Population Estimates for Humpback Chub (*Gila cypha*)
in Desolation and Gray Canyons,
Green River, Utah 2001-2015

Julie Howard
And
John Caldwell
Utah Division of Wildlife Resources
1165 S. Hwy 191 Suite 4
Moab, UT 84532

Final Report
January 2018

Upper Colorado River Endangered
Fish Recovery Program
Project Number 129

U.S. Bureau of Reclamation
Agreement Number R14AP00007

ACKNOWLEDGEMENT AND DISCLAIMER

This study was funded by the Upper Colorado River Endangered Fish Recovery Program. The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, the Colorado River Energy Distributors Association, and the National Park Service.

We would like to thank Utah Division of Wildlife Resources permanent and seasonal employees who assisted with the field work as well as Dr. Mary Conner of the Utah State University for Program MARK consultations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF KEY WORDS

Humpback Chub, *Gila cypha*, Desolation Canyon, Gray Canyon, Green River, population estimate, survival estimate

EXECUTIVE SUMMARY

Multi-pass, mark-recapture sampling was conducted in the fall of 2014 and 2015 (September-October) within Desolation and Gray Canyons (Deso/Gray) of the Green River in Utah to estimate adult (≥200 mm) humpback chub (*Gila cypha*) abundance. Three sampling passes were completed each year at six sites, encompassing approximately 10% of available fall habitat. The primary sampling method utilized multi-filament trammel nets. Additional sampling methods included baited hoop nets and submersible PIT antennas.

All previous and current population estimates were regenerated using model averaging of closed population estimation in Program MARK, which allowed the weighted incorporation of multiple models into the estimate. Humpback chub densities were calculated for each sampling site. The average site density was used to extrapolate a canyon-wide estimate. Sites where fewer than 15 individuals were captured and where fewer than two individuals were recaptured were excluded from the extrapolated estimate. These criteria were implemented in an attempt to limit the degree of uncertainty inherent in estimates generated using low sample size and few recaptures. Extrapolated estimates generated with the included sites using model averaging generally had a smaller 95% confidence interval range and a lower coefficient of variation than previous estimates generated using Program CAPTURE.

There were no statistically significant population trends in either the canyon-wide extrapolated estimates or in the site-specific estimates. The estimated 2014 population of humpback chub in Deso/Gray was 1,863 (924-2,802). This estimate was based on samples collected at approximately 8% of the available habitat. The estimated 2015 population of humpback chub in Deso/Gray was 1,672 (756-2,589). This estimate was based on samples collected at approximately 5% of the available habitat.

Adult humpback chub survival estimates for 2001 – 2014 were generated in Program MARK with the Cormac-Jolly-Seber model using all humpback chub encountered from 1985 to 2015. Survival estimates fluctuated over time but there was no statistically significant trend. The mean survival estimate for adult humpback chub from 2001-2014 was 60.7±7.9% which is lower than

survival of adult humpback chub in other upper basin populations (Black Rocks and Westwater) where survival estimates range between 64-71% (Francis et al. 2016, Hines et al. 2016). The presence of invasive smallmouth bass and walleye, which do not occur in large numbers in either Westwater or Black Rocks, may contribute to the lower survival of humpback chub within Deso/Gray canyons.

Documenting recruitment in Deso/Gray is difficult because juvenile humpback chub (100-200 mm) continue to elude our sampling efforts. A single juvenile chub (120 mm) was captured in 2014 and none were encountered in 2015. Reproduction, however, was documented by the capture of seven young-of-year humpback chub (70-90 mm) in 2015 using baited hoop nets. The relative proportion of first year adults (200-220 mm) to all adults captured, an alternative to a juvenile population estimate, was compared across years when sampling occurred in the fall and illustrated a statistically non-significant declining trend (r^2=0.382, p=0.139).

Although we found no statistically significant trends in population parameters, the majority of abundance metrics all peak in the late 1990's or early 2000's and decline through 2015. The general decline in these metrics and comparatively low adult survival rates are biologically concerning.

The humpback chub population in Deso/Gray is unique with low densities that span a large area, making it difficult to describe and monitor using the methods employed in the other upper basin populations. The addition of hoop nets to increase catch rates of adult, young-of-year and juvenile chubs and the addition of the submersible PIT antennas to increase recapture rates have increased the efficacy of population and survival estimates without a substantial increase in effort or funding. Other suggestions as to how to improve the accuracy and reliability of the extrapolated population estimates include a more detailed characterization and evaluation of the habitat and sites occupied by humpback chub within the reach and increasing the total number of sites sampled from less than 10% to approximately 20% of the occupied habitat.

INTRODUCTION

The humpback chub, *Gila cypha*, is a large-bodied cyprinid endemic to the seasonally warm and turbid waters of the Colorado River Basin. These fish are well adapted to the historic hydrograph of the basin exemplified by extreme fluctuations both within and among years. These fish are primarily found in canyon-bound reaches of the river characterized by swift deep water and rocky substrates (UDWR 1995, Valdez 1990). Humpback chub are believed to presently inhabit approximately 68% of their original range (USFWS 2002). Factors that may have contributed to the decline of this species include: stream alteration (dams, irrigation, dewatering, and channelization), habitat modification, competition with and predation by nonnative fish species, parasitism, hybridization with other *Gila* spp., and pollutants (USFWS 2002).

The humpback chub is currently protected under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 *et. seq*). In 1990, a recovery plan for humpback chub was completed (USFWS 1990); in 2002, updated recovery goals were approved to supplement the original recovery plan (USFWS 2002). Objective and measurable recovery criteria were identified to down-list and de-list the humpback chub. To down-list humpback chub, the following criteria must be met for a five-year period: 1) the trend in adult (age-4+; $\geq$ 200 mm TL) point estimates for each of the six populations does not decline significantly; 2) mean estimated recruitment of age-3 (150-199 mm TL) naturally produced fish equals or exceeds mean annual adult mortality for each of the six populations; 3) two of the genetically and demographically viable, self-sustaining core populations are maintained, such that each point estimate for each core population exceeds 2,100 adults; 4) certain site-specific management tasks to minimize or remove threats have been identified, developed, and implemented. De-listing may occur, if over a three-year period beyond down-listing: (see 1 and 2 above) three genetically and demographically viable, self-sustaining core populations are maintained, such that each point estimate for each core population exceeds 2,100 adults; certain site-specific management tasks to minimize or remove threats have been identified, developed, and attained.

According to the recovery plan, there are six self-sustaining humpback chub populations, one within the lower basin in the Grand Canyon on the Colorado River, and five within the upper basin in the Colorado River and Green River sub-basin. In the upper basin, the population of humpback chub in Desolation and Gray Canyons (Deso-Gray) on the Green River is considered the third largest, following the Black Rocks and Westwater populations on the Colorado River. Due to its potential designation as a third core population, the Deso-Gray humpback chub population will likely play a significant role in the delisting of this species, as stated in the delisting recovery criteria.

Humpback chub were first reported in Deso-Gray in 1975 (Holden and Stalnaker 1975) and have been monitored regularly since the early to mid 1980's. In 1985 the Utah Division of Wildlife Resources (UDWR) became responsible for monitoring this population. Beginning in 2001, mark-recapture population estimates were generated using Program CAPTURE. The initial strategy for generating these estimates was to combine all captures and recaptures throughout the reach into one estimate. However, upon further study it became apparent that humpback chub within the canyon showed 99% site fidelity, in violation of the basic closed population estimate assumption of movement throughout the study reach (Badame 2012). The methods for generating a canyon-wide population estimate were altered in 2006. Estimates were calculated for each site and an average site estimate was used to extrapolate an estimate for the entire Deso-Gray reach (Badame 2012).

Currently, in order to down-list the species all existing populations must have a stable population trend (down-listing criteria #1). The estimation of age-3 sub-adults, a measure of recruitment and population health (down-listing criteria #2) has been difficult to generate for the Deso-Gray reach, due to few captures of individuals between 150-199 mm total lengths. As a result, no population estimates have been generated for sub-adults in Deso-Gray. A surrogate metric for estimating recruitment was developed by Jackson and Hudson (2005) where the relative proportion of first-year adults among all adult chub captured was calculated for each sampling year. Survival is another metric commonly used to monitor population trends, but has yet to be utilized to describe the humpback chub population in Deso-Gray. Identifying reliable trends in survival estimates in addition to population estimates may be beneficial.

The objectives of this report were as follows: 1) calculate a population estimate for 2014 and 2015, 2) recalculate 2001-2003 canyon-wide population estimates using the site estimate extrapolation method developed by Badame (2012), 3) improve estimate viability by recalculating all estimates (2001-2011) using Program MARK model averaging, 4) generate survival estimates for the Deso-Gray reach, 5) evaluate efficacy of the current monitoring strategy and its effectiveness of generating a viable population estimate and 6) make recommendations as to how to improve monitoring of the humpback chub population in Desolation and Gray Canyons.

METHODS

Study Area

The Desolation and Gray Canyon reach of the Green River is located approximately 32 river miles downstream of the town of Ouray, UT, south of the Uinta Basin. It begins at Sand Wash (RM 216) and ends 12 river miles upstream of the town of Green River, UT (RM 120, Figure 1). The river between Sand Wash and Jack Creek Canyon (RM 190) is characterized by low gradient, slow water. Downstream of Jack Creek Canyon the river enters Desolation Canyon and cuts through the Wasatch and Green River formations, resulting in steeper gradient, swifter currents and a deep, confined canyon. The end of Desolation Canyon and the start of Gray Canyon occurs immediately below Three Fords Rapid (RM 156). Gray Canyon is lower in gradient and not as deep or confined as Desolation Canyon. It winds through the Mesa Verde Group and ends just downstream of Swasey's Rapid (RM 132). During the first few years of sampling for this project, 2001 to 2007, a total of 12 sites were sampled throughout both canyons located at RM's 189, 185, 182, 178.5, 174.4, 166.8, 160.4, 157.4, 154.4, 150.8, 148, and 145.7 (Figure 1). Included in the sites were four long-term trend sites that were sampled for a previous project since 1985 (ISMP). The length of a site was typically limited by the presence of rapids both upstream and downstream; median site length was approximately 0.5 miles ranging between 0.2 and 1.6 miles. Due to budget constraints, the number of sites sampled was reduced by 50% in 2010 (n=6), a schedule that has continued through 2015. Long term sites continued to be sampled. In Addition, two sites are selected from the other designated sites. Sampling previous to 2003 was conducted during summer. However, to reduce stress by minimizing fish capture and handling at water temperatures above 20°C (Hunt et al. 2012) sampling was shifted to September and October.

Fish Sampling and River Conditions

In 2014, three sampling passes were completed through Deso/Gray from September 1–8, September 16–23, and October 1–8. Mean daily flows during sampling ranged from 2,940-6,170 cfs (USGS gage #09315000, Green River at Green River gauge). Average water temperatures during each pass were 21.3^{o} C, 21.6^{o} C and 15.5 ^{o} C respectively. Total sampling effort included 1,276 trammel net hours, 346 hoop net hours, and 9.3 hours of electrofishing over three passes (Table 1). During the second pass, submersible PIT tag antennas were also deployed for a total of 471 hours.

In 2015, three sampling passes were completed through Deso/Gray on September 1-8, September 16–23, and October 1–8. Mean daily flows during sampling ranged from 2,000-3,600 cfs (USGS gauge #09315000, Green River at Green River). Average water temperatures during each pass were 19.6^{o} C, 16.7^{o} C and 14.8 ^{o} C respectively. Total sampling effort included 1,596 trammel net hours, 1,825 hoop net hours and 1,567 antenna set hours over three passes (Table 1). Electrofishing in Desolation and Gray canyons has had limited success and was discontinued in 2015 to allow for the reallocation of effort to hoop net and submersible PIT antenna sampling.

During each sampling trip of 2014 and 2015 one night was spent at each of the six sampling sites. In 2014 trammel nets, motorized cataraft electrofishing along shorelines, and baited hoop nets were used to sample fish. Additionally, submersible PIT tag antennas were used on one sampling trip. In 2015, trammel nets were used and because of success in 2014, hoop netting effort was greatly increased. Use of submersible PIT tag antennas was implemented on all three sampling trips because it increased the number of encounters. To accommodate the large increase in hoop netting and PIT antenna effort, electrofishing was not used in 2015 (budget constraints limit the number of personnel per trip and therefore number of boats; the electrofishing boat was exchanged for a boat with the purpose of carrying and deploying hoop nets and antennas). Hoop net structure (1/4” netting, 24”diameter, 4’length) and baiting (Purina

Aquamax Sport Fish) were modeled after sampling in the Grand Canyon lower basin (Trammell et al 2012). Electrofishing was conducted in the afternoon prior to the setting of nets. Six to eight trammel nets (12"outer mesh and 1" inner mesh) were set at each sampling location, depending on availability of habitat at each site. Trammel nets were set in the early afternoon and were checked every two hours until midnight and were set again at 5:00 AM and checked at regular intervals until midday. Hoop nets and antenna were set in the afternoon when trammel nets were being set and were pulled the following morning. Antenna data were downloaded after retrieval and before moving to the next camp.

All endangered fishes captured in hoop or trammel nets were returned to camp, processed and released alive. All endangered fish captured during electrofishing were processed immediately on the boat. Species, total length (mm), weight (g), and PIT tag number were recorded for identifiable chub, Colorado pike minnow and razorback sucker. Dorsal and anal fin ray counts were recorded for all chub. Chub species were identified using a suite of qualitative characters (i.e., degree of frontal depression, presence of scales on nuchal hump, angle of the anal fin relative to caudal peduncle, etc; Douglas et al. 1989, 1998). Small juveniles and hybridized chubs were identified to genus (not included in estimates). Endangered fishes with no detectable PIT tag, received a tag and the number was recorded. Fin clips for genetic analysis were collected from all untagged humpback chub greater than 200 mm and all untagged Colorado pikeminnow greater than 150 mm; samples were sent to Wade Wilson at the Southwestern Native Aquatic Resource and Recovery Center. Invasive fishes of interest (walleye, smallmouth, white sucker, etc) were weighed, measured and euthanized.

Data Analysis

All statistical tests were performed using SigmaStat 3.5, (SPSS Inc). Population statistics were derived using program MARK.

Catch Rates

Trammel net and hoop net catch rates were calculated as the number of fish captured per hour. Trammel net catch per unit effort (CPUE), of all humpback chub were determined for each pass for all years of the study. Hoop net catch rates were not comparable across years because hoop net sampling from 2002 to 2007 was inconsistent and was combined with minnow trapping. Linear regression analysis was used to test for trends in mean CPUE for sites sampled multiple years. The same analysis was used to compare mean long-term trend site CPUE over years. Catch rates by year and site were compared using an ANOVA with a Holm Sidak posthoc test. When necessary, data were natural log transformed prior to analysis to satisfy normality requirements.

Population Estimates

High site fidelity among humpback chub has been well documented in this system. Individuals occupy distinct, small home ranges during the fall that are typically bound by rapids on the upstream end and by a pool/eddy complex on the downstream end (Badame 2008; Jackson and Hudson 2005; Hudson and Jackson 2003; Valdez 1990). Past radio telemetry studies confirm that most home ranges during the fall average 0.9 to 0.5 river miles (Kaeding et al. 1990; Valdez 1990). To account for high site fidelity, Badame (2008, 2012) implemented a density based canyon-wide estimate. Site-specific estimates were calculated and an average site density was used as a population estimate for the Deso-Gray reach. Site specific estimates were computed using only fish captured, marked and recaptured within each site. The canyon-wide estimate was calculated by multiplying the average site density by 63, an estimated number of available sites of appropriate area and habitat quality for the fall range of humpback chub within the canyons (Badame 2012).

Mark-recapture population estimates were calculated for adult humpback chub at each site sampled using closed population Huggins p and c models in Program MARK. Model averaging was utilized when the AIC weights were less than 0.90; site population estimates were completed using model averaging of M_o (constant p), M_t (time varying p), and M_b (behavioral response) models when appropriate. Only chubs that had been marked during a previous pass and recaptured within the same year were included in the estimate. Site estimates were not computed if fewer than 15 individuals were captured and there were less than two recaptures. No population estimates were completed for juvenile humpback chub (150-199 mm) as very few individuals were encountered.

Survival

Adult humpback chub survival was determined using Cormac-Jolly-Seber in Program MARK and included all captures from all sites. Sampling prior to 2001(1985-2000) was irregular and infrequent; therefore, survival was calculated from 2001-2015 when sampling occurred regularly and effort increased. Fish marked prior to 2001 were included in these calculations if captured, however. In an attempt to maximize available encounters, any individuals encountered prior to 2001 were recorded as being present in 2001 and if those individuals were recaptured after 2001 (2002-2015) they were included in the estimates. The covariate of site was incorporated into the survival estimates to determine if survival varied among sites.

Recruitment

As an alternative to a juvenile population estimate, the relative proportion of first year adults (200-220 mm) to all adults captured was calculated and compared across years of the study as a representation of recruitment, as suggested by Jackson and Hudson (2005). The first-year adult size range is based on growth rate information from Westwater Canyon (Hudson and Jackson 2003, Chart and Lentch 1999), Desolation-Gray (Jackson and Hudson 2005), and Cataract Canyon (Valdez 1990). This metric was compared among all years when sampling occurred in fall with the exception of 2001-2002 because sampling occurred during summer. It is important to note that the first-year adult size range is an estimate and could include outlier younger or older individuals.

RESULTS and DISCUSSION

Sampling Summary

In 2014 electrofishing, trammel and hoop netting resulted in 110 adult humpback chub encounters (86 individuals) and one juvenile *Gila*. Antenna sets resulted in 14 humpback chub re-sights (11 individuals) where two chub were not detected by other sampling methods (88 adult individuals for all methods; Table 2).

In 2015 trammel and hoop net sampling resulted in 95 adult humpback chub encounters (63 individuals) and seven juvenile *Gila*. Antennas resulted in 30 humpback chub re-sights (20 individuals) where four chub were not detected by other sampling methods (67 adult individuals for all methods; Table 2).

Catch Rates

In 2014, mean trammel net CPUE of long-term trend sites was 0.08 fish/net hour and ranged from 0.02-0.14 fish/net hour. In 2015, mean trammel net CPUE for the long-term trend sites was 0.06 fish/net hour and ranged from 0.01 to 0.11 fish/net hour. Catch rates from 2001 to 2015 were not significantly different among long-term trend sites (F=0.857, p=0.466). Although a linear regression did not detect a significant trend, overall annual catch rates appear to have declined since 1997 when values peaked (0.23 fish/net hour; Fig. 2). During years when sampling was more intensive (2001 -2015), trammel net catch rates for long term trend sites were significantly higher in 2001-2002 than in later years (F=3.016, p=0.005). However, beginning in 2003, sampling was shifted to the fall. Comparisons between 2001-2002 catch rates and later years should be made with caution because seasonal variation in fish behavior and catchability may affect catch rates. No long-term sites exhibited significant declining trends in catch rate (p>0.05) from 2003-2015.

Mean CPUE of all sites in 2014 for humpback chub captured with trammel nets was 0.08 fish/net hour and ranged from 0.02 to 0.14. Mean CPUE of all sites in 2015 for humpback chub captured with trammel nets was 0.06 fish/net hour and ranged from 0.01 to 0.11. The addition of the non-long-term monitoring sites to the data did not substantially alter the means and ranges calculated from only the long-term monitoring sites. Since 2003, trammel net CPUE for adult humpback chub in Desolation and Gray Canyons shows no significant trend (r^2=0.078, p=0.544) and ranged between 0.04-0.08 fish/net hour (Fig. 3).

Population Estimates

Population estimates ($\hat{N}$) were generated for all years using model averaging (Appendix 1). Sites were excluded if too few individuals were encountered (<15) and less than two recaptures were recorded (Tables 2 and 3). These criteria were used to minimize the degree of uncertainty inherent in estimates generated using low sample size and low number of recaptures. Site specific estimates from the first three years (2001-2003) were excluded from trend analysis because of very high standard errors and very wide confidence intervals associated with extrapolated estimates (Table 3). The unreliability of the estimates from the first three years was most likely a function of low probability of capture with many fish initially captured but very few recaptured (Table 2). Low recapture rates created similar issues in the 2010 estimates and in 2011 no estimate was possible because of lack of recaptures. By evaluating data from 2001 to 2003 using model averaging and the extrapolation method, $\hat{N}$ and the 95% confidence intervals (CI) changed dramatically and both capture probability ($\hat{p}$) and the coefficient of variation (CV) increased; the estimates completed by Jackson and Hudson (2005) were canyon-wide and did not incorporate the model averaging technique. The site inclusion parameters for the new estimates limited the number of sites for the analysis from one to five of the 12 sampled sites (Tables 3 and 4).

The average site $\hat{N}$ ranged from 29 to 45 adult humpback chub. The number of sites that met the inclusion criteria each year ranged from three to five which represents between 5-8% of available habitat. Canyon-wide population estimates ranged from 1,672 to 2,856 adult humpback chub (2006-2015) with 95% CI of 756-4,162 (Table 3). Taking into account both CV and $\hat{p}$ for each annual estimate (Figure 5), four of the seven sampling years used in the trend analysis (2006, 2007, 2014, 2015) have higher precision and are more likely to represent the humpback chub population in Desolation and Gray Canyons. These years had capture-recapture rates greater than 20%.

The site specific estimates showed no significant trends over time for the long-term sites at Cedar Ridge, Log Cabin, Cow Swim and Coal Creek ($p>0.05$; Figure 4). Site estimates from 2001-2003 were excluded from analyses due to unreliability. Although there appears to be a declining trend at Coal Creek, it is important to note that 25 adult humpback chub were removed from the site in the fall of 2009 to develop hatchery brood stock. The removal of these fish may have contributed to the apparent decline in estimates at Coal Creek.

Survival

Survival estimates for all years of the study (2001-2015) ranged from 0.29-0.93 and did not show a clear trend (Figure 6). However, the years with a probability of recapture of at least 20% (2006, 2007, and 2014) yielded estimates with less variation. Due to the limited number of sampling events at each site, the model was unable to determine the effect of site (covariate) on survival estimates. The mean survival estimate for adult humpback chub in all years is 60.7±7.9% and the mean of the three years with the best estimates is 52.7±4.4% which is lower than survival of adult humpback chub in other upper basin populations (Black Rocks and Westwater) where survival ranges between 64-71% (Francis et al. 2016, Hines et al. 2016). The presence of invasive smallmouth bass *Micropterus dolomeiu* and, more recently, walleye *Sander vitreus* may contribute to the lower survival.

The submersible PIT antennas influenced the estimates by lowering the CV and increasing the recapture probability, mimicking higher recapture probabilities seen in years when effort (# sampling nights) was double (Figure 7). The submersible antennas appear to be a relatively low cost and low effort way of increasing the efficacy of population and survival estimates.

Recruitment

Reproduction was documented by the capture of seven young-of-year chub (70-90 mm) during sampling in 2015 and one juvenile (120 mm) in 2014 using baited hoop nets. The presence of juvenile chub (100-200 mm) continues to be difficult to document in Deso/Gray canyons with no individuals encountered during the 2015 sampling. The proportion of first year adults among adult humpback chub fluctuated from 4% in 2014 to 7.9% in 2015. There is a non-significant decline in the proportion of first year adults (200-220 mm) since sampling moved to the fall in 2003 (r^2=0.382, p=0.139; Figure 8). These data include an outlier (2003) but the proportion of first-year adults is very similar from 2006-2015.

CONCLUSIONS

The Deso/Gray humpback chub population is unique among upper basin populations in that it is hard to characterize using the same techniques employed in other population centers. The population spans 20 to 30 times the river length of the largest upper basin Colorado River populations (Westwater and Black Rocks) and chub are found in much lower densities (Francis et al. 2016, Hines et al. 2016). Both the large area and low fish densities make monitoring and describing this population difficult. Statistically significant declines have not been evident in catch rates at long-term trend sites, survival, recruitment, long-term trend site population estimates or canyon-wide population estimates. However, most metrics of abundance, including numbers of fish, catch-per-unit-effort, proportion of first year adults, and abundance estimates calculated by two techniques all peak in the late 1990's or early 2000's and decline through 2015; in combination with lower estimated survival rates than those of other upper basin populations, there is not support for the notion of a stable population. The increased occurrence of walleye and the downstream expansion of smallmouth distribution (Jones et al. 2015) warrant further investigations into their interactions with the humpback chub population in Deso/Gray.

The nature of the Deso/Gray population has led to two additional sampling methods that have provided useful capture and recapture data and include the use of baited hoop nets to capture young-of-year and juvenile chubs and the use of submersible PIT antennas to increase recapture rates. These additional methods have improved catch rates, site specific population estimates, and survival estimates. Maintaining data collection at long-term sites illustrates trends in population site estimates, catch rates and survival estimates (potentially) at different locations in Deso/Gray. Site specific data are an important monitoring tool for illustrating smaller scale trends throughout the canyon. For the duration of this study, no significant trends were detected at long-term trend sites. However, the ability to monitor for spatial changes in CPUE, survival or population estimates of these long-term trend data may be important in the future. Increasing the number of sites regularly monitored would bolster efforts to describe long-term population trends for the entire reach, while also potentially illuminating any smaller scale population trends. Additional long-term sites could be selected based on historical sampling frequency and location relative to current sites.

The extrapolated population estimate technique (based on density) may be an appropriate way to generate a canyon-wide estimate in Deso/Gray in lieu of dramatically increasing funding and effort. To improve the accuracy and reliability of the extrapolated population estimates, a detailed characterization and evaluation of available habitat and sites occupied by humpback chub in the canyons is necessary. The extrapolation estimate has been based on historical collections and field observations of potential habitat sites; these sites may or may not contain humpback chub. Documentation of sites currently occupied by humpback chub is necessary for a representative canyon-wide estimate. Extrapolated population estimate reliability and precision will also improve by increasing the number of sites sampled to approximately 20% of the representative occupied habitat within the reach; current canyon-wide estimates are extrapolated from 5-10% of available sites.

Using Program MARK and model averaging for the population estimates resulted in estimates with smaller 95% CI range and lower CV when the number of sites incorporated was greater than one. The site inclusion criteria were useful in minimizing the inclusion of low quality site estimates and served to improve the extrapolated population estimate reliability.

RECOMMENDATIONS

1. Trammel net sampling should continue as the primary sampling tool for adult humpbacks.
2. Increase submersible PIT antenna effort to increase number of encounters with tagged fish.
3. Target YOY and juvenile *Gila* and augment adult captures by using baited hoop nets. Hoop nets are effective at capturing small fish in Deso/Gray and more logistically compatible with trammel nets and PIT antennas than electrofishing. As this study evolves, continue to improve these methods and explore additional sampling techniques that may be less stressful to fish than trammel nets and increase captures or encounters of juvenile and adult fish.
4. Continue to use Program MARK's model averaging to estimate populations, as it is the most inclusive method available and is recommended for populations where captures and recapture rates are low.
5. Continue to work with UCREFRP Biology Committee, Utah State University and other interested parties to improve population abundance, survival and recruitment estimates and trend analyses in Deso-Gray in order to better understand current condition and predict future viability. Including but not limited to:
    a. Consider increasing the number of long-term sites from four to six in an attempt to increase monitoring consistency and estimate precision. Consider selecting one additional site within each canyon (Desolation and Gray).

b. Improve reach-wide extrapolated population estimates by better characterizing available habitat (i.e. documenting chub presence from existing data, describing site habitat and/or mapping site locations).

c. Upon completion of a reach-wide characterization of available habitat and documentation of chub presence, increase the number of sites sampled to approximately 20% of the occupied habitat within the reach to improve extrapolated population estimates.

6. Initiate a new investigation into the interactions of nonnative fish with the Deso/Gray humpback chub population.

LITERATURE CITED

Badame P.V. 2008. Population estimates for humpback chub (Gila cypha) in Cataract Canyon, Colorado River, Utah, 2003–2005. Final Report. Utah Division of Wildlife Resources.

Badame, P.V. 2012. Population estimates for humpback chub (*Gila cypha*) in Desolation and Gray Canyons, Green River, Utah 2006-2007. Final report of Utah Division of Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program. Denver, CO.

Chart T.E. and Lentch L.1999. Flow effects on humpback chub (Gila cypha) in Westwater Canyon. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 99-36.

Douglas M.E., W.L. Minckley, and H.M. Tyus. 1989. Qualitative characters, identification of Colorado River chubs (Cyprinidae; Genus Gila) and the “art of seeing well”. Copeia. 3: 653-662.

Douglas M.E., R.R. Miller, and W.L. Minckley. 1998. Multivariate discrimination of Colorado plateau Gila spp.: the “art of seeing well” revisited. Transactions of American Fisheries Society 127:163-173.

Francis, T. A., K. R. Bestgen, G. C. White. 2016. Population status of humpback chub, Gila cypha, and catch indices and population structure of sympatric roundtail chub, Gila robusta, in Black Rocks, Colorado River, Colorado, 1998-2012. Larval Fish Laboratory Contribution 199. Final Report from the U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program, Lakewood, Colorado.

Hines, B. A., K. R. Bestgen, G. C. White. 2016. Abundance estimates for humpback chub (Gila cypha) and roundtail chub (Gila robusta) in Westwater Canyon, Colorado River, Utah 2011–2012. Final Report, Project 132. Upper Colorado River Endangered Fish Recovery Program, Lakewood, Colorado. Larval Fish Laboratory Contribution 198.

Holden P.B. and C.B. Stalnaker. 1975. Distribution and abundance of mainstream fishes of the middle and upper Colorado River basin, 1967-1973. Transactions of the American Fisheries Society 104(2):217-231.

Hudson J. M. and J. A. Jackson. 2003. Population estimates for humpback chub (Gila cypha) and roundtail chub (Gila robusta) in Westwater Canyon, Colorado River, Utah, 1998–2000. Utah Division of Wildlife Resources. 2003.

Hunt, T. A. Hunt, D. L. Ward, C. R. Propper, A. C. Gibb. 2012. Effects of capture by trammel net on Colorado River native fishes. Journal of Fish and Wildlife Management. June 2012, Vol. 3, No. 1, pp. 133-141

Jackson, J.A., and J.M. Hudson. 2005. Population Estimate for Humpback Chub (Gila cypha) in Desolation and Gray Canyons, Green River, Utah 2001-2003. Final Report of Utah Division of

Wildlife Resources to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Jones, M.T., B. Haines, C. Smith, J. Howard, C. Michaud. 2015. Nonnative fish control in the Green River. Annual Report, Project 123a. Upper Colorado River Endangered Fish Recovery Program, Lakewood, Colorado.

Kaeding, L.R., B.D. Burdick, P.A. Schrader, and C.W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the Upper Colorado River. Transactions of the American Fisheries Society 119:135-144.

Trammell, M., B. Healy, E. Omana Smith, and P. Sponholtz. 2012. Humpback chub translocation to Havasu Creek, Grand Canyon National Park: Implementation and monitoring plan. Natural Resource Report NPS/GRCA/NRR—2012/586. National Park Service, Fort Collins, Colorado.

UDWR. 1995. Gila spp. investigations Green and Colorado Rivers, Desolation and Gray Canyons: 1985–1986; 1989–1992. Salt Lake City, UT.

USFWS. 1990. Humpback chub recovery plan, 2nd revision. Report of Colorado River Fishes Recovery Team to U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS. 2002. Humpback chub (Gila cypha) recovery goals: an amendment and supplement to the humpback chub recovery plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region 6, Denver, Colorado.

Valdez R.A. 1990. The endangered fish of Cataract Canyon. Final Report of Bio/West, Inc., Logan, Utah, to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Table 1. Effort for each gear type, total number of captures and/or encounters of identified humpback chub (HBC), and unidentified juvenile chub (*Gila sp.*) in Desolation and Gray Canyons, 2001-2015. All captures and encounters from all sampled sites are included.

			Trammel nets		Submersible Antennas		Hoop net/minnow trap		Electofishing	
Year	**Month (passes)**	**# Sites sampled**	**Hours**	**HBC**	**Hours**	**HBC**	**Hours**	**HBC (*Gila sp.*)**	**Hours**	**HBC**
2001	6-7 (3)	12	2,803	214	-	-	-	-	8	3
2002	6-7 (3)	12	2,008	239	-	-	1,440	6 (1)	22.5	38
2003	9-10 (3)	12	3,042	236	-	-	1,946	4 (1)	11	1
2006	9-10 (3)	12	3,289	119	-	-	729	9	16.4	12
2007	9-10 (3)	12	2,727	130	-	-	988	6	-	-
2010	9-10 (3)	5	1,163	68	-	-	-	-	7	5
2011	9-10 (3)	6	1,013	55	-	-	-	-	6.4	8
2014	9-10 (3)	6	1,276	99	471	14	346	15 (1)	9.3	6
2015	9-10 (3)	6	1,596	85	1,567	29	1,825*	10 (7)	-	-

*Hoop net effort from trip 1 not included in total due to incorrect setup.

Table 2. Summary of individual humpback chub captured from 2001-2015 from all methods for each sampling location upstream to downstream. The number of recaptured individuals is shown for each sampling year. Several individuals were captured and/or encountered multiple times in a year.

	2001	2002	2003	2006	2007	2010	2011	2014	2015	**Grand Total**
Gold Hole	14	35	2							**51**
Jack Creek				6	5					**11**
Cedar	16	23	14	8	11	12	19	18	15	**136**
Dripping Springs	5	16	26	14	1					**70**
Wildhorse				12	2			13		**27**
Log Cabin	25	44	47	9	9	15	10	10	8	**177**
Chandler	22	48	41	22	13	11	8		8	**173**
Cow Swim	27	25	22	14	5	8	3	17	15	**136**
Florence	18	16	14	18	5					**71**
Below 3 Fords	27	25	14	10	6					**82**
Range Creek				7	11		8	14		**40**
Curry	20	6	26	20	9		4		8	**85**
Coal Creek	22	25	38	25	20	9		15	13	**167**
Grand Total	**196**	**263**	**244**	**165**	**97**	**55**	**52**	**87**	**67**	**1226**
# recaptures	3	5	16	26	16	6	4	12	19	**107**

Table 3. Summary of regenerated population estimates ($\hat{N}$) for Desolation/Gray Canyons 2001–2015. Includes the average site $\hat{N}$, the canyon-wide extrapolated $\hat{N}$, 95% confidence interval (C.I.), coefficient of variation (C.V.), probability of capture ($\hat{p}$), the number of sampling sites included in the estimate, and the percent of available habitat those sites represent. 2011 was not included because of an insufficient amount of recaptures at sites.

Year	Average Site $\hat{N}$ (SE)	Extrapolated $\hat{N}$	95% CI	C.V.	$\hat{p}$	# sites	% habitat
2015	32 (16)	1,672	756-2,589	0.30	0.229	3	5
2014	30 (15)	1,863	924-2,802	0.26	0.264	5	8
2010	40 (28)	2,520	445-4,594	0.42	0.123	3	5
2007	29 (14)	1,794	788-2,801	0.29	0.245	4	6
2006	45 (21)	2,856	1,550-4,162	0.23	0.181	5	8
2003	110 (78)	6,935*	1,742-12,127	0.38	0.124	5	8
2002	268 (253)	16,931*	0-34,455	0.53	0.068	4	6
2001	49 (49)	3,087*	0-147	0.99	0.434	1	2

*Estimates are unreliable and of low precision due to low probability of capture-recapture with many fish initially captured but very few recaptured (See Table 2). Estimates should not be used when defining trends in the Deso/Gray population.

Table 4. Summary of previous population estimates ($\hat{N}$) where model averaging was not used. In 2001-2003 estimates were calculated canyon-wide instead of using the extrapolation method implemented for latter years of the study. Column headings include the 95% confidence interval (C.I.), coefficient of variation (C.V.), and probability of capture ($\hat{p}$).

Year	$\hat{N}$	95% CI	C.V.	$\hat{p}$	# sites
2011*	55	-	-	-	-
2010	1,625	1,023–5,465		0.17	4
2007	1,108	1,071–4,914		0.19	12
2006	2,578	1,151–9,736		0.14	12
2003	937	636–1,520	0.21	0.08	12
2002	2,612	1,477–8,509	0.36	0.05	12
2001	1,254	733–2,697	0.31	0.05	12

*Number of individuals encountered (estimate was not calculated due to insufficient recaptures)

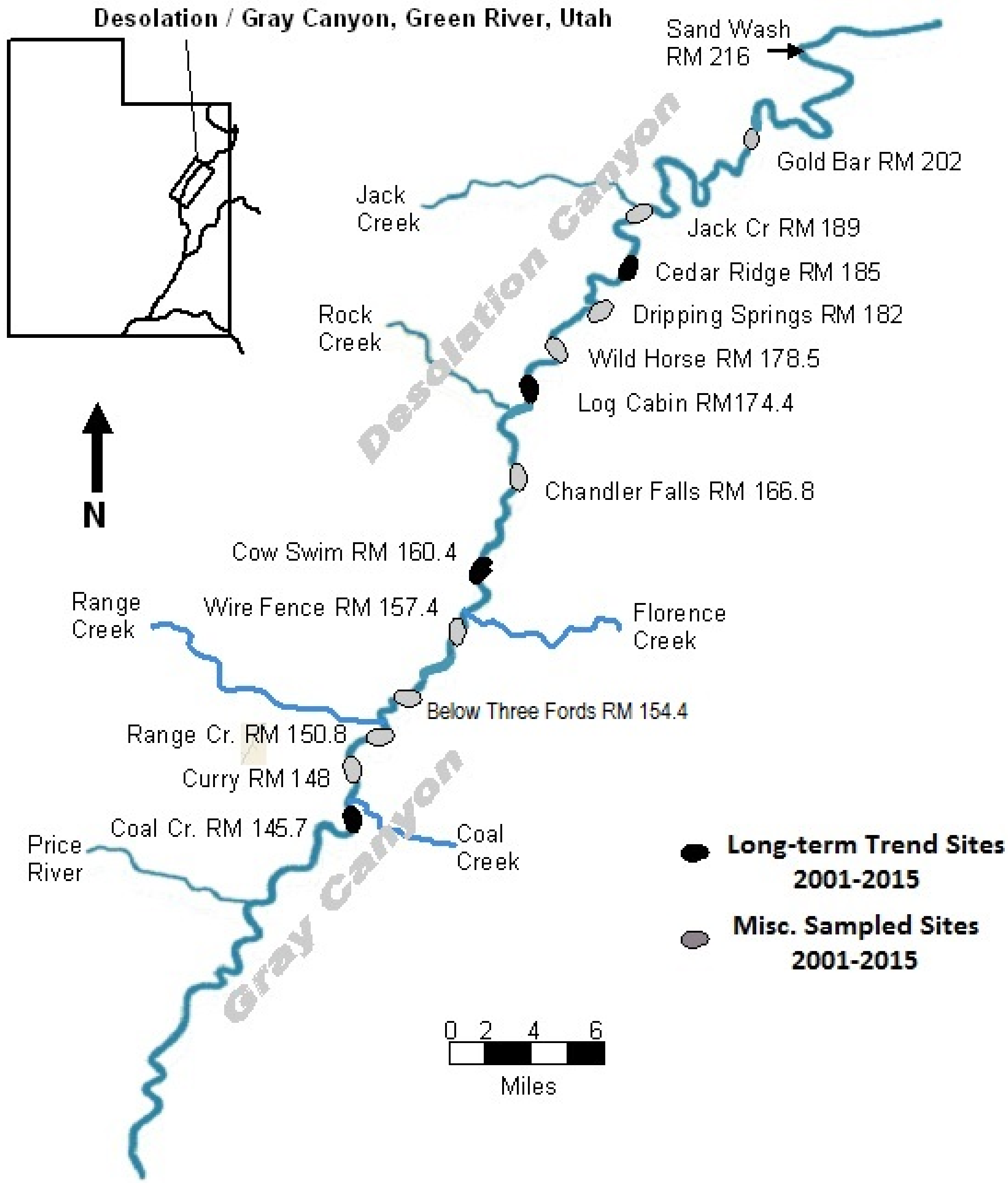

Figure 1. Locations of all sampling in Desolation and Gray Canyons on the Green River, 2001-2015. Jack Creek was switched to Gold Bar after 2003.

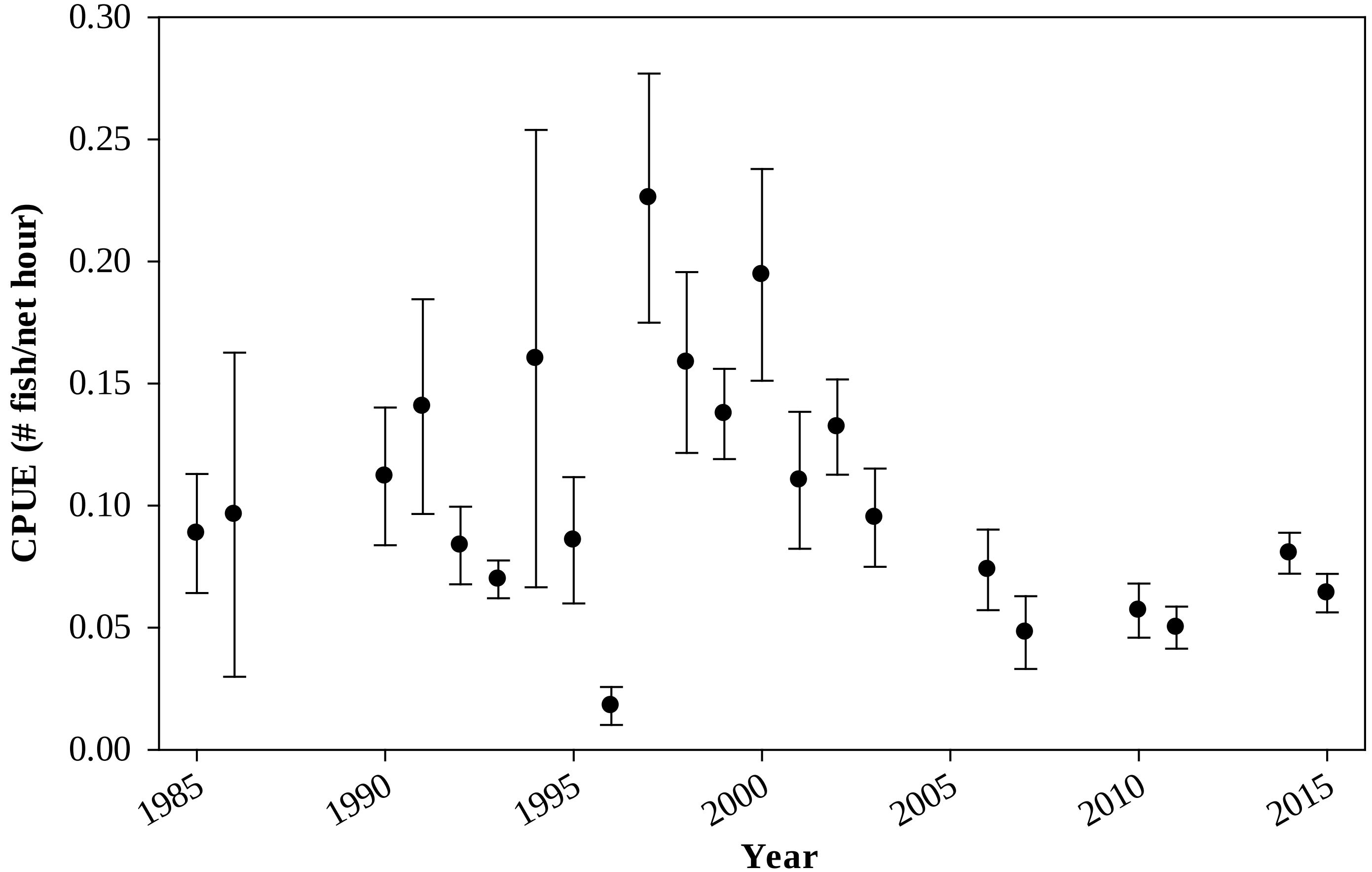

Figure 2. Long-term trend-site mean CPUE for all humpback chub (trammel net captures only), 1985-2015 including both summer and fall sampling events. The 1989 data point has been excluded as an outlier (0.59) to maintain scale. Error bars represent one standard error. Sampling was changed to from summer to fall beginning in 2003 (any comparison of CPUE from 2003-2015 to previous years should be made with caution).

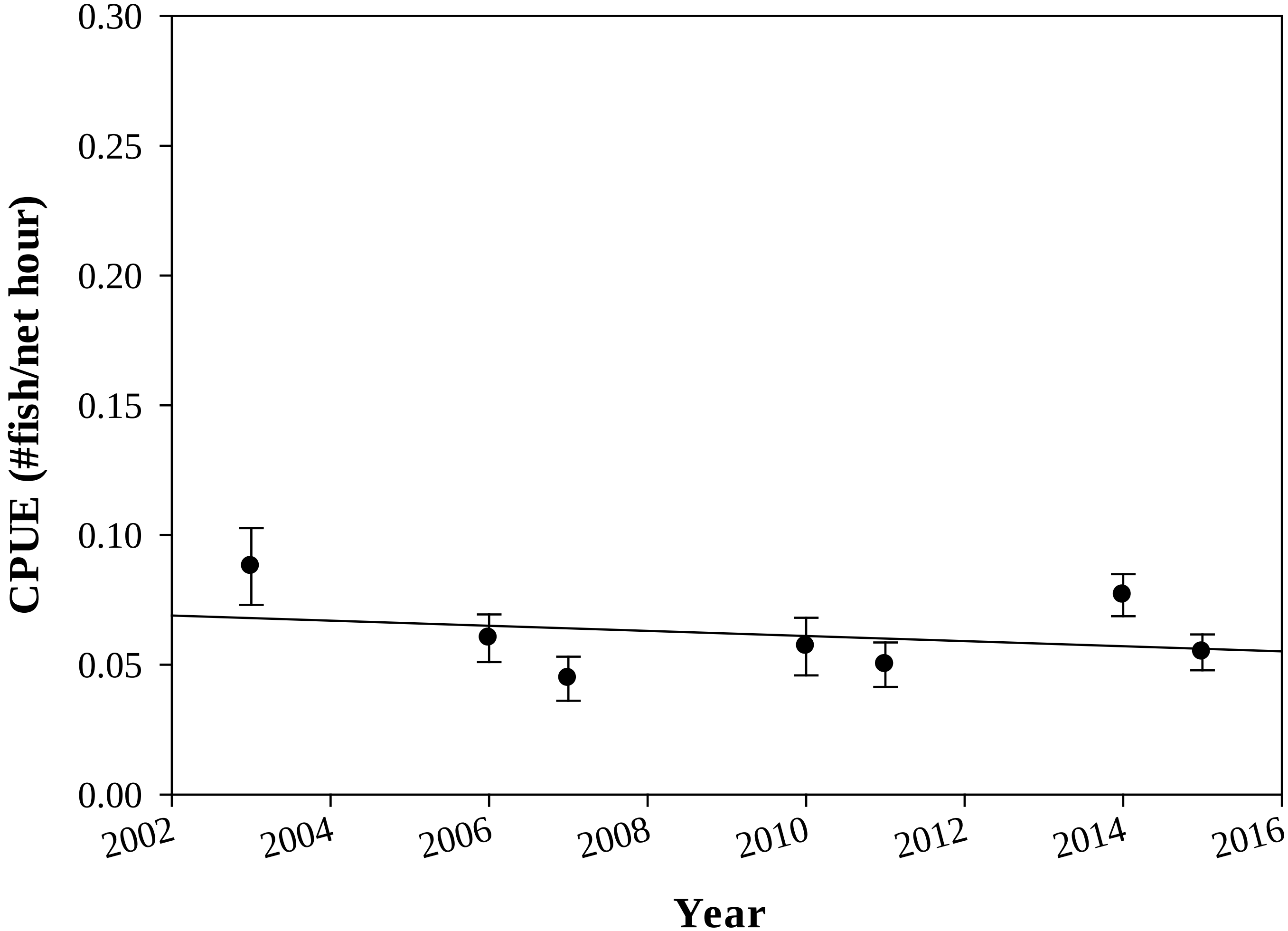

Figure 3. Mean CPUE for all sites sampled in Desolation and Gray Canyons for all humpback chub (trammel net captures only), 2003–2015. Only those years where sampling took place in the fall are included (excludes 2001-2002). Error bars represent one standard error. The trend line is based on a linear regression and is not significant (r^2=0.078, p=0.544).

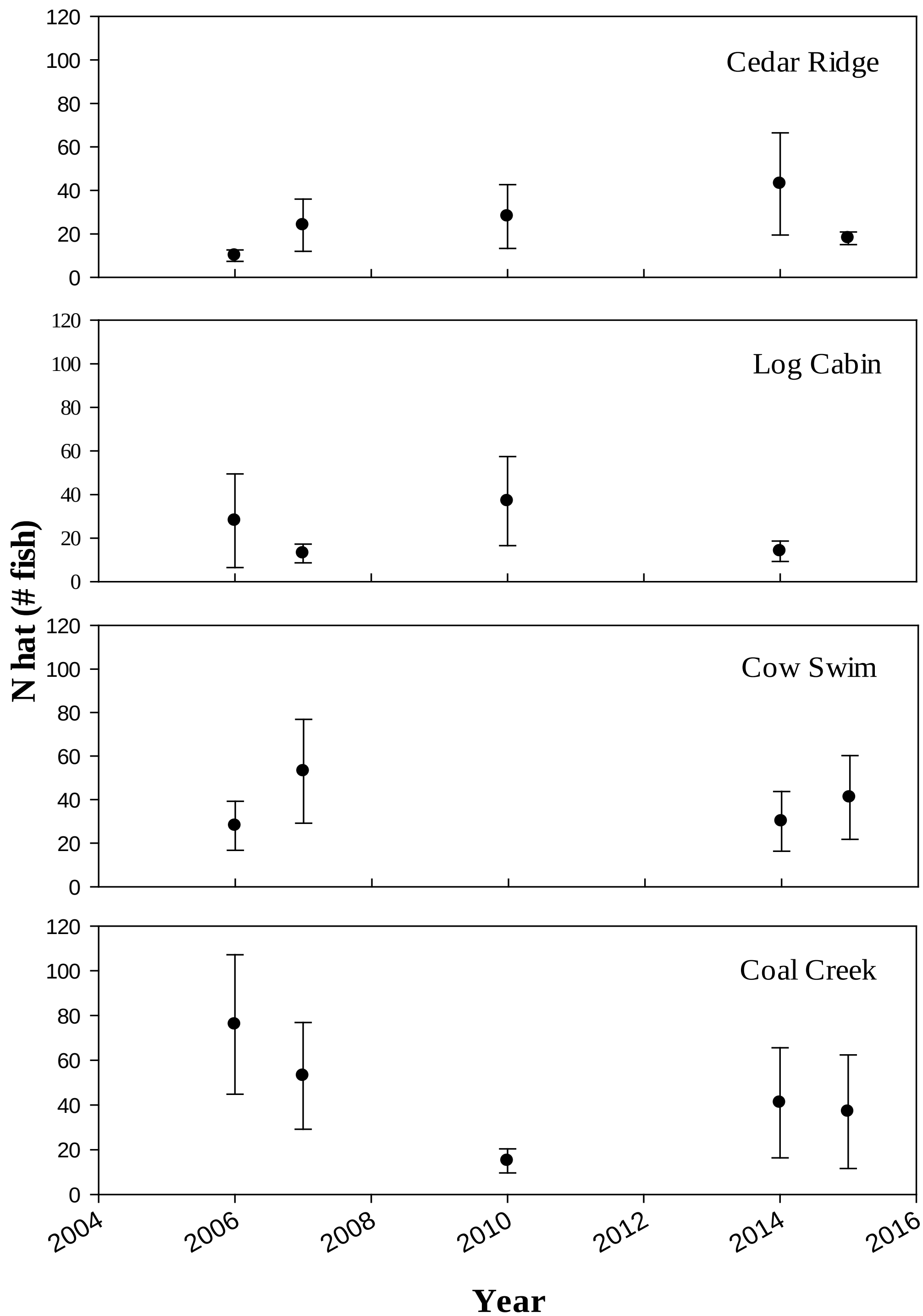

Figure 4. Population estimates at long-term sites from 2006-2015. Error bars represent one standard error. 2011 was not included because of an insufficient amount of recaptures. Sampling did not occur during all years of the study for all sites. The estimates from 2001-2003 were excluded due to high confidence intervals and low reliability.

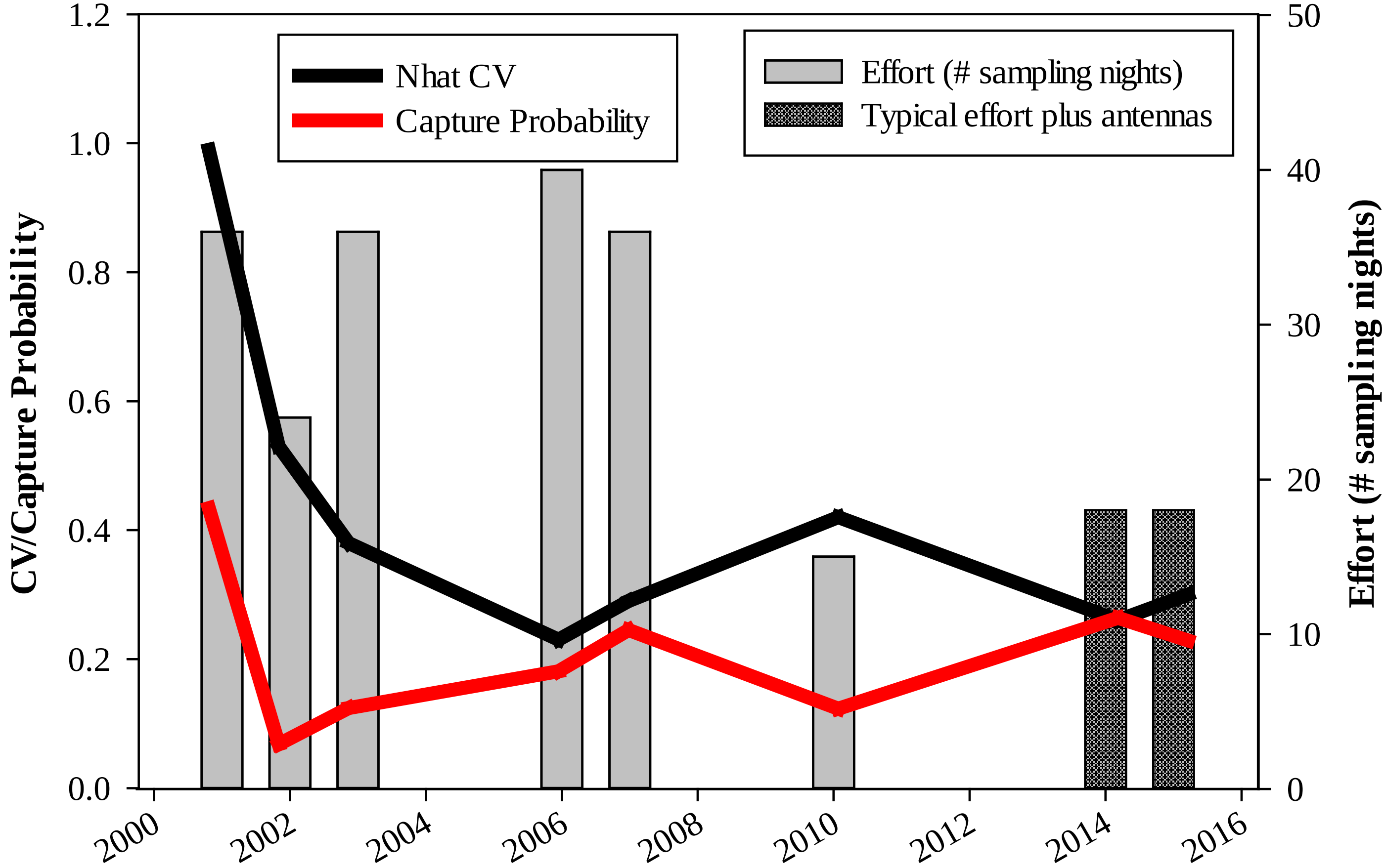

Figure 5. Annual effort (# sampling nights with and without submersible antennas), corresponding N̂ Coefficent of Variation (CV) and capture probability trends for Humpback Chub in Desolation and Gray Canyons.

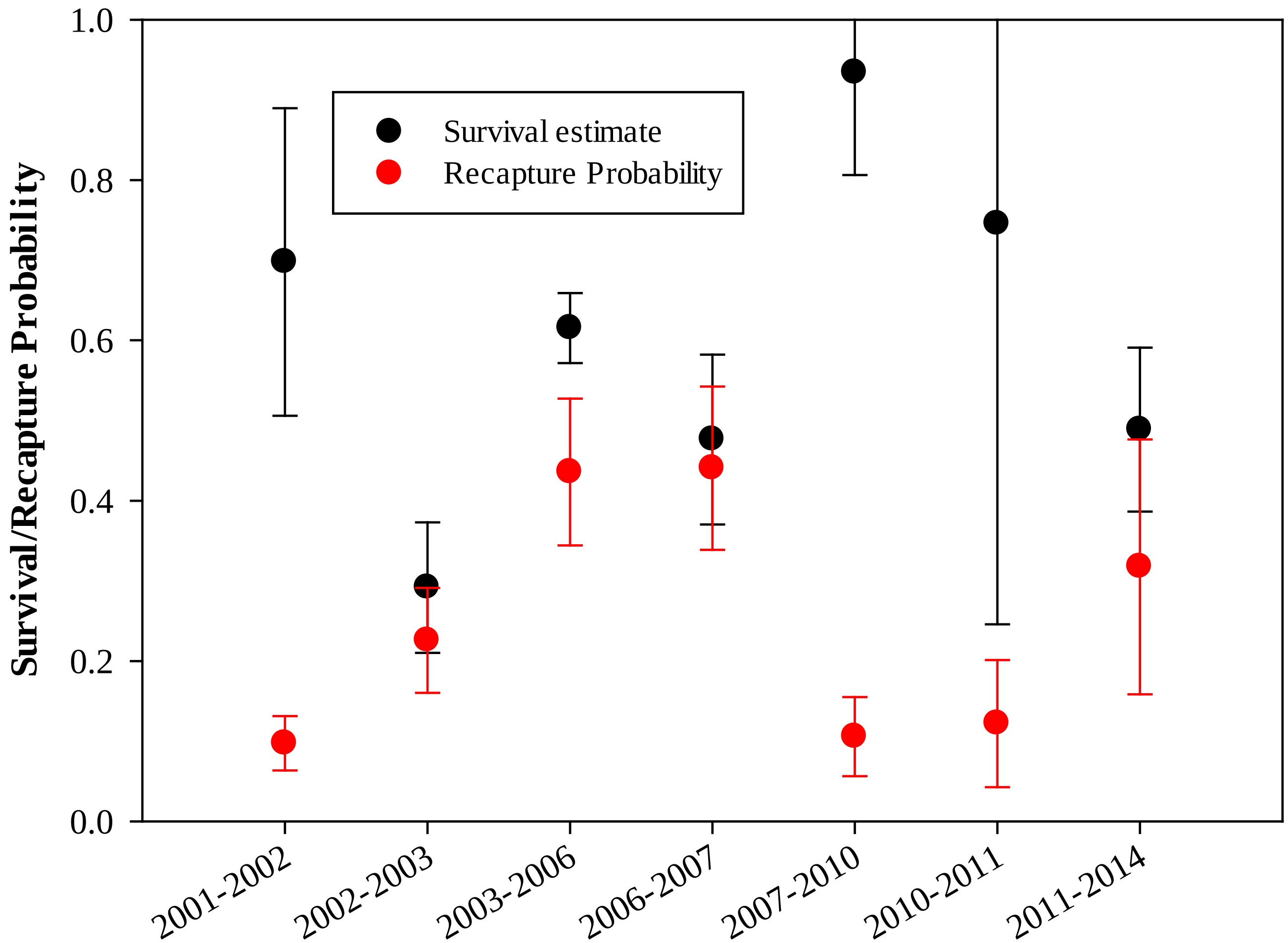

Figure 6. Desolation and Gray Canyon adult humpback chub survival estimates and recapture probabilities from 2001-2015.

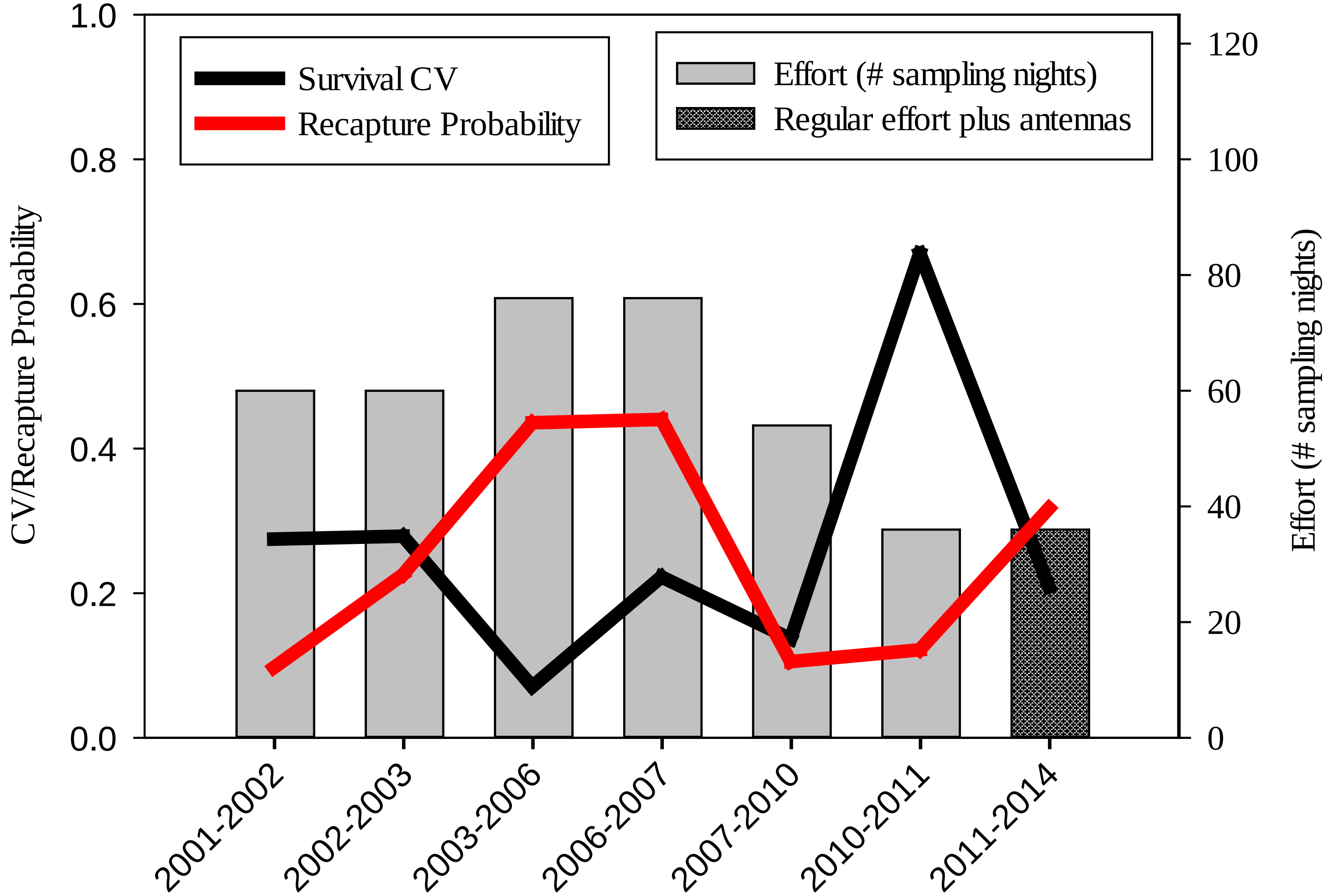

Figure 7. Annual effort (# sampling nights with and without submersible antennas) and corresponding survival estimate CV and recapture probability trends for Humpback Chub in Desolation and Gray Canyons.

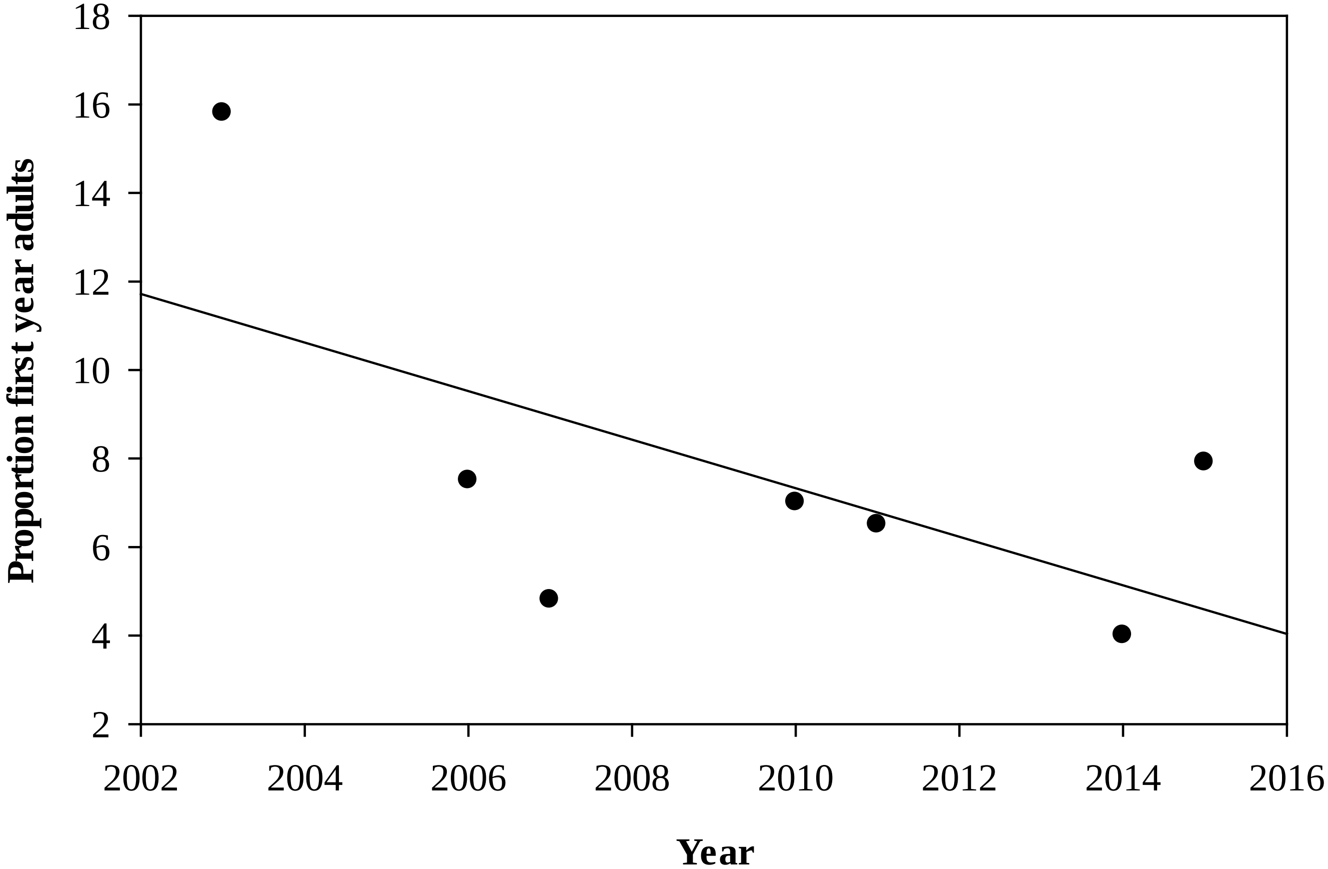

Figure 8. The proportion of first year adult (200-220 mm) humpback chub captured using all sampling methods in Desolation and Gray Canyons, 2003-2015. The trend line is not significant (r^2=0.382, p=0.139).

APPENDIX

Appendix 1. Program MARK Huggins model output by year and site for all models used in model averaging; models are listed from top to bottom by AIC weight (highest to lowest). Models were averaged at all sites where AIC weights for the top model were <0.90.

Year	Site	Model	AICc	Delta AICc	AICc Weights	Deviance
2001	**Below 3 Fords**	{p(.),c(.)} M_b	64.0439	0	0.069832	124.878
		{p(t)=c(t)} M_t	65.8482	1.8243	0.28049	124.5309
		{p(.)=c(.)} M_o	71.0336	6.9897	0.0212	133.9794
2002	**Coal Creek**	{p(t)=c(t)} Mt	40.8477	0	0.67238	109.5695
		{p(.)=c(.)} Mo	42.2856	1.4379	0.32762	113.1871
	Below 3 Fords	{p(.)=c(.)} Mo	42.2856	0	0.74424	109.613
		{p(t)=c(t)} Mt	44.4218	2.1362	0.25576	109.5695
	Gold Hole	{p(.)=c(.)} Mo	56.8313	0	0.71615	177.4348
		{p(t)=c(t)} Mt	58.6822	1.8509	0.28385	177.1617
	Log Cabin	{p(t)=c(t)} Mt	69.4639	0	0.5383	243.0662
		{p(.)=c(.)} Mo	69.7709	0.307	0.4617	245.4701
2003	**Coal Creek**	{p(t)=c(t)} Mt	78.5583	0	0.99988	192.1346
		{p(.)=c(.)} Mo	96.6616	18.1033	0.00012	214.4309
	Chandler Falls	{p(t)=c(t)} Mt	100.324	0	0.98699	200.0424
		{p(.)=c(.)} Mo	108.982	8.6574	0.01301	212.8873
	Cow Swim	{p(.)=c(.)} Mo	59.1549	0	0.89391	86.4312
		{p(t)=c(t)} Mt	63.4154	4.2605	0.10619	86.3321
	Log Cabin	{p(t)=c(t)} Mt	106.707	0	0.99921	240.4255
		{p(.)=c(.)} Mo	120.996	14.2882	0.00079	258.8782
	Curry	{p(t)=c(t)} Mt	68.852	0	0.83734	99.7288
		{p(.)=c(.)} Mo	72.1292	3.2772	0.16266	107.3472

2006	**Coal Creek**	{p(.)=c(.)} Mo	75.5821	0	0.56045	121.7765
2006		{p(t)=c(t)} Mt	76.0681	0.486	0.43955	117.9792
	Chandler Falls	{p(t)=c(t)} Mt	84.4493	0	0.84449	106.2931
		{p(.)=c(.)} Mo	87.8333	3.384	0.15551	116.1125
	Cow Swim	{p(.)=c(.)} Mo	47.874	0	0.55568	57.6269
		{p(t)=c(t)} Mt	48.3213	0.4473	0.44432	53.5426
	Dripping Springs	{p(.)=c(.)} Mo	44.545	0	0.55351	59.3019
		{p(t)=c(t)} Mt	46.312	1.767	0.22878	56.5374
		{p(.),c(.)} Mb	46.4112	1.8662	0.21771	58.9605
	Wire Fence	{p(.),c(.)} Mb	42.56	0	0.50219	43.5833
		{p(.)=c(.)} Mo	43.1289	0.5689	0.37786	46.3319
		{p(t)=c(t)} Mt	45.4236	2.8639	0.11994	41.7837
2007	**Cedar Ridge**	{p(.),c(.)} M_b	35.6600	0.0000	0.43155	43.5262
		{p(t)=c(t)} M_t	36.0997	0.4397	0.34638	41.5384
		{p(.)=c(.)} M_o	36.9888	1.3288	0.22207	47.1261
	Coal Creek	{p(.)=c(.)} M_o	63.2386	0.0000	0.76611	91.8741
		{p(t)=c(t)} M_t	65.6116	2.3730	0.23389	89.8875
	Log Cabin	{p(.)=c(.)} M_o	34.1552	0.0000	0.67738	30.1856
		{p(.),c(.)} M_b	36.2382	2.0830	0.23906	29.9287
		{p(t)=c(t)} M_t	38.3406	4.1854	0.08356	29.4876
	Range Creek	{p(.)=c(.)} M_o	36.9888	0.0000	0.71899	38.7503
		{p(t)=c(t)} M_t	38.8677	1.8789	0.28101	35.9306
2010	**Cedar Ridge**	{p(.)=c(.)} M_o	39.5340	0.0000	0.90293	42.0267
		{p(t)=c(t)} M_t	43.9945	4.4605	0.09707	41.8548
	Chandler Falls	{p(.)=c(.)} M_o	33.0631	0.0000	0.62259	40.2312
		{p(t)=c(t)} M_t	34.0642	1.0011	0.37741	36.5338

2010	**Log Cabin**	{p(.)=c(.)} M_o	47.0181	0.0000	0.6569	62.1175
		{p(t)=c(t)} M_t	48.3171	1.2990	0.3431	58.9241
2014	**Cedar Ridge**	{p(.)=c(.)} Mo	58.2015	0	0.65001	81.0476
		{p(.),c(.)} Mb	60.2563	2.0548	0.23266	80.9441
		{p(t)=c(t)} Mt	61.6256	3.4241	0.11732	80.0687
	Wildhorse	{p(t)=c(t)} Mt	41.4073	0	0.53939	48.0985
		{p(.),c(.)} Mb	42.1052	0.6979	0.3805	51.1488
		{p(.)=c(.)} Mo	45.2212	3.8139	0.08012	56.4901
	Log Cabin	{p(.)=c(.)} Mo	38.8381	0	0.70123	31.9427
		{p(.),c(.)} Mb	41.0913	2.2532	0.22729	31.8943
		{p(t)=c(t)} Mt	43.405	4.5669	0.07148	31.7294
	Cow Swim	{p(.)=c(.)} Mo	61.1327	0	0.6874	68.007
		{p(.),c(.)} Mb	63.2974	2.1647	0.23289	68.0034
		{p(t)=c(t)} Mt	65.4419	4.3092	0.0797	67.8873
	Coal Creek	{p(t)=c(t)} Mt	44.1282	0	0.83534	64.9758
		{p(.),c(.)} Mb	48.2388	4.1106	0.10697	71.3652
		{p(.)=c(.)} Mo	49.4735	5.3453	0.0577	74.7796
2015	**Cedar Ridge**	{p(.)=c(.)} M_o	60.059	0	0.53794	59.5692
		{p(t)=c(t)} M_t	61.375	1.3161	0.27858	56.3929
		{p(.),c(.)} M_b	62.21	2.1513	0.18348	59.5278
	Cow Swim	{p(.)=c(.)} M_o	55.655	0	0.81128	73.6778
		{p(t)=c(t)} M_t	58.572	2.9167	0.18872	72.1655
	Coal Creek	{p(.)=c(.)} M_o	47.018	0	0.47082	61.4379
		{p(.),c(.)} M_b	47.693	0.6746	0.33602	59.9197
		{p(t)=c(t)} M_t	48.8	1.782	0.19315	58.7275