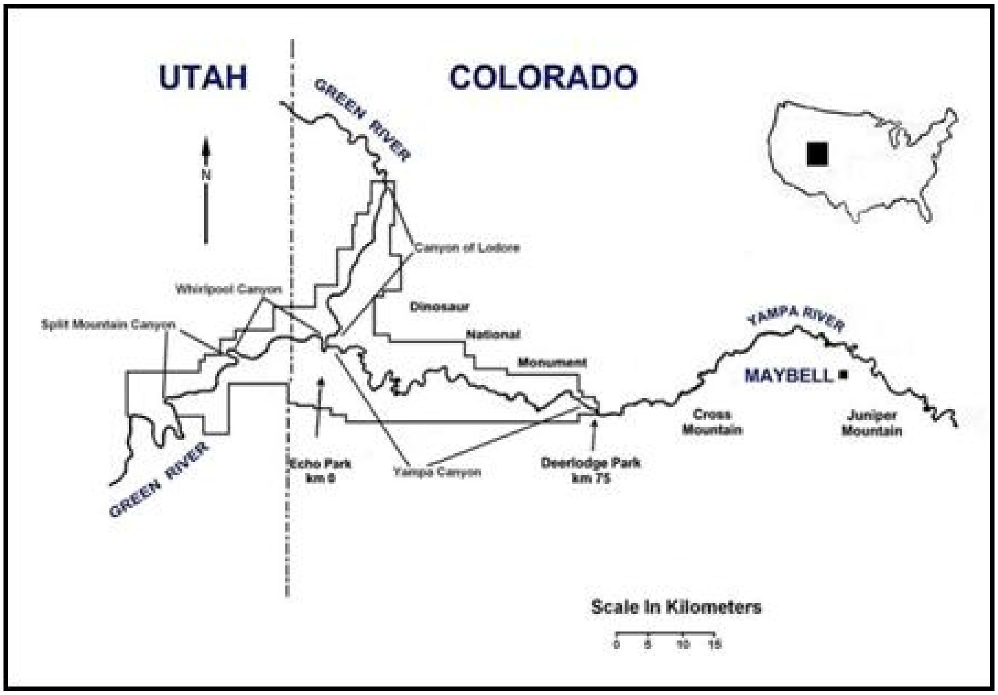

Figure 3-12. The Yampa River and adjoining reaches occupied by humpback chub. From Finney et al. (2004).

Analytical Methods.—Population estimates were derived using two methods (Haines and Modde 2002). First, the computer program CAPTURE (Otis et al. 1978; White et al. 1982) was used for population estimates from the capture-recapture data. No fish were recaptured in 1998 or 1999 and population estimates were not possible. In 2000, three fish were recaptured and model M_o was applied because of varying capture probabilities between sample occasions. For the second method, it was assumed that the population was stable between 1998 and 2000 (i.e., mortality equaled recruitment and therefore a constant N), and a binomial probability density function was used to calculate likelihoods of obtaining recapture data for the second and third passes each year. Since the data sets were independent, they were multiplied together to obtain the likelihood for the entire data set (Haddon 2001). An *N* was found that maximized the joint likelihood, and 95% CI were estimated using the likelihood profile. The population estimates applied to fish >150 mm TL (the smallest fish tagged). The simulation module in CAPTURE was used to examine how sampling effort could be improved by using time varying probabilities of capture (generated by beta distributions with alpha = 1.5 and beta = 2.5 for all runs) and the Darroch population estimator. Simulations were run for three capture probabilities and three population sizes. Relative bias was defined as (average *N*-hat-N)/N and coefficient of variation (*CV*) as SE/*N*-hat. Each trial consisted of 100 replications.

Population Estimates.—The density of humpback chub in Yampa Canyon is relatively low (Karp and Tyus 1990), estimated at less than 8 fish/km (Nesler 2000). A total of 609 individuals of all sizes were captured from 1998 to 2004. Most fish were captured in the upper portions of the study area, between Deerlodge and Mathers Hole. Small numbers of humpback chub have been caught at the head of Whirlpool Canyon on the Green River, just downstream of the Yampa River confluence. During 3 years of monitoring in 1998–2000, 86 (83 different and 3 recaptures) adult humpback chub > 150 mm TL were captured with raft electrofishing at a rate of 0.80 fish/hr and by angling at a rate of 0.04 fish/hr (Haines and Modde 2002). An earlier study in 1987–1989 captured 130 humpback chub mostly with electrofishing at a rate of 1.03 fish/hr and angling at a rate of 0.65 fish/hr (Karp and Tyus 1990).

The population of humpback chub in Yampa Canyon was estimated in 2000 as between approximately 100 and 2,000 adults, and was probably about 400 fish (N-hat = 391, 95% CI = 180–2,750) > 150 mm TL, based on a likelihood model of all data (i.e., 44 captures, 2 recaptures) that assumed the population was stable in 1998–2000. The size distribution of humpback chub in the lower Yampa River consisted of both adults and juveniles indicating some level of recruitment. A precise and accurate population estimate may be difficult to obtain because of the small number of humpback chub in Yampa Canyon.

Discussion.—The number of humpback chub in Yampa Canyon is small and standard population estimators are difficult to apply because of low numbers of captures and recaptures. Application of maximum likelihood estimators, such as described by Haines and Modde (2002), may be the best way to generate a reliable estimate for humpback chub in small populations, such as Yampa Canyon and Cataract Canyon.

Expanded sampling in 2003–2004 should continue to insure that the full extent of habitat occupied by the Yampa Canyon population is sampled. Numbers of fish in Whirlpool, Split, and Lodore canyons are small, but local concentrations may be revealed with continued sampling.

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. Size of adults may vary with population.

3.2.5 Cataract Canyon

Sampling Design.—Humpback chub were first reported in Cataract Canyon in 1980 (Valdez et al. 1982). Fish populations in Cataract Canyon have been sampled in 15 of 24 years from 1979 to 2003, and a total of 170 unique humpback chub have been captured (Valdez et al. 1982; Valdez 1990, 2004). 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 prior to 2003 was done to characterize the fish community and not to estimate population abundance.

Mark-recapture population estimates for humpback chub in Cataract Canyon were initially scheduled to begin in 2002. However, due to record low river flows, the beginning was delayed until fall 2003. Three sampling trips were conducted through Cataract Canyon in September through early November (Utah Division of Wildlife Resources 2004). Trammel nets and raft electrofishing were the principal sampling gears. Sampling occurred in three primary sites which were identified as trend sites from ongoing long-term monitoring (RM 212–211, RM 208.5–207, and RM 207–205). Due to low flows, the trend site at RM 207–205 was moved to RM 211.5–209.8. In addition to the three trend sites, two other elective sites were sampled. Both elective sites were located below the “Big Drops” section of the canyon at RM 201.5–201 and 201–200.5.

Analytical Methods.—A population estimate was calculated for humpback chub using Program CAPTURE within the Program MARK. The model selection procedure within CAPTURE was used to select an appropriate estimator. The null model (M_o) was selected by the program; this selection is supported by lack of any significant difference in catch rates between trips.

Population Estimates.—A total of 44 humpback chub captures were recorded during 1,375 hours of trammel netting, yielding a catch rate of 0.022 fish/net hr. Only two humpback chub were collected during 8.93 hours of electrofishing at a rate of 0.22 fish/hr. Overall, 32 unique individuals were captured with a mean total length of 240.8 mm (range 208–303 mm TL). None of the humpback chub captured were sub-adults (<200 mm TL). A population estimate, using 32 captures and 3 recaptures between trips, was 150 individuals (95% CI=71–407; *P*-hat=0.084; *CV*=0.50).

A total of 20 bonytail were also captured during 1,375 net hours of trammel netting, yielding a catch rate of 0.010 fish/net hr. Only two bonytail were collected during 8.93 hours of electrofishing at a rate of 0.22 fish/hr. Overall, 16 unique individuals were captured with a mean total length of 324.2 mm (range 194–366 mm TL). Only one of the bonytail captured was a sub-adult (< 200 mm TL). All bonytail captured were hatchery-reared and previously marked with coded wire tags. A population estimate, using 16 captures and 2 recaptures between trips, was 66 individuals (95% CI=31–212; *P*-hat=0.106; *CV*=0.59).

Discussion.—Numbers of humpback chub in Cataract Canyon are low and numbers of marks and recaptures may not be sufficient to generate reliable and precise estimates. The 3-pass effort in 2003 captured 32 unique fish and 3 recaptures for an estimate of 150 adults with a low precision of 0.50 *CV*. Additional years of sampling are needed to see if the numbers of recaptures can be increased over time for a more precise estimate. An alternative sampling design to the 3-pass estimator is for the series of sampling occasions to be implemented within a single trip; i.e., three passes can be made on a single eddy complex spaced 1-2 days apart to provide an estimate of the number of fish in an eddy complex. The number of large eddy complexes in Cataract Canyon is determinable and stable, and can be used as the basis for an expansion estimate for the entire population.

4.0 *AD HOC* COMMITTEE EVALUATION

A Population Estimates *Ad Hoc* Committee was convened following the second workshop of August 24–25, 2004. Committee members were asked to respond to 11 questions regarding the reliability and precision of population estimates for the eight regions of the upper Colorado River Basin. The following are the questions and a summary of responses:

1. Are the study design and field sampling techniques/methods being used appropriate to meet estimating model assumptions needed to obtain accurate, precise, robust population estimates? (i.e., are assumptions tested and met to the extent possible and do techniques

maximize fish captures; what can be reasonably done to meet the targets: CV=0.10–0.20, P-hat=$\geq$0.10)?

Response.—Committee members were in general agreement that current study design and field sampling techniques appear to be the most appropriate for population estimates, but target precision criteria may not be consistently achievable. Recommendations made during the two workshops were appropriate and continued refinement of sampling methods was encouraged, but members felt that environmental conditions, especially flow, affect capture efficiency and ultimately population estimate precision. Several committee members expressed reservation about population estimates meeting precision targets.

2. Are best analytical methods being used to test estimating model assumptions in order to derive accurate, precise, robust population estimates? (i.e., are mark-recapture model assumptions being tested and met; what are biases and how are effects of these evaluated?).

Response.—Committee members were in agreement that additional analyses should be performed with existing and future data sets to improve and better understand precision and to link population estimates with trend data for age-0 and juveniles; e.g., ISMP, larval drift, overwinter survival. Members also agreed that robust analyses, such as done by Bestgen et al. (2005), should be applied, where possible, to other data sets to better understand population status and trends. Members acknowledged that some data sets may not be sufficient to perform additional analyses.

3. Are population estimates being done consistent with needs of recovery goals? (e.g., length criteria for adults, juveniles; recruitment needs, etc.).

Response.—Committee members concurred that population estimates are being done consistent with recovery goals criteria for length of adults and juveniles by species. However, there is general acknowledgement that insufficient numbers of recruit-size fish are being captured to generate reliable estimates of recruitment. This is particularly problematic with humpback chub, and committee members recognize that alternative analyses may be available for evaluating recruitment, including examination of ISMP data for age-0 and juveniles. Some members also recommended additional sampling techniques and gears (e.g., small-mesh trammel nets) to more efficiently capture small fish.

4. Do estimates reflect entire population in the sample area or a portion of that population?

Response.—Committee members believe that sample efforts for Colorado pikeminnow in the Green River and Upper Colorado River subbasins are comprehensive and the majority of these populations are included in the respective estimates. Sample efforts for humpback chub appear to not adequately sample the majority of populations, particularly in Westwater Canyon and Desolation/Gray Canyons. Precision of population estimates in these areas appears to be limited by whitewater rapids that restrict sampling boundaries but not movement of marked and unmarked fish. Additional sample sites in both regions appear to yield variable results with no substantial increases in precision. Committee members believe that additional evaluation of sample areas and movement of fish to and from these areas is warranted.

5. Are fish being handled and held to minimize stress to individual fish?

Response.—Concerns for over-handling fish have been expressed by researchers, including members of the *ad hoc* committee. All committee members continue to be cautious about this issue and express that the gain in precision from additional sampling occasions may not be a reasonable tradeoff for stress to fish and possible latent mortality. Members acknowledge, commend, and encourage researchers to use aerators, salt baths, and holding fish less time to minimize stress. Committee members also agree that population estimates should be done for 3 consecutive years with 2 years off to minimize sampling stress to fish.

6. Do estimates reflect true population size and population trajectory?

Response.—Committee members were generally uncertain about the accuracy of estimates and whether estimates portray population trajectory. Some felt that an important difference or distinction is in interpreting a 3-year declining trend as (1) possibly within the norm of fluctuation, based on historic estimates or catch rate data; or (2) more seriously as the beginning of a long term declining trend. The first explanation was considered reasonable, but the second requires additional estimates. Some felt that we should continue to evaluate the short-term trend without over-reacting. All members felt that estimates have not been done for a sufficient period of time to understand population demography and dynamics. Some members expressed that precision and accuracy of population size and trajectory are confounded by environmental correlates, such as flow and nonnative predators.

7. Are sampling frequency and intervals between samples appropriate? (i.e., are 3, 4 passes adequate? Is there sufficient time between samples to allow mixing, or too much time with violation of closure? Should sampling/estimates be done 3 years on, 2 off, etc.?).

Response.—Committee members generally concurred with the strategy of close-interval sampling occasions (i.e., passes), but were uncertain as to the value of a 4th pass to gain precision, given the risk of over-handling fish. Time between sampling efforts did not appear to be a concern to members and all felt that current sampling design allows for mixing of marks within the population. However, the uncertainty of how to increase *P*-hat and precision of humpback chub population estimates, particularly in Westwater Canyon and Desolation/Gray Canyons, remained an issue with committee members.

8. What other program information/data or analyses should be considered to strengthen estimates or better understand demographics of these population? (e.g., ISMP, K-factors, etc.).

Response.—Most committee members recommended continuation of ISMP monitoring, specifically Colorado pikeminnow age-0 backwater seining and electrofishing for juveniles. Some members urged continuation of larval sampling for Colorado pikeminnow and razorback sucker. Members acknowledged that possible linkages identified by Bestgen et al. (2005) between population estimates and ISMP data are valuable for assessing long-term population trends.

9. What precautions should be taken by principal population estimate groups or other program activities to minimize fish handling and stress? (e.g., what other activities are potentially affecting fish and what can be done to meet study objectives and minimize handling?).

Response.—Most committee members acknowledged that multiple field sampling efforts in all regions occupied by Colorado pikeminnow and humpback chub increase the likelihood of fish being handled multiple time and being stressed or dying. Members urged comprehensive monitoring and evaluation of all field sampling efforts to minimize duplication of sampling in occupied habitats. Some researchers have refined sampling protocols to address these concerns; e.g., trammel netting of humpback chub in Desolation/Gray Canyons during spring also captured Colorado pikeminnow migrating to spawning sites; this activity was changed to sampling in fall when fewer Colorado pikeminnow are in the area.

10. What are management implications to enhance a particular population?

Response.—Responses by committee members to this question were varied as indicated by the following excerpted responses: (1) Population estimates conducted so far do not indicate a need to enact special management actions for specific populations. Ongoing efforts to control nonnatives, enhance flow regimes, and utilize propagation where needed will likely enhance many of the populations over the long-term and will be more productive than for example diverting resources to develop broodstock for a given population in response to a short-term trend; (2) In the Colorado River, flow recommendations have largely not been met, particularly during the drought years. Unfortunately, the populations may have to take their lumps because water has already been over committed; (3) It seems like management activities are ongoing for most populations. We would need to evaluate activities in all basins and determine if increased efforts would yield increased benefits; (4) Not sure, and am not sure exactly what is meant by the question.

11. Is current sampling design for Colorado pikeminnow in the San Juan River sufficient to evaluate success of the stocking program, and at what point should a mark/recapture population estimator be implemented?

Response.—Committee members agreed that mark-recapture population estimates on the San Juan River should not be implemented until sufficient numbers of Colorado pikeminnow are present from survival and reproduction from hatchery stocks. Some members recommended periodic surveys to monitor survival of hatchery fish with implementation of formal population estimates when hatchery fish are about 5 years of age.

5.0 DISCUSSION

Population estimates are being conducted for all wild populations of Colorado pikeminnow and humpback chub in the Colorado River Basin. Wild populations of Colorado pikeminnow occur in three regions, including the Green River, Upper Colorado River, and San Juan River subbasins. Numbers of wild fish in the San Juan River are currently too low for formal mark-recapture estimates, but augmentation with hatchery stocks is increasing numbers of fish and population estimates may be possible in about 2006. The precision of population estimates in the Green River and Upper Colorado River subbasins has been evaluated for 2000–2003 and since 1992, respectively. Increased crew sizes and sample occasions have generally not substantially and consistently improved precision. These evaluations have been confounded by low flows from ongoing drought in the Colorado River Basin. Hence, precision may vary with sample conditions, but guidelines of P-hat ≥ 0.10 and $CV \leq 0.15$ may be achievable in only some years, and current field sampling methods and data analyses protocols may be suitable for the most reliable and precise estimates possible.

Abundance estimates for all wild populations of humpback chub are also available, with the most recent estimate starting in Cataract Canyon in 2003. Population estimates for humpback chub are not as precise as for Colorado pikeminnow, apparently because boundaries of sampling areas are confined by whitewater rapids but fish movement occurs across these boundaries between sampling occasions. This movement causes losses of marked fish from sample areas and emigration of unmarked fish that may bias estimates. These effects have not been evaluated. Effort should continue at sampling more areas within Westwater Canyon and Desolation/Gray Canyons to better distribute marked fish and increased recapture rates. Like precision of Colorado pikeminnow estimates, precision of humpback chub estimates may be approaching maximum achievable levels which are below the guidelines of P-hat ≥ 0.10 and $CV \leq 0.15$. For the smaller humpback chub populations in Yampa Canyon and Cataract Canyon, traditional mark-recapture estimators may not be suitable because these populations are small and numbers of captures and recaptures are small. Researchers should continue to evaluate maximum likelihood estimators, such as implemented by Haines and Modde (2002) in Yampa Canyon, and/or multiple mark-recapture occasions within the same trip, as recommended for eddy complexes in Cataract Canyon (Utah Division of Wildlife Resources 2004). Researchers continue to use standard morphometric and meristic characters to distinguish the three species of *Gila* in the Colorado River Basin (Douglas et al. 1989, 1998) with no concerns expressed over difficulty of field determinations.

A robust sampling design, such as used by Bestgen et al. (2005) for Colorado pikeminnow, provides a comprehensive assessment of population size and precision, and integrates available abundance, survival, and recruitment data. However, suitable data may not be available for other populations. Nevertheless, past and ongoing monitoring programs may provide important information to better understand population dynamics. Jackson (2004a, 2004b) used ISMP catch data to compare with population estimates and provide inference on past population abundance from catch rate estimates. Innovative approaches that incorporate all available and suitable data will help to provide a better understanding of population dynamics. Nesler (2000) used ISMP mark and recapture data (not part of a rigorous population estimate sample design) to generate population estimates for Colorado pikeminnow and humpback chub that provided insight into population magnitude prior to formal population estimates.

The purpose of this report is to focus on development and evaluation of reliable and precise population estimates of Colorado pikeminnow and humpback chub. Two population estimates workshops have provided guidance to researchers and recommendations have been implemented to improve precision. For those controllable variables that affect field sampling and data analyses protocols, all reasonable refinements are being made, and ongoing evaluations may conclude that current estimates are the best possible. However, the over-riding effect of low flows from ongoing drought in the Colorado River Basin is uncontrolled, difficult to evaluate, and undoubtedly affecting field sampling. Researchers unanimously agree that low flows in the past few years have negatively affected fish capture efficiency, and generally reduced precision of abundance estimates. Correlating flow conditions and other environmental correlates to population estimates can be difficult, and investigators are encouraged to quantify influencing correlates, where possible. Combined with apparent declines in some populations of Colorado pikeminnow and humpback chub, the effects of drought and other environmental correlates are difficult to isolate. Even more difficult is the need to identify linkages between population demographics and environmental correlates. Evaluation of these linkages is needed but outside of the scope of this report.

6.0 RECOMMENDATIONS

The following are recommendations extracted from the two population estimates workshops to guide principal investigators in conducting of population estimates of Colorado pikeminnow and humpback chub in the Upper Colorado River Basin. The recommendations are not prioritized, but are numbered for ease of reference.

1. Continue to refine the current study design and field sampling techniques being used for each of the eight upper basin regions for population estimates of Colorado pikeminnow and humpback chub.
2. Continue to use mark-recapture methods with Program CAPTURE or Program MARK for analysis of data. Investigators should examine model selection from these programs carefully and provide a description and justification for the model and

population estimate used, especially if that model does not provide the best fit for the data.

3. Evaluate, quantify, and correlate effects of environmental factors on population estimates, especially effects of flow, temperature, and nonnative fish.
4. Use available ancillary fish data to aid in narrowing the range of causal mechanisms behind an observed trend; e.g., data from ISMP, larval drift, overwinter survival.
5. Perform additional analyses with existing and future data sets to improve and better understand precision of population estimates and to link population estimates with trend data for age-0 and juveniles.
6. Use robust analyses, such as done by Bestgen et al. (2005), where possible, to better understand population status and trends.
7. Capture more recruit-size fish for population estimates and reliable estimates of recruitment.
8. Use all means necessary and feasible to minimize stress on native fish, including use of aerators, salt baths, and holding fish less time.
9. Conduct population estimates for Colorado pikeminnow for 3 consecutive years with 2 years off to minimize sampling stress to fish. Conduct initial population estimates for humpback chub for 3 consecutive years with 2 years off, followed by 2 and 2.
10. Continue to conduct population estimates of the endangered fish for a sufficient period of time to understand population demography and dynamics and until precision and accuracy of population size and trajectory are reconciled with respect to environmental correlates, such as flow and nonnative native.
11. Continue ISMP monitoring, specifically Colorado pikeminnow age-0 backwater seining; electrofishing for juveniles; and larval sampling for Colorado pikeminnow and razorback sucker. Linking population estimates with trend data is valuable for assessing long-term population trends.
12. Implement mark-recapture population estimates for Colorado pikeminnow on the San Juan River when deemed appropriate under the approved stocking plan (e.g., when hatchery fish have been at large for at least 5 years).
13. Improve precision of estimates whenever possible through adaptive management by refining sampling design and techniques and through improved analytical methods.

14. Seek out and implement other analytical methods that help to better understand population dynamics, especially size-specific mortality, such as Ricker or Beverton and Holt recruitment curves and models.
15. Continue to seek new ways to incorporate mark-recapture information from fish captured and recaptured during nonnative fish removal efforts or other projects.

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