Humpback Chub *Gila cypha* Monitoring in Desolation and Gray Canyons of the Green River, Utah, 2018-2019

Project 129

U.S. Bureau of Reclamation

Agreement Number R19AP00059

John Caldwell

Utah Division of Wildlife

1165 S. Hwy 191 Suite 4

Moab, UT 84532

DRAFT REPORT

August 2021

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.

Mention of trade names or commercial products does not constitute
endorsement or recommendation for use by the authors, the Fish and Wildlife Service, U.S. Department of Interior, or members of the Recovery Implementation Program.

Contents

List of Tables

List of Figures

Key Words

Humpback Chub, *Gila cypha*, Desolation Canyon, Gray Canyon, Green River, abundance estimation, survival probability and estimation, robust model, closed population model

Executive Summary

Humpback chub were sampled in Desolation and Gray Canyons in the fall of 2018 and 2019 to monitor the status of the population. Sampling crews used trammel nets and hoop nets to capture chub at six sites in 2018 (four long-term monitoring sites and two additional sites) and four sites in 2019 (three long-term monitoring sites and one additional site). Crews launched remote submersible passive integrated transponder (PIT) antennas at each site, which remained for the duration of fall sampling. Two fewer sites were sampled in 2019 to facilitate more sampling time at individual sites. Three long-term sites were monitored in both years; no sampling occurred at one of the long term monitoring sites in 2019 due to landowner access concerns.

Trammel nets accounted for the majority of the adult catch. Hoop nets had very low catch rates but successfully sampled a variety of sub-adult size classes. Since 2003, when fall sampling began, there were no significant trends in trammel catch per unit effort (CPUE), proportion of adults that are first year adults, and proportion of trammel net samples containing at least one humpback chub.

Individual site abundances were estimated by constructing closed capture models for each year and site. Two techniques were used to account for the heterogeneity between physical captures and antenna detections. First, datasets with antenna detections eliminated were analyzed. Second, antenna detections were included in capture-recapture datasets using methods from Conner et al. (2020), which used a covariate to indicate fish tagged before the closed capture period. Only two sites had enough previously tagged fish to facilitate modeling with antenna detections. Individual site abundance estimates were generally higher than previous estimates but not significantly. The reach-wide population was not estimated because of the lack of specific information needed to design an appropriate sampling regime.

Survival was estimated individually at long-term monitoring sites using Cormack-Jolly-Seber estimators. Annual survival appeared to slightly decline over time. However, this was driven by the most recent survival period (2018 to 2019) and future recaptures may change this estimate. Additionally, the modeled apparent survival probabilities used to estimate annual survival were variable and had high standard errors. When compared to other Upper Colorado River Basin populations, mean annual survival is lower for the Desolation and Gray Canyons population.

Recommendations are to continue sampling with trammel nets and hoop nets. To increase net captures, as many sites as possible should be sampled for two nights per pass. If remote submersible PIT antennas are used, researchers should attempt to increase detections. Additionally, to gather information needed for e a reach-wide abundance estimate, an investigation should be conducted to determine the total number of sites where humpback chub aggregate in the fall and to quantify the variation among sites.

Introduction

One of the five extant populations of humpback chub *Gila cypha* inhabits Desolation and Gray Canyons, a 68-mile reach of the Green River in Utah. This population is the only remaining population in the Green River sub-basin[1]. Humpback chub were first reported in Desolation and Gray Canyons in 1975 (Holden and Stalnaker 1975) and have been monitored by the Utah Division of Wildlife Resources (UDWR) since 1985.

The humpback chub is currently listed as endangered under the Endangered Species Act of 1973, as amended (ESA; 16 U.S.C. 1531 et. seq). Anthropogenic changes to streamflow and impacts from nonnative fish, both competition and predation, are the primary threats to humpback chub in the Upper Colorado River Basin (U.S. Fish and Wildlife Service [USFWS] 2018a). In 1990, a recovery plan for humpback chub was completed (USFWS 1990). Recovery criteria were updated and approved in 2002 to supplement the original recovery plan (USFWS 2002). Downlisting and de-listing criteria include stable abundance trends for adult (age-4+; > 200 mm total length (TL)) and recruit (age-3; 150-199 mm TL) humpback chub in all extant populations. Thus, estimating abundance over time for each population is important for tracking progess toward recovery.

The USFWS completed a thorough review of the species' taxonomy, range and distribution, life history, ecology, and projected viability in a Species Status Assessment (SSA) report (USFWS 2018a). Subsequently, the USFWS recommended to reclassify the species as threatened in a 5-year review (Service 2018b); the Service officially proposed to downlist the humpback chub from endangered to threatened in January 2020 (USFWS 2020). Their review of the best available information indicates humpback chub meet the definition of a threatened species rather than an endangered species (USFWS 2020) despite only partially meeting the 2002 recovery criteria. The USFWS states:

> "While recovery plans provide important guidance to the Service, States, and other partners on methods of enhancing conservation and minimizing threats to listed species, as well as measurable criteria against which to measure progress towards recovery, they are not regulatory documents and . . . [a] decision to revise the status of a species . . . is ultimately based on an analysis of the best scientific and commercial data, . . . regardless of whether that information differs from the recovery plan." (USFWS 2020)

Prior to 2001 the humpback chub population in Desolation and Gray Canyons was monitored primarily with catch-per-effort data obtained in one trip per year using trammel-net and electrofishing captures. In 2001, UDWR researchers began estimating abundance of the Desolation and Gray Canyons population using capture-recapture techniques. Estimating abundance of the Desolation and Gray Canyons population is problematic because they occur throughout the entire 68 miles at varying densities, appearing to aggregate at certain locations with preferable habitat. The initial strategy was to sample fish at several locations identified as chub aggregation sites and conduct a single analysis to estimate abundance for the entire population. However, because humpback chub in the upper basin have shown high site fidelity

[1] A population in Hideout Canyon in the Green River was considered extirpated in the 1960s by the construction of Flaming Gorge Dam; a population in the Green and Yampa Rivers in Dinosaur National Monument was considered extirpated around 2006, when the last humpback chub was collected (USFWS 2018a).

and mostly appear to aggregate at the same location each year, modeling assumptions of mixing between mark-recapture events were violated (Badame 2012). Therefore, recent efforts focused on producing reliable, site-specific mark-recapture estimates at individual sample sites. To produce a reach-wide estimate of abundance, past researchers averaged individual site estimates and extrapolated (Badame 2012, Howard and Caldwell 2018). However, extrapolating to a reach-wide estimate is problematic because the true number of aggregation sites and the variation among them is unknown.

The abundance of age-3 sub-adults, a measure of recruitment and population health for humpback chub (down-listing criteria #2) has been difficult to estimate for the Desolation and Gray Canyons population because very few individuals between 150-199 mm total lengths are captured. As a result, abundance of sub-adults has not been estimated for this population. Jackson and Hudson (2005) developed a surrogate metric for estimating trends in recruitment by calculating the proportion of first-year adults among all adult chub captured and comparing that to other sampling years. This metric has been reported for subsequent sampling events.

Annual survival has been used to monitor population trends in other long-lived fish species (Janney et al. 2008), and was first estimated for the Desolation and Gray population following 2014-2015 sampling (Howard and Caldwell 2018). Monitoring trends in survival in addition to abundance provides another metric that can elucidate population stability over time.

To increase the number of individual humpback chub at sites, submersible PIT antennas have recently been used to detect fish passively. The antennas were used experimentally in 2014 and 2015 but uncertainties existed about the best way to incorporate passive detection data in the capture-recapture datasets without creating bias. In 2018 and 2019, antennas were used at all sites.

The objectives of this study were to: 1) Obtain site-specific population estimates of late juvenile/adult humpback chub at long-term sampling sites within the Desolation and Gray Canyon reach and extrapolate to a reach-wide estimate; and 2) Determine mean estimated recruitment of naturally produced sub adult humpback chub (150-199 mm) in Desolation/Gray Canyon.

Additional objectives of this report were to: 1) detail the 2018 and 2019 sampling of the Desolation and Gray Canyons humpback chub population; 2) determine the best method for including antenna detections in the capture-recapture analysis; 4) estimate survival; 5) compare results to past sampling that also occurred during fall; and 6) make recommendations on how to improve monitoring of the humpback chub population in Desolation and Gray Canyons.

Methods

Study Area

The Desolation and Gray Canyons reach of the Green River begins at Sand Wash approximately 216 river miles upstream from the confluence with the Colorado River. Downstream of Sand Wash the river is low gradient and low velocity for approximately 25 river miles. At Jack Creek, the gradient and velocity increases and the river begins to cut through the Wasatch and Green River formations creating Desolation Canyon. Desolation Canyon is deep and confined, and approximately 44 river miles in length. Desolation Canyon ends and Gray Canyon begins immediately below Three Fords Rapid. Gray Canyon passes through the Mesa Verde Group for approximately 24 miles, is lower in gradient, less deep, and less confined as Desolation Canyon. Gray Canyon terminates immediately downstream of Swasey's Rapid as the river enters another low gradient reach.

While humpback chub may be distributed throughout Desolation and Gray Canyons, past researchers have chosen sampling sites where aggregations of chub occur. Outside of these aggregation sites chub have been documented occasionally. Chub aggregation sites have been described as typically bound by a rapid and the subsequent pool/eddy complex downstream. Badame (2012) estimated that 63 of these sites occur throughout the reach. Thirteen of these sites have been sampled during previous fall monitoring (2003 – 2015; Table 1). Four of the sites are long-term monitoring sites and have data from most years when sampling occurred in the reach. Sampling at the other nine sites occurred less frequently. In 2018, the four long-term monitoring sites and two additional sites were sampled. In 2019 only three long-term monitoring sites were sampled because access to the fourth was precluded by landowners; the site was replaced with an additional site for four sites total. In addition, during 2019 sampling effort was doubled at two sites to increase the likelihood of recaptures.

Fish Sampling

Sampling crews used trammel nets and scented hoop nets to capture humpback chub during three passes. Eight trammels and 15 hoop nets were set at each site. Trammel nets were 75 feet in length and six feet in depth with 12-inch square outer panels and one-inch square inner panels. Trammel netting targeted the higher activity periods of morning and evening (Chart and Lentsch 1999, Jackson and Hudson 2005). Trammels were set at 1500 for evening sampling and checked every two hours until removal from the water at 2300. Trammels were set at 500 for morning sampling and checked every two hours until removal from the water at 1100. Hoop nets were two feet in diameter, four feet in length, had a throat 4 inches in diameter, and were covered with ¼ inch black nylon mesh netting. Hoop nets were scented by suspending a 125 ml plastic cylindrical container with drilled holes filled with bait (AquaMax Grower 600 for Carnivorous Species, Purina Mills Inc.) in the center of the net. Scented hoop nets were set between 1500 and 1700 and retrieved the following morning between 900 and 1100. Additionally, two remote submersible PIT antennas were deployed at each site and remained for the duration of fall sampling. These antennas continued to sample between passes, detecting tagged fish when crews were not present. In 2018, a single antenna was deployed during the first pass and the second antenna was deployed during the second pass. In 2019, two antennas were deployed during the first pass.

Sampling crews recorded total length (mm), and weight (g) for each captured humpback chub and scanned each individual for a PIT tag. A PIT tag was implanted in all chub not previously containing one and the number was recorded. Dorsal and anal fin ray counts were also recorded for each chub.

Data Analysis

Catch per unit effort (CPUE) was calculated for trammel netting and hoop netting as number of humpback chub captures per net hour for each sample. CPUE was compared among sites and passes with the Kruskal-Wallis test because distributions were not normal. Comparisons to CPUE from previous studies were made with data from Howard and Caldwell (2018). Additionally, the percentage of samples containing at least one chub was calculated. Linear regressions were used to test for trends over time including all years when sampling occurred in the fall.

Size distribution was determined by developing length frequency graphs using 20 mm size classes. Recruitment was assessed by calculating the percentage of all adult chub that were first year adults (Jackson and Hudson 2005). Adult chub were defined as all fish equal to or greater than 200 mm TL. First year adult chub were defined as chub between 200 and 220 mm TL (inclusive). The size range was estimated using growth data and is described in Jackson and Hudson (2005). It should be noted that the size range estimate for first-year adults could include outlier younger or older individuals. Linear regression was used to test for a trend in recruitment over time including all years when sampling occurred in the fall. Data from before 2018 was taken from Howard and Caldwell (2018).

Closed capture modeling was used to estimate abundance separately at each site. The closed capture model was used because of the high site fidelity observed in Upper Colorado River Basin humpback chub populations during fall. Badame (2008) observed 100% site fidelity of humpback chub in Cataract Canyon recaptured during the study period. Jackson (2006) reported that humpback chubs in Westwater Canyon recaptured over periods between 4 and 13 years showed an 85% site fidelity and fidelity increased to over 90% when looking at within year recaptures. Hines et al. (2016) found transition rates in between Westwater Canyon and Black Rocks to be less than 2%. Jackson and Hudson (2005) recorded only one recapture that moved away from the original capture location during fall Desolation and Gray Canyons sampling in 2003. However, they reported three fish moving out of original capture locations during the summer sampling period in 2001 and 2002 and between years they found ten fish to move from original capture locations. While humpback chub appear to occasionally move among sites between years, the low number of fish moving within a given year satisfies the closed population assumption in this situation. Additionally, the short sampling period of approximately one fall month further reduced the likelihood of fish moving in and out of the sites.

Because PIT antennas were constantly operating throughout the closed capture period, the detection data needed to be organized into capture periods that correspond with physical capture events. The entire closed capture sampling period was divided into three even capture periods. For example, antennas were launched at approximately 1200 on 13 September 2018 and retrieved at approximately 1200 13 October 2018 for a total of 720 hours (30 days). The 30 days were divided into three 10-day capture periods (e.g. Capture Period 1: 1200, 13 September 2018 – 1200, 23 September 2018) each containing one net sampling event. Antenna detections were assigned a capture period based on the date and time stamp associated with the detection.

Including antenna detections in capture-recapture modeling without accounting for the heterogeneity in capture probabilities between physical captures (nets) and antenna detections may result in an underestimation of population size. Only the previously tagged portion of the population is detectable by antennas, which artificially increases the recapture probability by detecting individuals in that subset fish more often. Scenarios where a portion of the population is more likely to be captured (a violation of the equal catchability assumption) are known to result in an underestimation of abundance (Chao and Huggins 2005).

Abundances of humpback chub were estimated at individual sites using the Huggins p (probability of capture) and c (probability of recapture) with the models of Otis et al. (1978). Two techniques were used to account for the heterogeneity between physical captures and antenna detections. The first technique eliminated antenna detections from the capture-recapture dataset and. The second technique included antenna detections by using methods from Conner et al. (2020). Fish that contained a tag before the start of the closed capture period, which were available for antenna detection and physical capture, were modeled with an individual covariate that indicated the presence of the tag. Program MARK (White and Burnham 1999) was used for all analyses. Models were constructed with both constant and time varying *p* and *c*. When models were constructed so that *p* and *c* were variable through time and not equal, the final *p* was set equal to the final *c* so that the final *p* remained identifiable. The Akaike Information Criterion adjusted for small sample size [AIC_c] was used to determine model weights (Burnham and Anderson 1998). The coefficient of variation was calculated as the standard error divided by the associated abundance estimate.

Survival was modeled for the four long-term monitoring sites individually using the Cormack-Jolly-Seber estimators. Survival probabilities directly from the model output were not comparable because the apparent survival parameter was not consistently annual. For example, Coal Creek was sampled in 2014, 2015, and not again until 2018 (Table 1). In this situation survival could be estimated from 2014 to 2015 (annual rate) and from 2015 to 2018 (probability of surviving three years). Since the probability of surviving three years is equal to the product of the probability of surviving each one-year period $((S_{2015-2016})(S_{2016-2017})(S_{2017-2018}) = S_{2015-2018})$, the annual survival rates were estimated by taking the cubic root of the three-year survival probability.

Results

2018

Sampling crews completed three passes in 2018 through Desolation and Gray Canyons on 12 – 19 September 2018, 27 September – 4 October 2018, and 9 – 16 October 2018. Mean daily flows during sampling ranged from 1930-4360 cubic feet per second (USGS gauge #09315000, Green River at Green River). Average water temperatures declined with each pass from 22° C to 19° C to 8° C. Sampling sites included the four long-term trend monitoring sites located at river miles 185.0 (Cedar Ridge), 174.5 (Log Cabin), 160.0 (Cow Swim), 145.5 (Coal Creek) and two sites selected from those previously sampled during the 2003-2015 sampling located at river miles 178.5 (Wild Horse), and 151.0 (Range Creek).

The total number of unique humpback chub captured and/or detected by all methods was 107 and consisted of 93 adults, 8 sub-adults, and 6 juveniles (four were not tagged because they were small juveniles). Trammel netting resulted in 105 humpback chub captures (86 unique individuals). Hoop netting resulted in 24 captures (all unique individuals; three were also captured in trammel nets). Antennas detected 30 unique individual humpback chub, all of which were also captured in nets during 2018 sampling. Total effort included 1883 trammel net hours, 4658 hoop net hours and 6402 antenna set hours over three passes (Table 2).

Mean CPUE for humpback chub captured by trammel nets at all sites combined was 0.06 fish per net hour (Figure 1). Mean CPUE by site and pass is summarized in Table 2. CPUE varied significantly among passes at Cow Swim ($p < 0.01$) but not at other sites. Mean CPUE of all sites combined varied significantly among passes ($p = 0.04$). Nine percent of all trammel net samples contained at least one humpback chub (Figure 2).

Total lengths of humpback chub captured by trammel net ranged from 197 to 358 mm. Total lengths of chubs captured by hoop net ranged from 54 to 315 mm (Figure 3 and Figure 4). The proportion of first year adult (200-220 mm) humpback chub captured was 13% (Figure 5).

Abundances were estimated at individual sites for all size classes combined because the sparse data precluded abundance estimates by size class. Analyses including antenna detections in the capture-recapture datasets were not successful for the 2018 closed capture period because few previously tagged fish were captured or detected. When antenna detections were removed from the data set, a model with constant p was ranked highest for Cedar Ridge, Coal Creek, Log Cabin, Range Creek, and Wild Horse, while a model allowing for variation of p over time was ranked highest for Cow Swim. At Cedar Ridge, sampling resulted in 14 unique humpback chub. Mean p_i was 0.13 and estimated abundance was 41 (CV = 0.59). At Coal Creek, Sampling resulted in 32 unique humpback chub. Mean p_i was 0.12 and estimated abundance was 104 (CV = 0.42). At Cow Swim, sampling resulted in 25 unique humpback chub. Mean p_i was 0.02 and estimated abundance was 406 (CV = 0.99). At Log Cabin, sampling resulted in 12 unique humpback chub. Mean p_i was 0.14 and estimated abundance was 36 (CV = 0.57). At Wild Horse, sampling resulted in 16 unique humpback chub. Mean p_i was 0.12 and estimated abundance was 52 (CV = 0.60). At Range Creek, sampling resulted in only four unique humpback chub. Because of the sparse data, no further analyses were conducted. A complete summary of abundance estimates, associated coefficient of variation, and mean p_i by site and technique is included in Table 5.

Several non-target species were captured in 2018 and are summarized by site in (Table 5).

2019

Sampling crews completed three sampling passes in 2019 through Desolation and Gray Canyons on 9/12–9/19/19, 9/27–10/4/19, and 10/9–10/16/19. Mean daily flows during sampling ranged from 2480 – 2720 cubic feet per second (USGS gauge #09315000, Green River at Green River). Average water temperatures measured on site during each pass were 19° C, 13° C, and 11° C respectively. Sampling sites included three of the four long-term monitoring sites (Cedar Ridge, Cow Swim, Coal Creek) and one site selected from those previously sampled during the 2003-2015 sampling periods (Wild Horse). Log Cabin (fourth long-term trend site) was not sampled in 2019 due to private property access concerns and the need to access the east bank at this site. Effort was increased at Cedar Ridge and Cow Swim by sampling an additional night during each pass to increase captures and recaptures. Wild Horse and Coal Creek were sampled a single night each pass.

Due to landowner access concerns, Cedar Ridge was sampled approximately 0.5 miles upstream from the historic location during pass one. This location did not facilitate sampling downstream of the riffle where nets have been set during past sampling. Thus, results from pass one at Cedar Ridge were not included in any totals or analyses with the exception of length frequency and is summarized here separately. Total effort from pass one included 215 trammel net hours, 639 hoop net hours, and 356 antenna hours. One adult humpback chub was captured in a trammel net. Passes two and three sampled at the historic Cedar Ridge location.

The total number of unique humpback chub captured and/or detected by all methods was 113 and consisted of 106 adults and 1 sub-adult. Trammel netting resulted in 105 humpback chub captures (93 unique individuals). Hoop netting resulted in 22 captures (20 unique individuals; five were also captured in trammel nets). Antennas detected 26 unique individual humpback chub (21 of those were also captured in nets during 2019 sampling). Total effort included 1543 trammel net hours, 4700 hoop net hours and 4977 antenna set hours over the three passes (Table 2).

Mean trammel net CPUE of all sites combined was 0.07 ($n = 808$) (Figure 1). Regression analysis indicated no trend over time ($p > 0.05$). Mean CPUE by site and pass is summarized in Table 3. CPUE varied significantly among passes at Cedar Ridge ($p < 0.01$), Coal Creek ($p < 0.01$), and Wild Horse ($p = 0.05$). Mean CPUE of all sites did not vary significantly among passes. Eleven percent of all trammel net samples contained at least one humpback chub (Figure 2). Regression analysis indicated no trend over time ($p > 0.05$).

Total lengths of humpback chub captured by trammel net ranged from 206 to 360 mm. Total lengths of chubs captured by hoop net ranged from 154 to 345 mm (Figure 3 and Figure 4). The proportion of first year adult (200-220 mm) humpback chub captured was 8% (Figure 5). Regression analysis indicated no trend over time ($p > 0.05$).

Abundances were estimated at individual sites for all size classes combined because the sparse data precluded abundance estimates by size class. When antenna detections were included in the dataset, the highest ranked models for Coal Creek and Wild Horse allowed for time variation in p and included the individual covariate. Modeling with antenna detections was not successful for

Cedar Ridge and Cow Swim because of sparse data. When antenna detections were eliminated from the dataset, a model allowing for variation of p over time was ranked highest for all sites. At Cedar Ridge, sampling resulted in 21 unique humpback chub. Mean p_i was 0.26 and estimated abundance was 43 (CV = 0.51). At Coal Creek, sampling resulted in 36 unique humpback chub. Without antenna detections, mean p_i was 0.09 and estimated abundance was 130 (CV = 0.50). With antenna detections, mean p_i was 0.14 and estimated abundance was 132 (CV = 0.58). At Cow Swim, sampling resulted in 32 unique humpback chub. Mean p_i was 0.06 and estimated abundance was 177 (CV = 0.64). At Wild Horse, sampling resulted in 23 unique humpback chub. Without antenna detections, mean p_i was 0.05 and estimated abundance was 142 (0.93). With antenna detections, mean p_i was 0.07 and estimated abundance was 128 (CV = 0.87). A complete summary of abundance estimates, associated coefficient of variation, and mean p_i by site and technique is included in Table 5. Because of high CVs, comparisons to results from Howard and Caldwell (2018) are limited and interpretations of abundance estimates should be made cautiously. However, site-specific abundance estimates generally appear stable (Figure 6).

Several non-target species were captured in 2019 and are summarized by site in (Table 6).

Survival

Cedar Ridge: Apparent survival ranged from 0.17 (2003-2006; CV = 0.68) to 0.53 (2006-2007; CV = 0.79) (Figure 8). Estimated annual apparent survival ranged from 0.22 to 0.76 with a mean from 2003 to 2019 of 0.56. Survival appeared to decrease from 2007 to 2014 then remained stable through 2019 (Figure 9).

Coal Creek: Apparent survival ranged from 0.13 (2003-2006; CV = 0.58) to 0.73 (2006-2007; CV = 0.38) (Figure 8). Estimated annual apparent survival ranged from 0.30 to 0.79 with a mean from 2003 to 2019 of 0.63. Survival appeared to decrease from 2007 to 2014 then remained stable through 2019 (Figure 9).

Cow Swim: Apparent survival from 2006 to 2007 was not estimable. Apparent survival ranged from 0.09 (2010-2014; CV = 1.16) to 0.87 (2014-2015; CV = 0.33) (Figure 8). Estimated annual apparent survival ranged from 0.27 to 0.87 with a mean from 2003 to 2019 of 0.63. Survival fluctuated and appeared to decline from 2015 to 2019 (Figure 9).

Log Cabin: Survival parameters were not estimable because of sparse data.

Overall mean estimated annual survival from 2003 to 2019 for Cedar Ridge, Coal Creek, and Cow Swim, was 0.61.

Discussion

Analysis of long-term demographic metrics, and catch rates suggests that the Desolation and Gray Canyons humpback chub population is apparently stable at long-term monitoring sites. Trammel net CPUE, and the proportion of trammel net samples containing humpback chub all displayed stable trends. Site-specific abundance estimates also showed stable trends. However, because of high CVs and sparse data, site-specific abundance estimates should be interpreted cautiously. The proportion of adults that are first year adults was higher than the long-term average in 2018, potentially indicating either increased recruitment but could also be due to lower survival of older adults. Survival showed a decreasing trend. However, this is driven by the most recent survival period that includes only one capture period, whereas all other estimated survival periods have had at least two. Because Humpback Chub are long lived, 2018 fish may be captured in future sampling events increasing the estimated survival for 2018 to 2019.

A reach-wide abundance estimate was not presented in this report. Using the extrapolation method from previous reports to arrive at a reach-wide population estimate was not possible because the number of sites where humpback chub aggregate has not been verified and sites likely vary in quantity of available habitat and humpback chub abundance. Additionally, variation among sites may not be represented in the relatively small number of sites sampled during this study. To extrapolate site-specific estimates to a reach-wide population estimate, an investigation to determine the number of humpback chub aggregations and quantify the variation among them is needed. Until then, site estimates should not be extrapolated to a reach-wide abundance.

The Desolation and Gray Canyons estimated mean annual survival is equal to the previous estimate from Howard and Caldwell (2018) despite inclusion of different years. The previous estimate included 2001 and 2002 fish. Those years were not included here because fish sampling occurred during summer, whereas all subsequent years (from 2003 on) sampling occurred during fall. When compared to other upper basin populations, Desolation and Gray (0.61) was lower than the mean survival for Westwater (0.75) (Hines et al. 2020) and Black Rocks (0.72) (Francis et al. In Draft). Further comparisons of survival rates with other populations should be made cautiously because of the high variance in the Desolation and Gray modeled apparent survival rates used to estimate annual survival and because these populations occur in a different basin with a different flow regime.

Estimating abundance with antenna detections in the dataset was only successful for two sites in 2019 and no sites in 2018 because few fish tagged before the closed capture period were captured or detected. Additionally, the abundance estimates at those two sites were not substantially improved by including antenna detections. If antennas are used in further Desolation and Gray Canyons studies, an attempt should be made to increase detections by baiting antennas (Van Haverbeke et al. 2019).

When interpreting any data from the Desolation and Gray Canyons population it is important to consider that this population is of low density and spread over a large geographic area making it fundamentally difficult to sample. However, when considering multiple demographic parameters and the apparent stability of long-term monitoring sites, the Desolation and Gray Canyons population appeared stable during the 2006 – 2019 monitoring period.

Recommendations

- Given the current lack of information needed to attempt a reach-wide abundance estimate, it may be beneficial for this specific population to consider other metrics when determining the status of the population, such as reproduction, recruitment, survival, CPUE, and site-specific abundance trends.

- If a reach-wide abundance estimate is desired, an investigation should be conducted to determine the total number of sites where humpback chub aggregate in the fall and to quantify the variation among sites.

- Future monitoring should plan for two-night sampling at as many sites as possible and consider three-night sampling. Two-night sampling in 2019 resulted in more captures of individuals and recaptures of tagged fish than single night sampling in 2018.

- Trammel nets, while stressful to fish, accounted for the majority of adult humpback chub captures and therefore should continue to be used in future sampling with appropriate mitigation (2 hour sets and avoid temperatures above 20 degrees C(Hunt et al. 2012)).

- Hoop nets should continue as a sampling method. While the catch rates were much lower than trammel nets, they appear to sample more size classes than trammel nets and are important in documenting reproduction and recruitment. Additionally, they are less stressful to fish and allow sampling in a variety of habitats where trammel nets are ineffective.

- Researchers should use methods for baited hoop nets from Van Haverbeke et al. (2019) to increase retention and capture of humpback chub in hoop nets. Additionally, if researchers continue to use antennas, bait should be used to increase detections (Van Haverbeke et al. 2019).

- In addition to the long-term monitoring sites, researchers should consider sampling Chandler, Wild Horse, and Curry. These sites all have several years of capture-recapture data and could provide additional sites for long-term trend monitoring.

Tables

Table 1. Humpback chub fall sampling locations in Desolation and Gray Canyons. The number of unique humpback chub captured and/or detected (that were included in capture-recapture datasets) is reported when researchers sampled at the location. Shaded rows are long-term monitoring sites.

River Mile (Site Name)	2003	2006	2007	2010	2011	2014	2015	2018	2019
202.0 (Gold Hole)	2								
189.0 (Jack Creek; Lone Tree)**		6	5						
185.0 (Cedar Ridge)	14	8	11	12	19	18	15	15	21
182.0 (Dripping Springs)	25*	14	1						
178.5 (Wild Horse)		12	2			13		16	23
174.5 (Log Cabin)	41*	9	9	15	10	10	8	12	
166.8 (Chandler Falls)	35*	22	13	11	8		8		
160.0 (Cow Swim)	19*	13*	5	8	3	17	15	25	32
157.4 (Wire Fence; Florence Creek)**	14	20*	5						
154.4 (Pats Squeeze; Below Three Fords)**	13*	4*	6						
151.0 (Range Creek)		12*	11		8	14		4	
148.0 (Curry Rapid)	20*	18*	9		4		8		
145.0 (Coal Creek)	36*	26*	20	9		15	13	32	36

*Total number of unique humpback chub corrected from the number reported in Howard and Caldwell 2018

**Researchers have used different names for similar sampling locations or sampling that occurred near the listed river mile.

Table 2. Total number of unique humpback chub captured or detected by each method for all sites combined along with the total effort for all sites combined. Several fish were captured and/or detected by multiple methods.

	Trammel nets		Hoop nets		Antennas	
Year	n	Effort (hrs)	n	Effort (hrs)	n	Effort (hrs)
2018	86	1883	20	4658	30	6402
2019	93	1543	20	4700	26	4977

Table 3. Trammel net catch per unit effort by site and pass from 2018 in Desolation and Gray Canyons.

Site	Pass	Mean CPUE	Standard Deviation
Cedar Ridge	1	0.06	0.17
	2	0.04	0.23
	3	0.03	0.15
Coal Creek	1	0.07	0.22
	2	0.13	0.30
	3	0.12	0.29
Cow Swim	1	0.08	0.23
	2	0.15	0.25
	3	0.02	0.13
Log Cabin	1	0.03	0.13
	2	0.08	0.22
	3	0.03	0.12
Range Creek	1	0.00	0.00
	2	0.01	0.07
	3	0.01	0.07
Wild Horse	1	0.07	0.23
	2	0.04	0.14
	3	0.04	0.14

Table 4. Trammel net catch per unit effort by site and pass from 2019 in Desolation and Gray Canyons.

Site	Pass	Mean CPUE	Standard Deviation
Cedar	2	0.16	0.39
	3	0.02	0.11
Coal Creek	1	0.01	0.07
	2	0.12	0.26
	3	0.18	0.38
Cow Swim	1	0.07	0.20
	2	0.02	0.11
	3	0.06	0.19
Wild Horse	1	0.06	0.22
	2	0.14	0.29
	3	0.04	0.13

Table 5. Summary of highest ranking models, abundance estimates (N), coefficient of variation (CV), lower 95% confidence interval (LCI), upper 95% confidence interval (UCI), mean probability of capture (*p*), number of unique individuals captured and/or detected (C), and, where modeling with antenna detections was possible, number of fish containing a tag before the closed capture period (Prev Tag) by year, site, and modeling technique (Tech). Technique 1 used datasets with antenna detections eliminated. Technique 2 included antenna detections using methods from Conner et al. 2020.

Year	Site	Tech	Model*	N	CV	LCI	UCI	*p*	C	R	Prev Tag
2018	Cedar Ridge	1	*p*(.)=*c*(.)	41	0.59	20	134	0.13	14	2	
	Coal Creek	1	*p*(.)=*c*(.)	104	0.42	56	250	0.12	32	4	
	Cow Swim	1	*p*(t)=*c*(t)	406	0.99	95	2102	0.02	25	1	
	Log Cabin	1	*p*(.)=*c*(.)	36	0.57	18	117	0.14	12	2	
	Range Creek	1	*p*(.)=*c*(.)	8	0.75	4	35	0.22	4	1	
	Wild Horse	1	*p*(.)=*c*(.)	52	0.60	24	172	0.12	16	2	
2019	Cedar Ridge	1	*p*(t)=*c*(t)	43	0.51	25	131	0.26	20	2	
	Coal Creek	1	*p*(t)=*c*(t)	130	0.5	63	355	0.09	34	3	
		2	*p*(t*PrevTag)=*c*	132	0.58	60	420	0.14	36	9	8
	Cow Swim	1	*p*(t)=*c*(t)	177	0.64	69	599	0.06	32	2	
	Wild Horse	1	*p*(t)=*c*(t)	142	0.93	42	707	0.05	21	1	
		2	*p*(t+PrevTag)=*c*	128	0.87	42	600	0.07	23	2	4

* Model notation: *p* = probability of initial capture, *c* = probability of recapture, "." = constant *p* or *c* for the sampling occasions, t = variable *p* or *c* for the sampling occasions, PrevTag = individual covariate given to fish that were tagged before the closed capture period (initial capture can be by antenna or net).

Table 6. Non-target fish captured during humpback chub sampling in Desolation and Gray Canyons by year and site (BB= black bullhead *Ameiurus melas*, BC = black crappie *Pomoxis nigromaculatus*, BT = bonytail *Gila elegans*, CP = Colorado pikeminnow *Ptychocheilus lucius*, FR = flannelmouth sucker x razorback sucker hybrid, GS = green sunfish *Lepomis cyanellus*, NP = northern pike *Esox lucius*, RZ = razorback sucker *Xyrauchen texanus*, SM = smallmouth bass *Micropterus dolomieu*, WE = walleye *Sander vitreus*, WS = white sucker *Catostomus commersonii*).

Year	Site	BB	BC	BT	CP	FR	GS	NP	RZ	SM	WE	WS
2018	Cedar Ridge				7		1	1	6	3		1
	Coal Creek	6		1	1					1		
	Cow Swim		13		3				5	1		1
	Log Cabin		3		2		1		10	3		
	Range Creek		10		7		2			4		1
	Wild Horse		1		3				5	8		
2019	Cedar Ridge	2	7	2	1	1			24	29		
	Coal Creek	2	2	7	2		1		1	6		
	Cow Swim	3	8	4	2		2		7	18	1	
	Wild Horse		1				1		4	7		

Figures

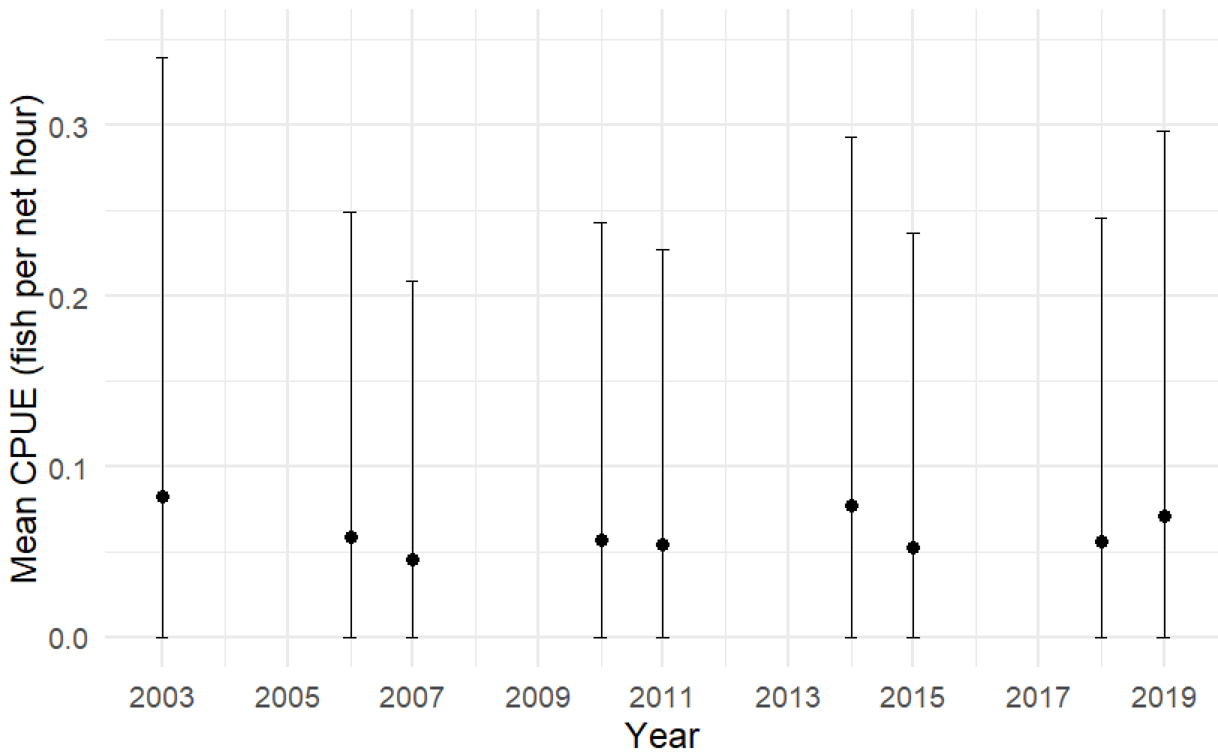

Figure 1: Mean trammel net catch per unit effort (CPUE) of Humpback Chub by year for all years when sampling occurred in the fall for Desolation and Gray Canyons. Error bars represent standard deviation.

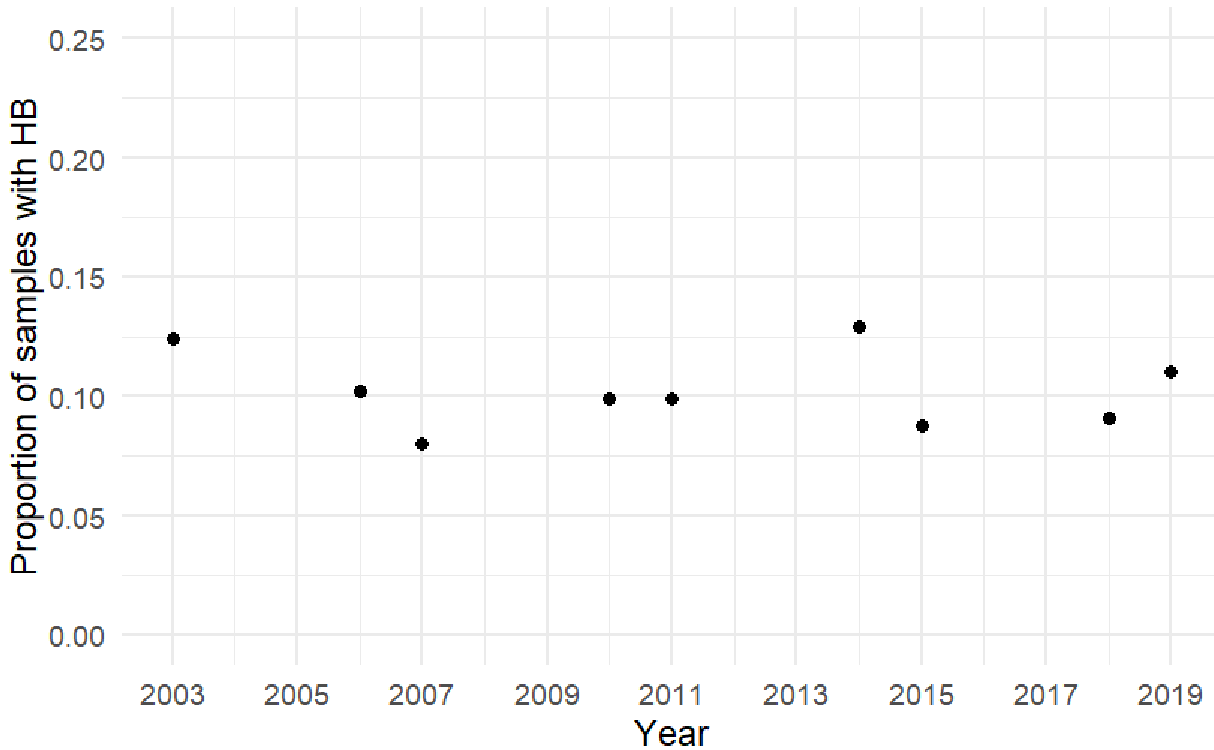

Figure 2. Proportion of trammel net samples from Desolation and Gray Canyons containing at least one humpback chub. Regression analysis indicated no trend over time ($p > 0.05$).

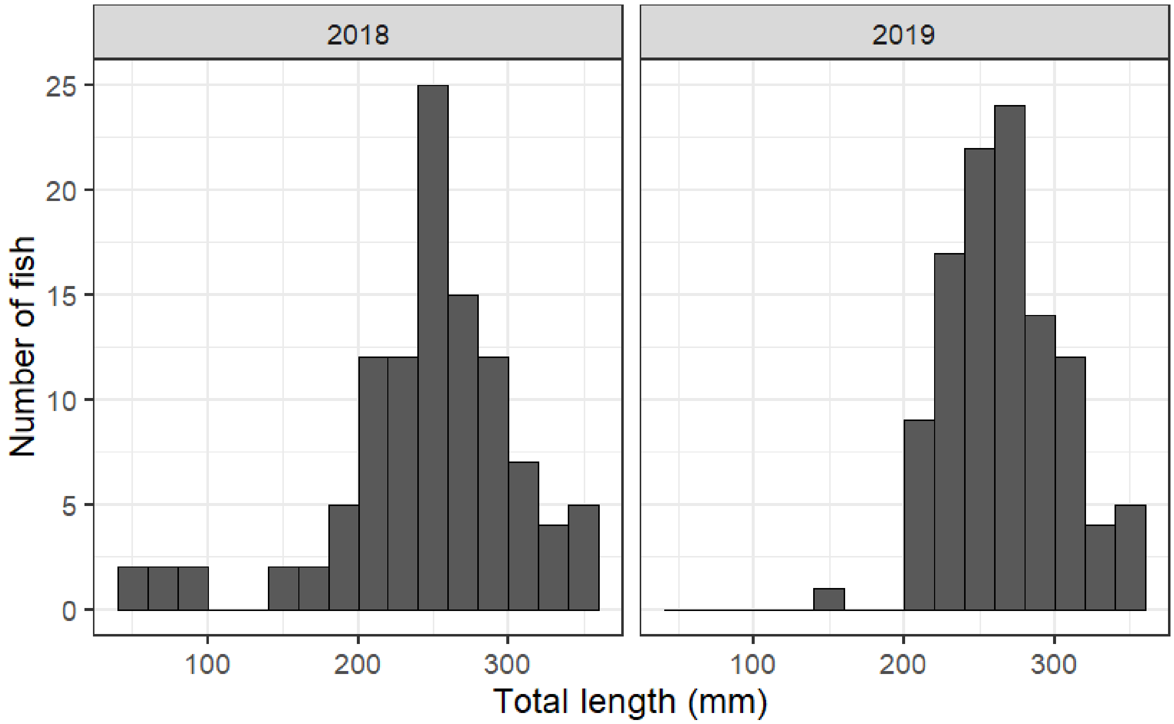

Figure 3. Length frequency of humpback chub captured in Desolation and Gray Canyons with trammel nets and hoop nets by year.

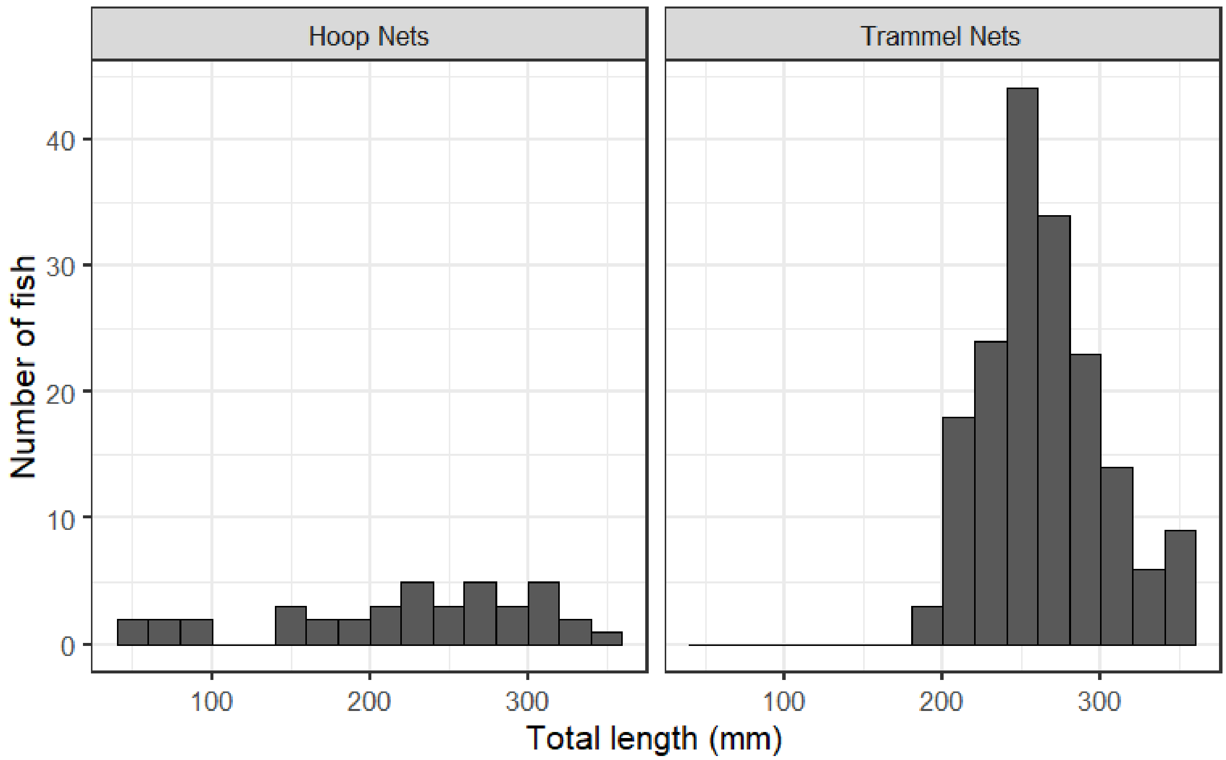

Figure 4. Length frequency of humpback chub captured in Desolation and Gray Canyons with trammel nets and hoop nets by gear type during 2018 and 2019 sampling.

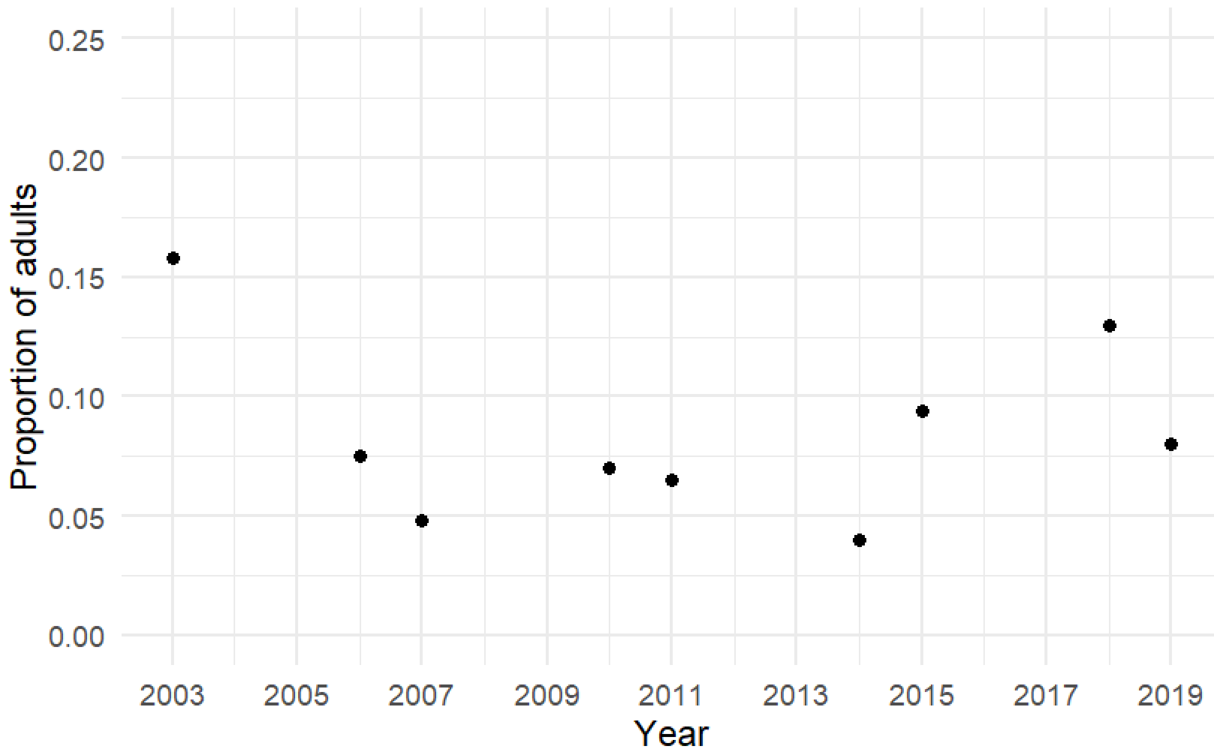

Figure 5. Proportion of all adults (≥ 200 mm total length) that were first year adults (≥200 mm and ≤ 220 mm). Regression analysis indicated no trend over time ($p > 0.05$).

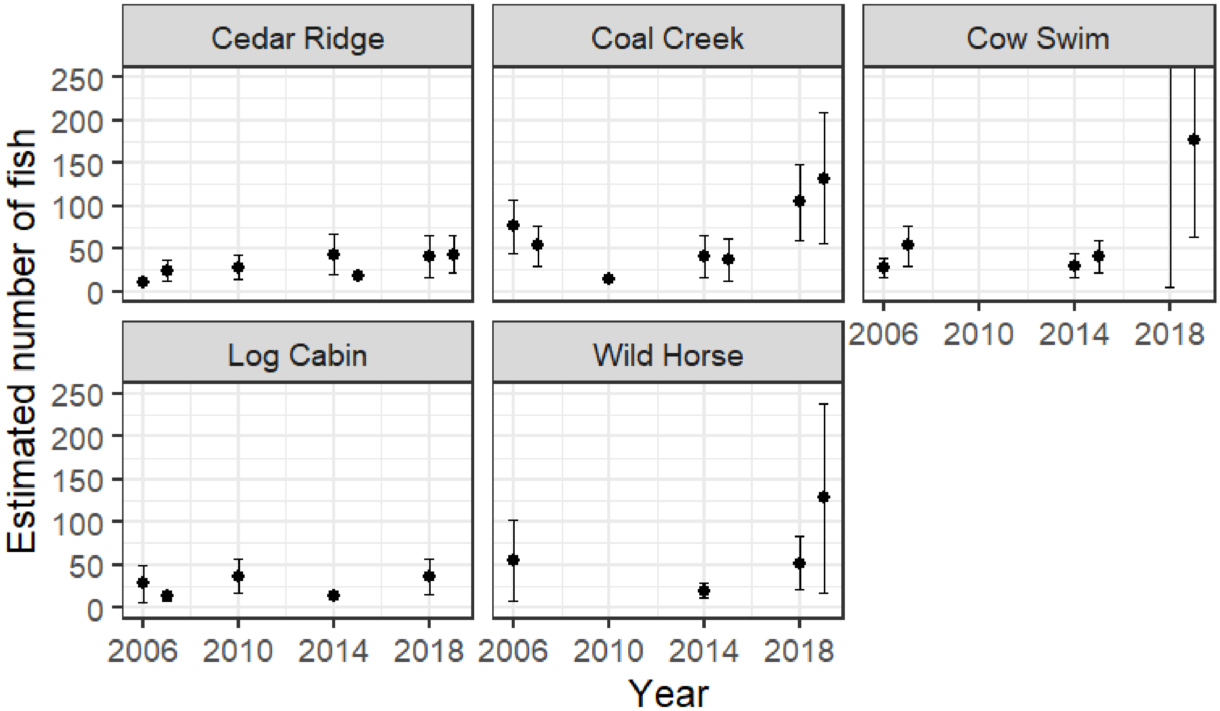

Figure 6. Abundance estimates from 2018 and 2019 (antenna detections included in capture-recapture datasets when possible) compared to past estimates (2006 – 2015) reported by Howard and Caldwell (2018) when sampling occurred in fall. Huggins estimators were used for all abundance estimates. Error bars represent standard error. Abundance estimates from 2003 are not included because Jackson and Hudson 2005 did not report site-specific abundance estimates.

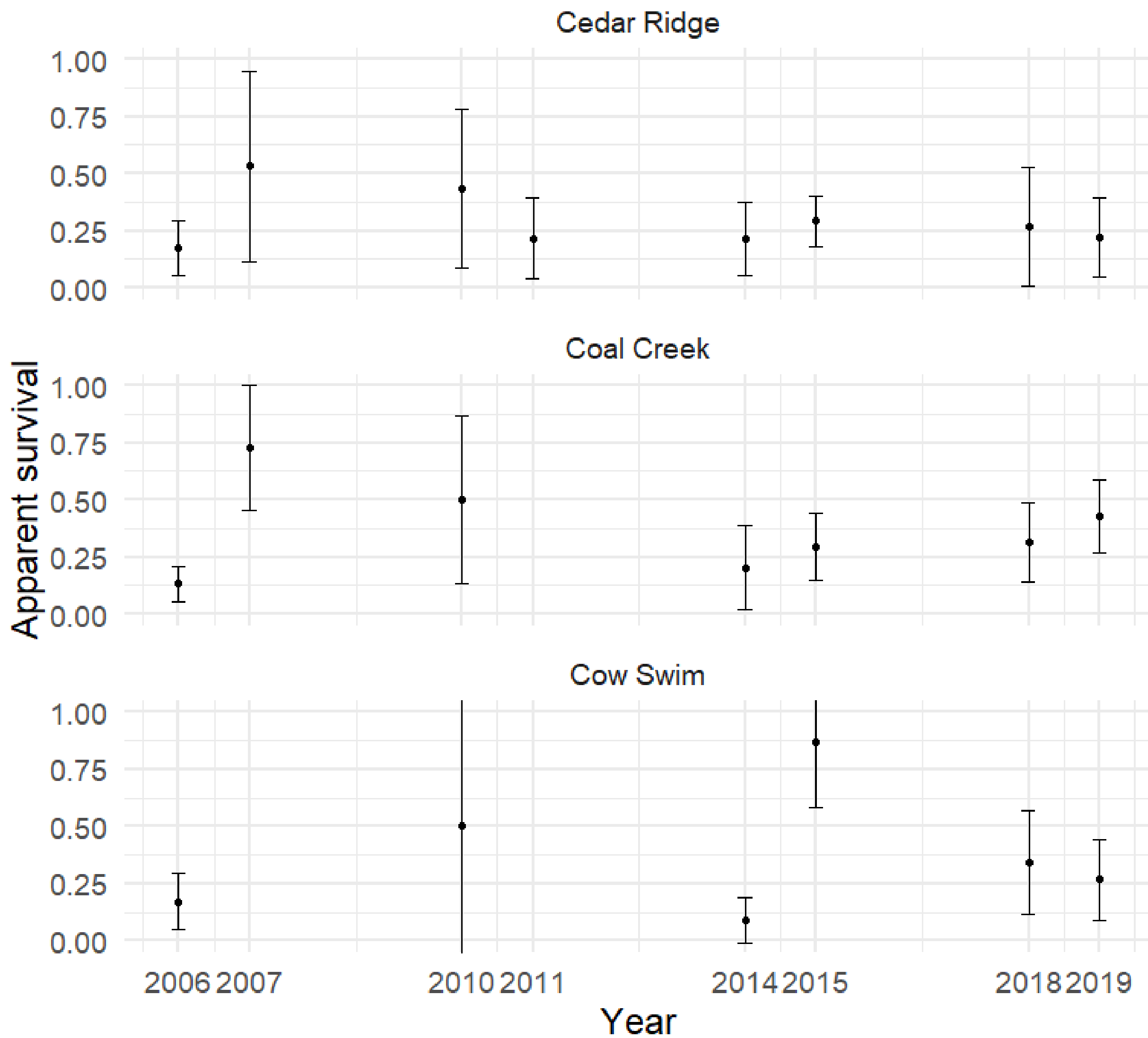

Figure 7. Modeled survival for long-term monitoring sites in Desolation and Gray Canyons from robust modeling of 2003 - 2019 capture-recapture data. Missing values are because of sparse data (Coal Creek 2011; Cow Swim 2007 and 2011). Survival for Log Cabin was inestimable because of sparse data. Note that some survival estimates are for multiple years. For example, Cedar Ridge 2010 is the probability of surviving from 2007 to 2010 because there was no fish sampling in between years. Error bars represent standard error.

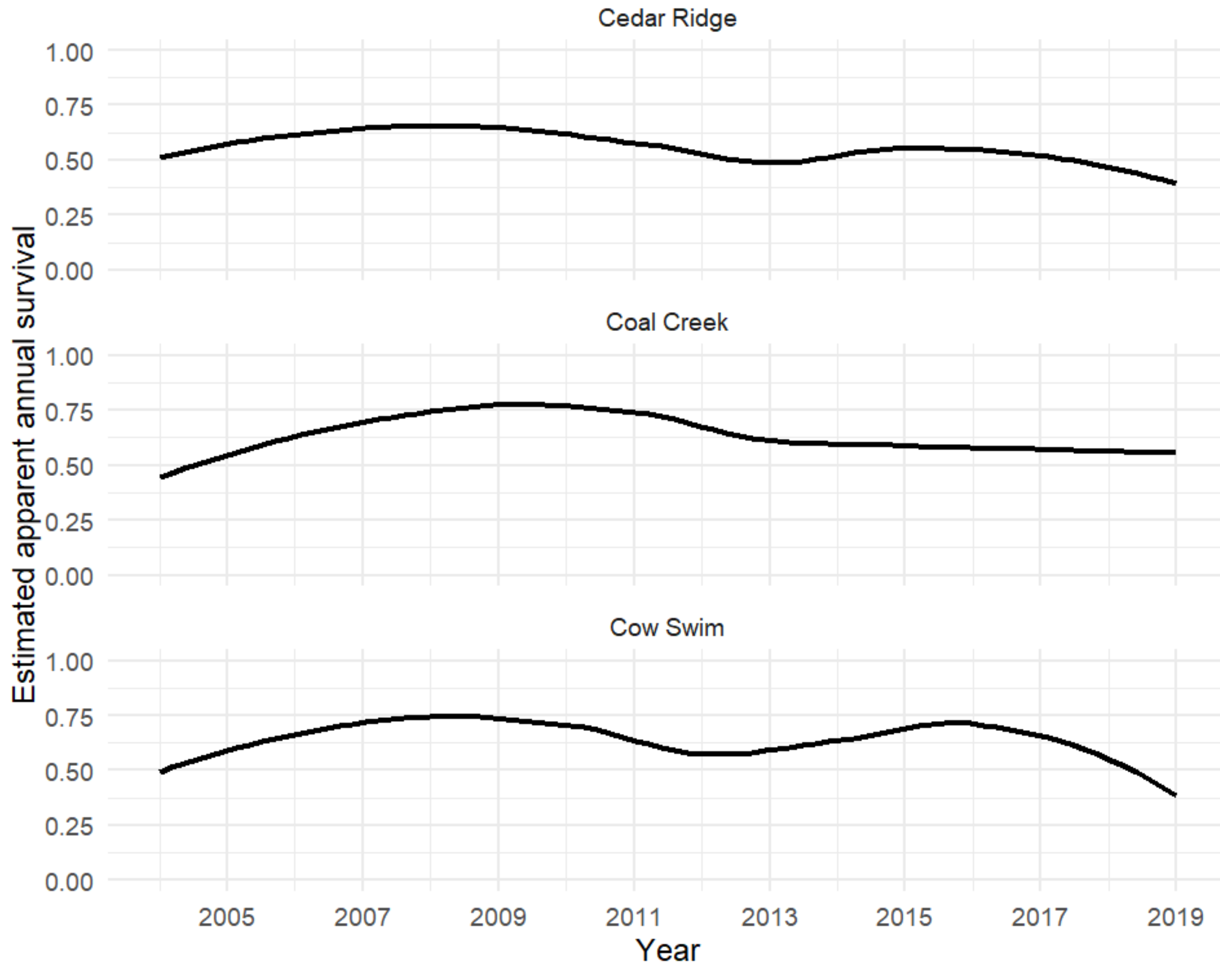

Figure 8. Estimated apparent annual survival for long-term monitoring sites in Desolation and Gray Canyons from robust modeling of 2003 - 2019 capture-recapture data. Survival was modeled for years when sampling occurred. Then, annual survival was estimated for years between sampling events using the modeled multi-year survival.

Literature Cited

Badame, P.V. 2008. Population Estimates for Humpback Chub (Gila cypha) In Cataract Canyon, Colorado River, Utah, 2003–2005. Final Report, Project 22L. Utah Division of Wildlife Resources, Salt Lake City, Utah.

Badame, P.V. 2012. Population Estimates for Humpback Chub (Gila cypha) in Desolation and Gray Canyons, Green River, Utah 2006-2007. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 12–06.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag, New York, New York, USA. 353 pp.

Chao, A., and R.M. Huggins. 2005. Chapter Two Classical closed population capture-recapture models' in Amstrup, S.C., T.L. McDonald, and B.F.J. Manly (editors) *Handbook of capture-recapture analysis.* Princeton, NJ: Princeton University Press, pp 22-35.

Chart T.E. and Lentsch 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.

Conner, M.M., P.E. Budy, R.A. Wilkison, M. Mills, D Speas, P.D, Mackinnon, and M. Mckinstry. 2020. Estimating population abundance with a mixture of physical capture and PIT tag antenna detection data. Canadian Journal of Fisheries and Aquatic Sciences 77:1163-1171.

Francis, T.A., K.R. Bestgen and 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 to the Upper Colorado River Endangered Fish Recovery Program Project Number 131. Grand Junction, Colorado.

Francis, T.A., K.R. Bestgen and G.C. White. In Draft. 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, 1998-2017. Larval Fish Laboratory Contribution 222. Final Report from the U.S. Fish and Wildlife Service to the Upper Colorado River Endangered Fish Recovery Program Project Number 131. Grand Junction, Colorado.

Hines, B. A. K. R. Bestgen, and 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.

Hines, B. A., K. R. Bestgen, and G. C. White. 2020. Abundance estimates for humpback chub (Gila cypha) and roundtail chub (Gila robusta) in Westwater Canyon, Colorado River, Utah 2016–2017. Final Report, Project 132. Upper Colorado River Endangered Fish

Recovery Program, Lakewood, Colorado. Larval Fish Laboratory Contribution 219, Colorado State University, Fort Collins, CO.

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.

Howard, J. and J. Caldwell. 2018. Population Estimates for Humpback Chub (Gila cypha) in Desolation and Gray Canyons, Green River, Utah 2001-2015. Final Report, Project 129. Upper Colorado River Endangered Fish Recovery Program, Lakewood, Colorado.

Hunt, T. A., 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. Utah Division of Wildlife Resources, Salt Lake City, Utah. Publication Number 05–25.

Janney, E.C., R.S. Shively, B.S. Hayes, P.M. Barry and D. Perkins. 2008. Demographic Analysis of Lost River Sucker and Shortnose Sucker Populations in Upper Klamath Lake, Oregon, Transactions of the American Fisheries Society, 137:6, 1812-1825.

Otis, D.L., K.P Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs. 62:1–135.

Pollock, K. H. 1982. A capture-recapture design robust to unequal probability of capture. Journal of Wildlife Management 46:757–760.

U.S. Fish and Wildlife Service (USFWS). 2018a. Species status assessment for the Humpback Chub (Gila cypha). U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, CO. Version 1.1.

U.S. Fish and Wildlife Service. 2018b. Humpback Chub (Gila cypha) 5-year Review: Summary and Evaluation. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Lakewood, CO.

U.S. Fish and Wildlife Service. 2020. "Endangered and Threatened Wildlife and Plants; Reclassification of the Humpback Chub from endangered to threatened with a section 4(d) Rule; Proposed Rule," 85 Federal Register 14 (22 January 2020), pp. 3586-3601.

Van Haverbeke, D.R., M.J. Pillow, and K.L. Young. 2019. Monitoring Humpback Chub in the Colorado River, Grand Canyon during fall 2018. U.S. Fish and Wildlife Service, Flagstaff, AZ. 32 pp.

White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. Bird Study 46 Supplement: 120–138.