Grand Canyon

National Park Service
U.S. Department of the Interior

Grand Canyon National Park

Translocation of Humpback Chub to Grand Canyon Tributaries: 2020 Annual Report

Annual Report Prepared for:
Upper Colorado Region, Bureau of Reclamation
Interagency Agreement Numbers: R18PG00066 and R17PG00048
December 2020

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Photo: Humpback chub translocation in Bright Angel Creek, June, 2020. Credit: Brian Healy/NPS

KEY FINDINGS

1. During federal fiscal year (FY) 2020 (October 1, 2019 – September 30, 2020), the Grand Canyon National Park (GCNP) Native Fish Ecology and Conservation Program (NFEC) conducted 2 monitoring events on the Colorado River in the Shinumo Inflow reach, in Bright Angel Creek (1 translocation trip), and Havasu Creek (1 trip) to complete humpback chub translocations and associated monitoring activities. A total of 415 juvenile humpback chub were translocated to Bright Angel Creek in June.

2. Numbers of humpback chub captured during monitoring or trout suppression (Bright Angel, fall/winter 2019-20) include: Havasu (October 2019): 97, Bright Angel: 4, and in the Shinumo Creek/Shinumo Inflow of the Colorado River: 13 (July 2020) and 10 (September 2020). Trends in abundance based on bootstrapping suggests recruitment occurred in Havasu Creek in the summer of 2019.

3. Operations related to humpback chub translocations were limited in spring and summer 2020 due to the COVID-19 pandemic. Monitoring planned to occur in Havasu Creek in May, and collections of larval humpback chub for 2021 translocations scheduled for April or May 2020 at the Little Colorado River, were cancelled to protect NPS employees and because access to the Navajo Nation was restricted due to the virus.

4. Reproduction and recruitment of the translocated population of humpback chub in Havasu Creek, first observed in 2016, continued to be observed in October 2019. Humpback chub translocated to Shinumo Creek were extirpated in 2014, but recaptures or detections of individuals originally translocated to Shinumo Creek continued to be noted in the Colorado River, Little Colorado River, and Bright Angel Creek in 2020.

5. Preliminary survival estimates that are comparable to the source population suggest that humpback chub translocated to Havasu Creek are contributing to the overall population in Grand Canyon; the creek is also isolated from stressors of the Colorado River (e.g., including future fish invasions) and is providing critical population redundancy for the species. Shinumo Creek may have provided a rearing opportunity that enhanced dispersal and survival into the mainstem aggregations until fire and associated flooding extirpated the population from the creek, but may be a potential future site for additional reintroductions if the tributary can be treated for non-native fish.

6. Limited nonnative fish control was conducted in Shinumo Creek in 2020, but all rainbow trout captured in the creek or in the mainstem in July (5) and September (1) 2020 were humanely euthanized, in compliance with Section 106 of the National Historic Preservation Act. Three rainbow trout captured incidentally during hoop-netting were removed from Havasu Creek in October 2019.

INTRODUCTION

The humpback chub (*Gila cypha*) is a federally endangered cyprinid fish species endemic to the Colorado River basin, persisting in six populations, with the largest found in Grand Canyon National Park (GCNP), Arizona (U. S. Fish and Wildlife Service [USFWS] 2018). Humpback chub were thought to occur in nine aggregations in the Colorado River in Grand Canyon; however, the aggregation found near the confluence with the Little Colorado River (LCR) was the only aggregation known to be maintained by local reproduction (Valdez and Ryel 1994; Valdez and Masslich 1999), until evidence of reproduction was noted in the western Grand Canyon (Van Haverbeke et al. 2017, Rogowski et al. 2018) and in the translocated population in Havasu Creek (Healy and Nelson 2013, Healy et al. 2020a).

Beginning in 2009, translocations of juvenile humpback chub from the LCR to other Colorado River tributaries and associated nonnative fish control were implemented to conserve humpback chub and contribute towards conservation measures listed in Biological Opinions (BO) for the operations of Glen Canyon Dam, including in the current BO for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) (USFWS 2016). These conservation measures include translocation of humpback chub to Shinumo, Havasu, and Bright Angel creeks, and evaluations of other potentially suitable tributaries, associated monitoring, and nonnative fish control (USFWS 2016). Translocations were initiated to Bright Angel Creek in 2018 following the successful stream-wide suppression of invasive salmonids that began in 2012 (Healy et al. 2018, 2020b), and on the recommendation of the GCD Adaptive Management Program Science Advisors.

The existing fish communities in tributaries targeted for translocations vary in their composition (Valdez et al. 2000), and invasive fishes can limit the effectiveness of translocations in establishing new populations (Al-Chokhachy et al. 2009, Cochran-Biederman et al. 2015). Nonnative fish control is necessary to improve survival of translocated humpback chub, and an important pre-cursor to translocations in all three tributaries to minimize predation risk to translocated fish (USFWS 2011). Suppression of invasive salmonids was particularly important in Bright Angel Creek, where large populations of nonnative rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) were present (Carothers and Minckley 1981, Otis 1994, Omana Smith et al. 2012). Both species of introduced trout are known to prey upon native fish (Yard et al. 2011, Whiting et al. 2014, Spurgeon et al. 2015a), including endangered humpback chub (Yard et al. 2011). A comprehensive analysis of trout suppression activities in Bright Angel Creek indicated suppression can also lead to rapid positive response in native fish communities (Healy et al. 2020b). Current trout control results in Bright Angel Creek are described in (Schelly et al. 2020).

The purpose of this report is to describe fiscal year (FY) 2020 (October 1, 2019 – September 30, 2020) activities of the GCNP – Native Fish Ecology and Conservation Program

(NFEC) related to translocations of humpback chub and associated monitoring and nonnative fish control in tributaries, as described in the 2016 LTEMP BO (e.g., USFWS 2016).

During FY2020, the (NFEC) completed monitoring trips to Shinumo (2 trips), Bright Angel (1 translocation trip), and Havasu (1 trip) Creeks associated with translocation tasks (Table 1). A total of 415 juvenile humpback chub were translocated to Bright Angel Creek in June.

OBJECTIVES

Although the objectives of translocating humpback chub may vary by tributary, under adaptive management framework of the GCNP Comprehensive Fisheries Management Plan (CFMP; U. S. Deparment of Interior [USDOI] 2013), success is measured by: 1) the establishment of a second spawning and recruiting population in the mainstem or tributary; or 2) sufficient survival and growth to provide a rearing ("grow-out") opportunity to augment the local mainstem aggregation. The failure of at least 20% of translocated humpback chub to survive in the creek or adjacent mainstem aggregation for at least 1 year would indicate that the translocation failed to meet objectives, and the project would be re-evaluated and discontinued, if appropriate (USDOI 2013).

Indicators for the evaluation of these initial experimental translocation efforts for each of the potential outcomes include (*a*) retention of translocated humpback chub for a minimum of one year, (*b*) similar or increased survival of juveniles relative to survival in the Colorado River (mainstem), (*c*) similar or increased growth rates relative to the Little Colorado River and mainstem, (*d*) contributions to the mainstem aggregation, (*e*) evidence of successful reproduction, (*f*) evidence of recruitment to maturity (Trammell et al. 2012, USDOI 2013). Data collected between 2009 and 2019 are available to assess criteria *a* through *f* for 2009, 2010, 2011, and 2013 cohorts translocated to Shinumo Creek, and for cohorts translocated annually to Havasu Creek between 2011 to 2016. Insufficient data are available to evaluate indicators for humpback chub translocated to Bright Angel Creek in 2018 and 2020 (e.g., a minimum of 3 sampling periods are needed for survival modeling).

METHODS

Study Area

Humpback chub collections, translocations, nonnative fish control, and monitoring associated with the conservation measures activities occurred in four tributaries of the Colorado River, including the LCR, Shinumo, Bright Angel, and Havasu creeks, within the boundaries of GCNP (Figure 1, Table 1). Monitoring of humpback chub in the LCR is completed by the USFWS, in cooperation with the U. S. Geological Survey – Grand Canyon Monitoring and Research Center (GCMRC).

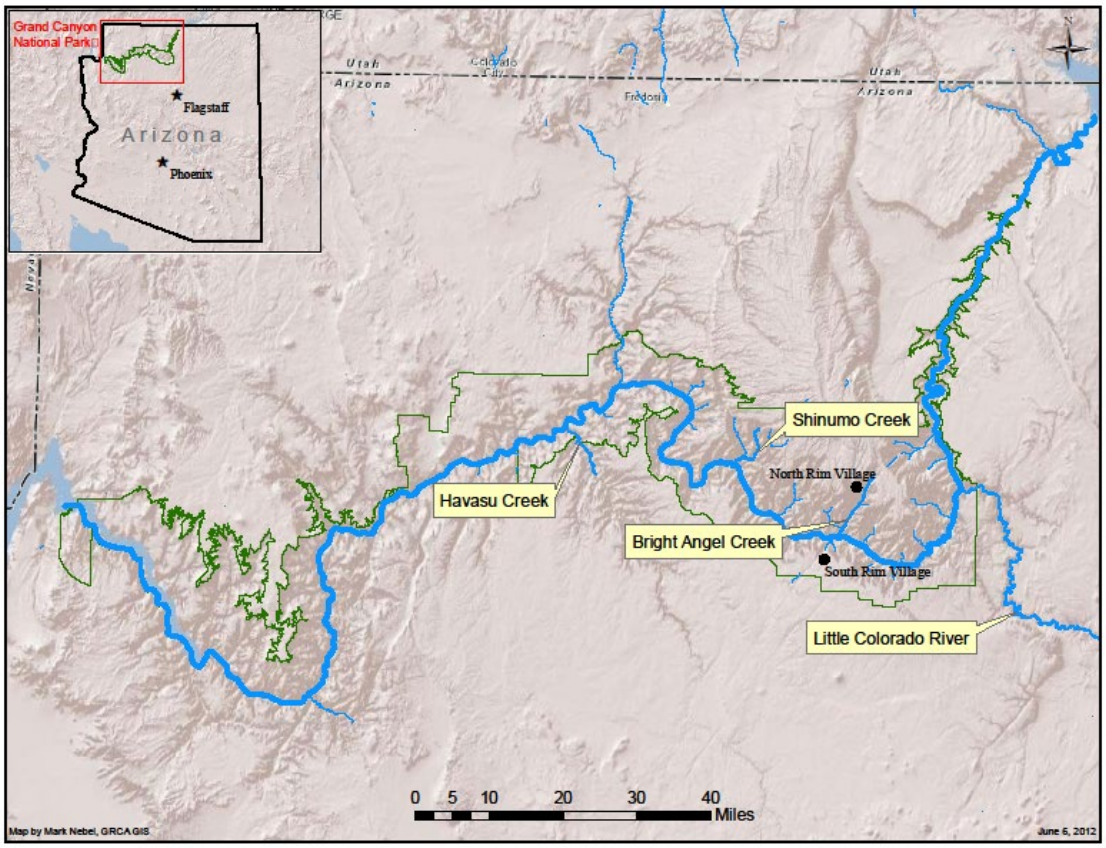

Figure 1. The project area, including the Little Colorado River which is the source for collections of humpback chub for translocations, and translocation sites including Shinumo Creek, and Bright Angel Creek, Havasu Creek in Grand Canyon National Park (green boundaries).

Table 1. Planned translocations or monitoring of humpback chub in fiscal year 2020.

Location	Dates completed	Activity
Havasu Creek (May)	COVID-cancellation	Monitoring
Havasu Creek	Oct. 8 -12, 2019	Monitoring
Little Colorado (June)	COVID-cancellation	Larval collection
Bright Angel Creek	June 8-11, 2020	Translocation
Shinumo Creek/Inflow	July 21- Aug. 1, 2020	Monitoring
Shinumo Creek/Inflow	Sept. 2-18, 2020	Monitoring

Humpback Chub Translocation Program

During FY2020, the NFEC program completed three translocation monitoring trips, including one to Havasu Creek in October 2019, and one to sample the Shinumo Creek-Colorado River Inflow reach in July and the third to the Shinumo Creek-Colorado River Inflow in September 2020 (Table 1). In addition, in collaboration with the USFWS– Southwest Native Aquatic Resources and Recovery Center (SNARRC), the NFEC program translocated 415 juvenile humpback chub to Bright Angel Creek in June (Table 2, Figure 2). Humpback chub translocated to Bright Angel Creek in 2018 were captured during the fall 2019/winter 2020 electrofishing operations to target and remove trout in the creek (Schelly et al. 2020). All invasive species captured incidental to monitoring in Havasu Creek (3 rainbow trout) and in the Shinumo Creek Inflow reach (5 rainbow trout in July, 1 in September) were humanely euthanized and put to beneficial use, to the extent practical and safe, and consistent with outcomes of Section 106 consultation with Traditionally Associated Tribes (U.S. Department of Interior 2013). The COVID-19 pandemic resulted in temporary closures of GCNP and the Navajo Nation which led to delays or cancellations of two planned trips including the spring Little Colorado River young-of-year (YOY) humpback chub collection trip, the monitoring trip planned for Shinumo Creek in June (delayed), and the May 2020 Havasu Creek monitoring trip (Table 1).

The June 2020 translocation to Bright Angel Creek was the second of several planned to occur (Table 2), consistent with agency guidance documents, including the USFWS – NPS Translocation and Refuge Framework (Van Haverbeke et al. 2016), Humpback Chub Genetics Management Plan (USFWS 2010), and CFMP (USDOI 2013). These guidance documents suggest at least 1,000 humpback chub be translocated per translocation site over a period of 5 years (i.e., 200 or more annually). Across all tributaries, the 2020 translocation event was the 13th translocation with 415 chub released (Table 2, Table 3, Figure 2). Translocations to Bright Angel have typically been limited by failed larval collections due to low production in the source (the LCR) with the exception of 2019 when sufficient YOY fish were collected to supplement the refuge population at SNARRC and allow for 415 fish to be released in Bright Angel Creek in 2020. The translocation to Bright Angel and other humpback chub monitoring events are described below.

Table 2. Summary of average size at tagging, tag dates, release dates, and number of humpback chub released into Shinumo, Havasu, and Bright Angel creeks from 2009-2020, listed in order of release date (see Spurgeon et al. 2015b, Schelly et al. 2019, Healy et al. 2020a). The 2020 translocation is highlighted in gray.

Tributary	Hatchery Tagging Date	Average Length (mm)	Average Weight (g)	Release Date	Number Translocated
Shinumo Creek	May 18, 2009	127.9	18.7	June 15, 2009	302
Shinumo Creek	June 10, 2010	121.1	15.3	June 23, 2010	300
Shinumo Creek	May 5, 2011	88.9	5.4	June 21, 2011	300
Shinumo Creek	June 10, 2013	123.3	14.8	June 15, 2013	200
Havasu Creek	May 5, 2011	86.1	4.8	June 28, 2011	243
Havasu Creek	May 10, 2012	124.7	16.7	May 13, 2012	298
Havasu Creek	May 9, 2013	123.1	14.9	May 14, 2013	300
Havasu Creek	May 14, June 5, 2014	123.5	16.4	May 14, 2014, June 5, 2014	300, 209
Havasu Creek	May 13, 2015	131	20.3	May 20, 2015	300
Havasu Creek	May 10, 2016	130	18.5	May 18, 2016	305
Bright Angel Creek	May 1, 2018	258	141	May 14, 2018	116*
Bright Angel Creek	June 1, 2020	129	17.5	June 9, 2020	415

*A hatchery tagging error led to an uncertain number of uniquely tagged fish released.

Table 3. The number of humpback chub translocated to each tributary from 2009-2020.

Tributary	Total # translocated
Shinumo Creek	1,102
Havasu Creek	1,955
Bright Angel Creek	531

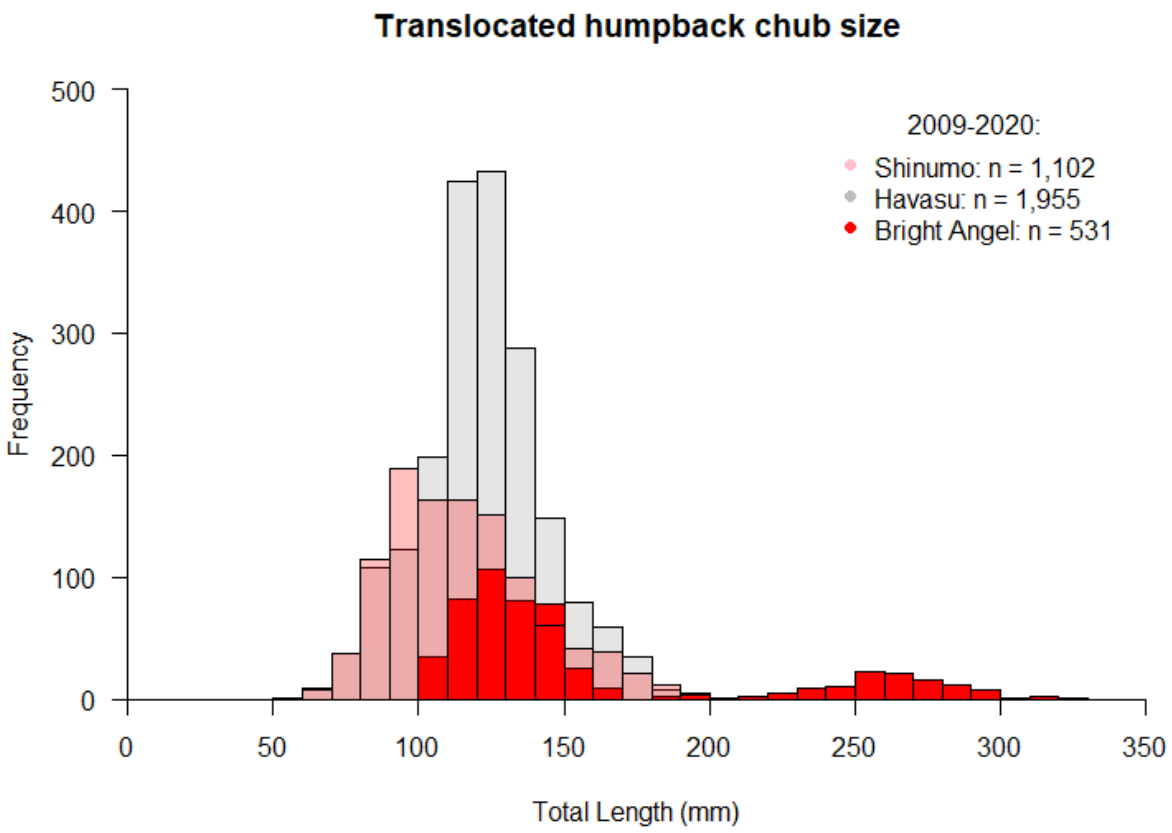

Figure 2. Size structure of all translocated humpback chub to Shinumo, Havasu, and Bright Angel Creeks between 2009 and 2020. The total number of fish translocated by tributary is provided in the legend.

Shinumo Creek-Colorado River Inflow Humpback Chub Monitoring – Summer 2020

Two monitoring trips were conducted in 2020 in Shinumo Creek and the Shinumo Creek inflow reach of the Colorado River (river miles 108.4-109.3; Figure 3). Crews set 20 hoop nets over 3 nights (60 total net sets) covering the Inflow, as well as 3 nets in the lower ~200 m of Shinumo Creek itself on each trip (Figure 3). Thirteen humpback chub were captured in July and 10 were captured in the Shinumo Creek Inflow or Creek mouth in September. Of all the humpback chub captured on both trips, 9 were released during previous translocations including 6 from 2010, 2 from 2013, and 1 from the 2011 cohort. Young-of-year humpback chub were captured on both trips, including one from below Shinumo Creek Falls and one from the Inflow reach in July, and 5 between 53 and 89 mm total length (TL) captured during the September trip. Spawning was observed in Shinumo Creek below the falls in June 2019, but no monitoring was conducted upstream of the waterfall (reaches 1-5) in Shinumo Creek in 2020 due to limitations on crew size associated with COVID-19 recommendations to protect employees.

A comprehensive analysis of survival and site fidelity was initiated in 2020 using mark-recapture/resight data (2009 – 2019) for all translocated fish in translocation sites and the mainstem collected by the NPS and all cooperating agencies, and including detections of translocated fish on the Shinumo Creek or LCR PIT-tag antenna systems, for fish translocated to Shinumo (n = 1,102) and Havasu Creeks (n = 1,955, Figure 2, Table 3). Preliminary modeling indicates that juvenile humpback chub that were translocated to Shinumo Creek survive at similar rates relative to survival in the LCR (Spurgeon et al. 2015b; Healy et al. *in prep*.). However, survival during the interval corresponding to the catastrophic ash-laden flood that occurred during the summer of 2014 following the Galahad Fire in the Shinumo Creek watershed suggests that high mortality, rather than high emigration, occurred during this flood, likely due to a combination of toxic ash and flood severity.

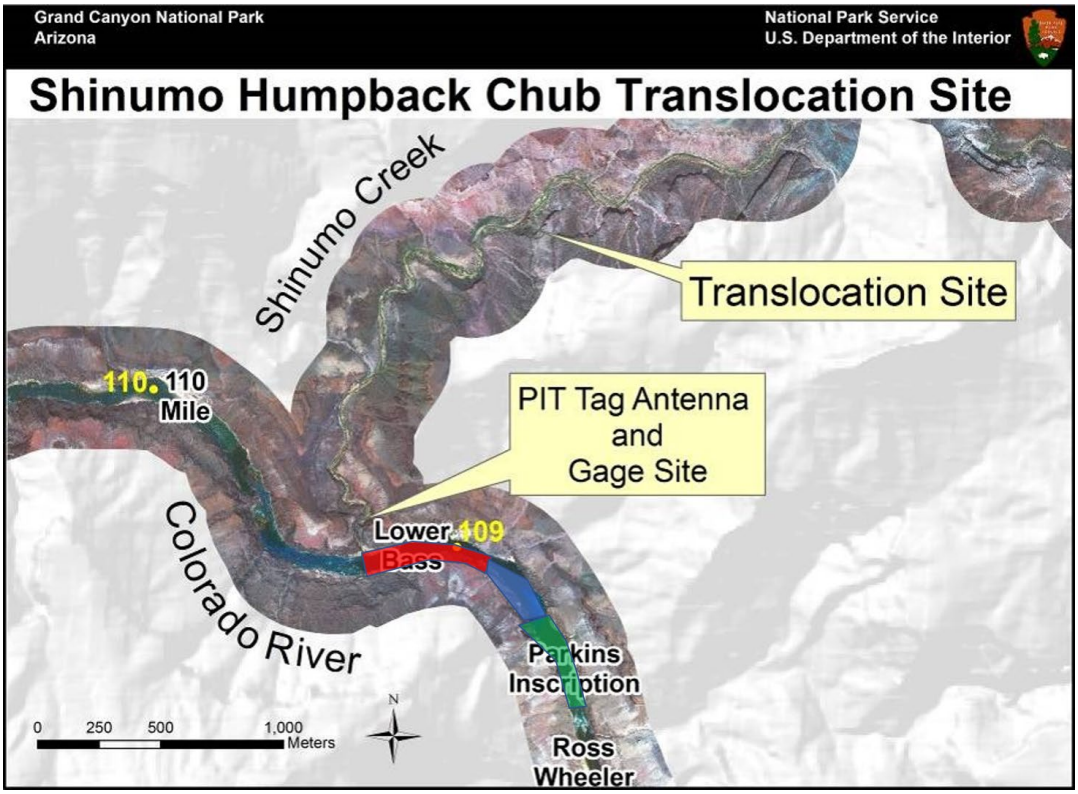

Figure 3. Location of the former PIT tag antenna, translocation site, and 3 sampling reaches in the Shinumo Creek Inflow of the Colorado River are colored (red-lower reach, blue-middle, green-upper). The hoop net sampling reach was bounded on the lower end by Shinumo Rapid, downstream of Lower Bass Camp, and on the upstream end by Bass Rapid, just downstream of the site of the abandoned Ross Wheeler vessel.

Havasu Creek Monitoring and Abundance Estimation

Monitoring was designed to estimate abundance of humpback chub at translocation sites at least once per year in Shinumo and Havasu Creeks where populations are isolated above barriers (Trammell et al. 2012, DOI 2013). Genetic management plans recommend that at least

200 humpback chub should be maintained at each site if reproduction occurs, with occasional augmentation with LCR fish, as necessary to maintain genetic integrity (USFWS 2010, Van Haverbeke et al. 2016). Although abundance in 2019 appeared to drop below this threshold in Havasu Creek (see Figure 4 below), USFWS and NPS decided to forgo augmentation in 2020 in order to gain further understanding of the population dynamics through continued mark-recapture modeling of humpback chub in Havasu Creek.

In FY2020, it was not possible to obtain an abundance estimate in Havasu Creek using two-pass closed-population abundance models because the May 2020 two-pass sampling trip was cancelled. As an alternative, a boot-strapping technique (Buckland and Garthwaite 1991) was used to model abundance and calculate confidence intervals for FY2020 and all sampling occasions using total catch of humpback chub and past capture probability estimates from the first (or only) pass from each spring and fall monitoring trip. Variance was estimated by pooling first-pass capture probability estimates obtained through past closed-population model estimates (Healy et al. 2020b), and recapture probability estimates from a joint-live recapture/resight (JLRR) open-population model (Barker 1997) for sampling occasions when a single netting pass was conducted (Healy et al. *in prep.*). In general, single-pass sampling is conducted in the fall, except for 2014 when two-passes were completed to obtain an annual abundance estimate, after logistical constraints limited sampling in spring (see Table 4; Healy et al. 2020a). To standardize catch by effort and estimate abundance, total humpback chub catch (tagged and untagged individuals) from the first pass of each trip was used to calculate the abundance ($\hat{n}$) using the mean capture probability ($\hat{p}$) from all occasions ($\hat{n} = 1st\ pass\ catch/\hat{p}$). The variance and confidence intervals were estimated using bootstrap (1,000 samples with replacement, see Appendix for R code and distributions of $\hat{p}$ from open and closed models).

The abundance estimate for humpback chub in Havasu Creek in FY2020 was calculated based on catch from the October 2019 monitoring trip. The abundance estimate was 167 with a 95% confidence interval of 143 – 200, which was higher than the spring 2019 bootstrapped estimate of $\hat{n} = 116$ (95% C.I. = 106 – 128; Figure 4). The 2019 spring bootstrapped estimate was similar to the $\hat{n}$ estimate using two-pass closed-population models from spring of 2019 ($\hat{n} =$ 116, 95% C.I. = 109 - 153), suggesting this method may be appropriate in lieu of two-pass mark-recapture sampling when logistical constraints limit sampling to a single pass. Abundance in fall 2019 likely increased as a result of new recruits in the population (Figure 5), which is typical of spring-fall trends (Healy et al. 2020a). Mean $\hat{p}$ estimates were higher in spring closed-population sampling than in fall sampling events (0.76 vs. 0.58) estimated from the JLRR model (see Appendix Figure A1). Since the last translocation in 2016, abundance generally declined in Havasu Creek, however a particularly strong year class in 2017 led to a temporary increase evident in spring 2018 estimates (Figure 4; Table 4). A fall 2018 estimate could not be generated since flooding interrupted sampling of most of the creek, including in reach 3 where the majority of humpback chub. Modeled estimates are only possible when at least one complete sampling pass is completed.

Havasu Creek Survival and Recruitment

Mark-recapture data collected beginning in 2011 through fall of 2019 in Havasu Creek by NPS, and by all cooperators sampling throughout the Colorado River ecosystem, were used for preliminary survival and fidelity estimates, using the JLRR model as described above (Healy et al. *in prep.*). As in Shinumo Creek, modeling suggests survival of translocated fish was comparable to survival of juvenile humpback chub in the LCR (Yackulic et al. 2014, Dzul et al. 2016, Healy et al. 2020a), meeting criteria for success established for translocations (Trammell et al. 2012, U.S. Department of Interior 2013). Preliminary analysis suggests survival may be density-dependent, and that flooding may also influence humpback chub survival; higher flood frequency and magnitude was associated with higher survival (Healy et al. *in prep.*). Annual recruitment of humpback chub produced *in situ*, which was estimated using a temporal symmetry model (Pradel 1996), was negatively related to rainbow trout and humpback chub density, but a model including flooding during the natal year was also supported (preliminary results, Healy et al. *in prep.*).

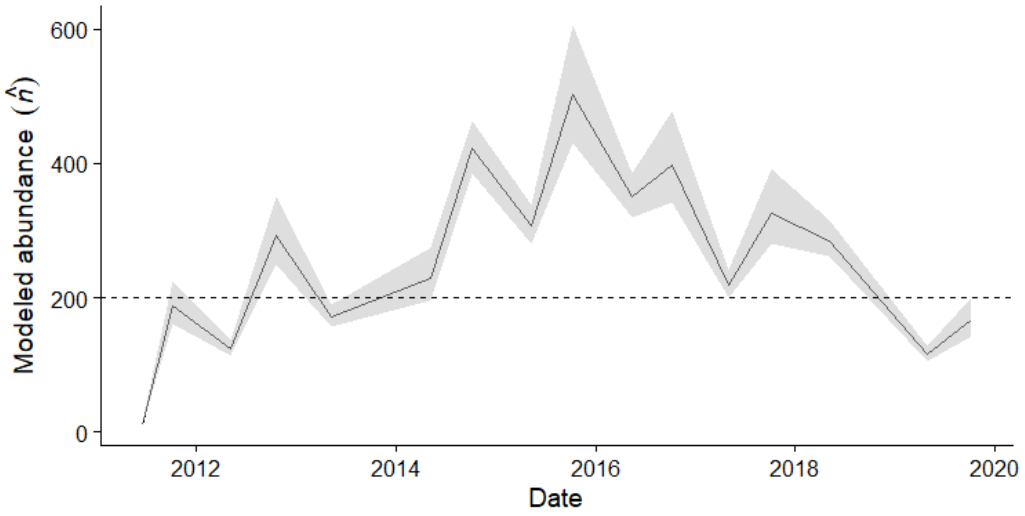

Figure 4. Modeled Havasu Creek humpback chub abundance (all size classes) for spring and fall sampling occasions between June 2011 (pre-translocation) and October 2019. Abundance estimates were derived using single-pass total catch and mean capture probability estimates ($\hat{n} = 1st\ pass\ catch/\hat{p}$) and bootstrapped confidence intervals (shaded band) from open and closed models (first pass capture probability only). Dashed horizontal line indicates the minimum population size objective from the Comprehensive Fisheries Management Plan.

Table 4. Havasu Creek humpback chub catch on the 1st hoop-netting pass, 1st – pass capture and probabilities estimated from open (Joint-live recapture/resight model, Healy et al. *in prep.*) or closed population models (Huggin's models; see Healy et al. 2020a) used for generating abundance estimates and bootstrapped confidence intervals (see text, and Appendix). The capture probabilities for the first and last sampling events are confounded in time-varying open models ($\hat{p}$ =NA). Abundance estimates and 95% confidence intervals are also displayed for each sampling event in Havasu Creek from 2011 through 2019.

Trip Date (start date)	Humpback chub catch (1st pass)	1st pass capture probability ($\hat{p}$)	Model	Abundance Estimate ($\hat{n}$)	Upper 95% C. I.	Lower 95% C.I.
6/15/2011	7	NA	open	12	14	10
10/8/2011	109	0.55	open	187	225	160
5/6/2012	94	0.68	closed	124	137	114
10/16/2012	170	0.48	open	292	351	250
5/7/2013	130	0.68	closed	172	189	157
5/7/2014	133	0.83	open	229	275	196
10/8/2014	319	0.53	closed	422	465	386
5/13/2015	232	0.83	closed	307	338	281
10/7/2015	293	0.58	open	504	605	431
5/11/2016	265	0.88	closed	350	386	321
10/6/2016	232	0.48	open	399	479	342
5/4/2017	166	0.76	closed	219	242	201
10/3/2017	190	0.58	open	327	392	280
5/3/2018	216	0.81	closed	285	315	261
4/30/2019	88	0.94	closed	116	128	106
10/8/2019	97	NA	open	167	200	143

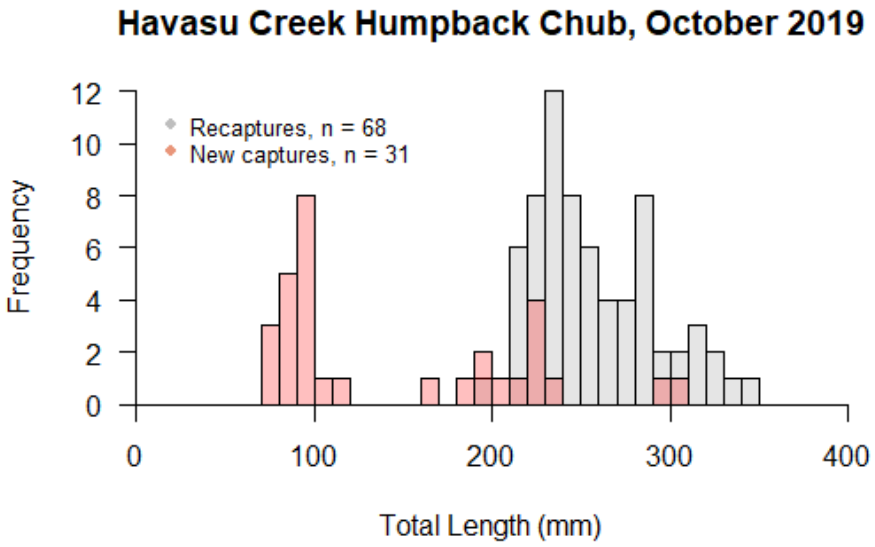

Figure 5. Size structure of humpback chub captured during October 2019 single-pass hoop-net sampling in Havasu Creek, including new recruits to the population (salmon colored bars).

Bright Angel Creek Captures and Passive-integrated Transponder Antenna Detections

Humpback chub were rarely captured during electrofishing in Bright Angel Creek during the 2019-2020 fall-winter electrofishing season (Schelly et al. 2020). Only 4 unique PIT-tagged individuals were recaptured, and one was captured twice. Three of the 4 fish captured were translocated in 2018. The origin of the 4th recaptured fish could not be discerned since the PIT tag number could not be found in GCMRC or NPS databases or in lists of translocated fish. All fish were recaptured and released in reach 2 in Bright Angel Creek, between approximately 3 – 6 km from the Colorado River.

Low catch rates of humpback chub in Bright Angel Creek may be partly related to capture method and water temperature. Electrofishing may not be an ideal method for monitoring humpback chub during the winter months in Bright Angel Creek when water temperatures are colder (mean 6.7°C during sampling in reaches 1-3). Past experience in Shinumo Creek (NPS data, B. Healy personal observation) and in the Colorado River (Yackulic et al. 2018), suggests capture probability is lower when water temperatures are cold compared to summer hoop-netting, when water is warmer and fish may be more active. For instance, only 6 humpback chub were recaptured in Shinumo Creek during March 2014 electrofishing operations when temperatures averaged ~10°C, but 114 were recaptured with hoop nets during June 2014 netting operations when water temperatures are much warmer (~18-19°C; NPS data).

Analysis of Bright Angel Creek PIT-tag antenna data revealed detections of a total of 57 unique humpback chub (50 released in 2018 and 7 from the 2020 Bright Angel Creek

translocation). Generally, these detections occurred during the summer months, peaking in May and June (Figure 6). In addition, 10 non-translocated humpback chub tagged in the Colorado River or Little Colorado River and one fish released in Shinumo Creek in 2011 were also detected between July 3, 2018 and May 12, 2020 (Table 5). Both upstream and downstream movements of translocated and non-translocated humpback chub were detected, although as of October 14, 2020, only downstream movements (i.e., dispersal) of the 2020 translocated cohort have been observed. The detection of only 7 humpback chub belonging to the 2020 cohort (out of 415 total released) suggests low emigration rates from the translocation site, but additional monitoring is needed to assess survival within the creek.

The Bright Angel Creek PIT tag antenna also revealed movements of other species within the creek. Native flannelmouth sucker (n = 1,466) and bluehead sucker (18), and invasive brown trout (n = 2) and rainbow trout (n = 13) tagged outside of Bright Angel Creek by non-NPS crews (USGS-GCMRC data) were also detected on the antenna array. The brown trout detected on the antenna were later captured and removed by NPS electrofishing crews, as were 2 of the rainbow trout detected at the antenna. Both brown trout and 3 rainbow trout detected were initially tagged upstream of Lees Ferry and tagging locations of rainbow trout ranged from river mile -12 to 164.

Detection data from the Bright Angel Creek array will be incorporated into mark-recapture models to estimate survival, emigration rates, and potentially abundance for translocated humpback chub once sufficient sampling has been completed to populate individual encounter histories. Detections of PIT-tagged humpback chub translocated to Shinumo Creek on the Shinumo Creek antenna system proved to be valuable in understanding emigration and survival of translocated humpback chub early in the translocation program (Spurgeon et al. 2015b), which ultimately informed planning of future translocations (Pine et al. 2013).

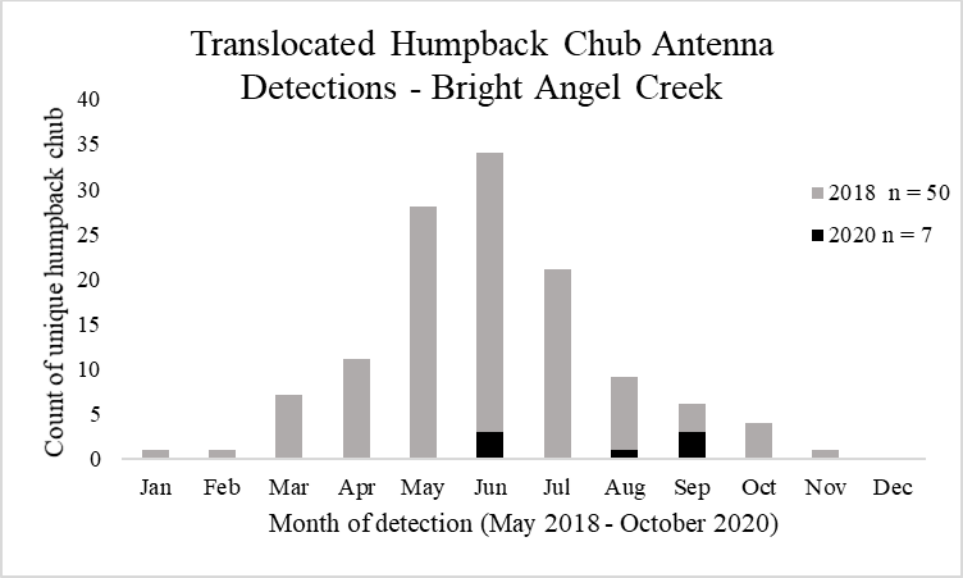

Figure 6. Counts by month of unique individual humpback chub translocated to Bright Angel Creek on May 16, 2018 and June 11, 2020 detected on the Bright Angel Creek passive-integrated transponder antenna array. Detections between May 20, 2018, And October 14, 2020 are included (antenna installation completed May 9, 2018).

Table 5. Humpback chub tagged/released outside of Bright Angel Creek and detected on the Bright Angel Creek PIT-tag antenna array between May 9, 2018 and October 15, 2020. River/tributary codes: SHI = Shinumo Creek, COR=Colorado River, LCR=Little Colorado River.

River/Trib.	Tagging Location (River mile)	Tagging date	PIT-tag	Size at Tagging/ capture (TL)	Antenna det. (latest date)
SHI	NA	21-Jun 2011	3D9.1C2D9AFB11	87	04-Jun 2019
COR	87.9	09-Sep 2019	3D9.2794E89517	277	23-Jul 2018
COR	91.82	10-Sep 2019	3D9.2794E8C3FF	321	13-Jul 2018
COR	87.77	09-Sep 2019	3D9.2794E9AB84	311	18-May 2019
COR	63.46	20-Sep 2013	3DD.003BA0A7CE	436	05-Jun 2019
COR	87.9	09-Sep 2019	3DD.003BB9A809	294	19-Jun 2019
COR	87.45	25-Aug 2018	3DD.003BB9AF70	260	19-Jul 2018
COR	63.79	18-Jan 2016	3DD.003BCA8465	138	09-Aug 2019
COR	64.08	21-Sep 2015	3DD.003BCA8465	131	09-Aug 2019
COR	79.94	03-May 2015	3DD.003BCAB3F0	140	03-Jul 2018
COR	61.31	14-Sep 2016	3DD.003BCF2D05	177	26-Apr 2020
LCR	NA	21-Apr 2018	3DD.003BCF2D05	214	26-Apr 2020
COR	SHI inflow	15-Jun 2015	3DD.003BA20EC6	214	12-May 2020

Planned Activities – 2021

In 2021, the NFEC program is planning to continue monitoring trends in abundance of the Havasu Creek humpback chub population, to work cooperatively with USGS-GCMRC to analyze genetic material collected from recruits, and assess drivers of growth, survival, and recruitment in Shinumo (growth and survival only) and Havasu Creeks through mark-recapture modeling. Monitoring will consist of single- and two-pass hoop-netting in October 2020 and May 2021, respectively. Planned installation of portable (temporary) PIT tag antennas (pending completion of compliance) near the mouth of Havasu Creek may also improve the precision of emigration and survival estimates, since resight rates of fish that emigrated from Havasu Creek were low, which may limit precision of fidelity and survival estimates (Healy et al. *in prep.*). Improving precision of these estimates will allow for a clearer understanding of factors limiting growth, recruitment, and survival of humpback chub, which will inform future management of the population.

Since very few humpback chub translocated to Bright Angel Creek have been recaptured during winter, abundance cannot currently be estimated. In order to improve these estimates, in addition to fall-winter electrofishing, the NFEC program will conduct a hoop-net monitoring event during warmer months when antenna data have indicated higher levels of activity of humpback chub (May or June). Portable PIT tag antennas positioned through the creek may also augment capture histories and facilitate abundance and survival analyses.

Monitoring at Shinumo Creek and the Shinumo Creek Inflow reach of the Colorado River is currently planned for June and September of 2021. The NFEC program will consult with the BOR and USFWS to assess additional data needs and priorities for continued monitoring at Shinumo Creek. In a separate effort, NPS is working with additional collaborators to complete a thorough analysis of post-fire/flood stream habitat and fish and macroinvertebrate community data (with USGS-GCMRC and University of Kentucky cooperators, planned for 2021). These analyses will inform future monitoring needs, potential invasive trout control, and translocations of humpback chub.

All translocation-related activities in 2021 are contingent on the ability of crews to conduct monitoring and collection trips while mitigating the risk of COVID-19 exposure and infection. NFEC staff will continue to coordinate with NPS epidemiologists to develop and implement COVID-19 mitigations and manage risk to the extent possible, which could include trip cancellations or postponements. Nonetheless, in consultation with the Navajo Nation and USFWS, collection of YOY humpback chub targeting the early life stages (to minimize impact to the adult population, sensu Pine et al. 2013), is planned in 2021. Collection would occur at the LCR during the spring of 2021 and would be released in Bright Angel Creek or Havasu Creek, or would be used to augment the refuge population at SNARRC in 2022.

ACKNOWLEDGEMENTS

Funding was provided by the Bureau of Reclamation, Upper Colorado Region, and in 2019, the NPS Native Fish Ecology and Conservation Program received a grant from the Arthur L. and Elaine V. Johnson Foundation and the Grand Canyon Conservancy to support translocations. Numerous cooperating agencies, universities, non-governmental organizations, as well as volunteers provided valuable assistance during planning and implementation of these projects. These include the U.S. Fish and Wildlife Service, Arizona Game and Fish Department, USGS-GCMRC, Grand Canyon Wildlands Council, University of Missouri and USGS Coop. Unit, Utah State University, the University of Florida, and the Museum of Northern Arizona. The NPS Cooperative Ecosystems Study Unit also coordinated funding. The NPS-GCNP aviation unit and the NPS River District provided valuable logistics support as well.

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Appendix A– R code for bootstrap confidence intervals

Bootstrapping is a nonparametric method which computes estimated standard errors, confidence intervals for hypothesis testing. The following code was developed in R (R Core Team 2019) to implement bootstrapping for Havasu Creek abundance estimates and confidence intervals.

```
#import data
Hav_bootpcaps<-
read.csv("C:/Users/BHealy/Documents/fish_program/monitoring/Havasu/FY2020/HBC_pcaps_1stpassCaps.csv",
sep=",", header = TRUE)

openModelAll<-subset(Hav_bootpcaps, Model=="open")
#here subsetting for p-caps for bootrapping by removing 1st/last confounded p-hats in open
openModel<-subset(Hav_bootpcaps, Model=="open" & Pass1pcap>0)
closedModel<-subset(Hav_bootpcaps, Model=="closed")

open.mnpcap<-mean(openModel$Pass1pcap, na.rm=TRUE)

B = 1000
n = 6
boot.samples = matrix(sample(openModel$Pass1pcap, size = B * n, replace = TRUE),
                      B, n)
boot.statistics = apply(boot.samples, 1, mean)
hist(boot.statistics)
openpcap.se = sd(boot.statistics)
openpcap.se
me = (10 * 2 * openpcap.se)/10
open.pcap.int<-open.mnpcap + c(-1, 1) * me

openModelAll$n.hat<-openModelAll$Pass1HBCcounts/open.mnpcap
openModelAll$upper<-openModelAll$Pass1HBCcounts/open.pcap.int[1]
openModelAll$lower<-openModelAll$Pass1HBCcounts/open.pcap.int[2]

openModelAll$Date<-as.Date(openModelAll$Date)
plot(openModelAll$n.hat~openModelAll$Date)

plotopen<-
ggplot(data=openModelAll,aes(x=Date,y=n.hat))+geom_point()+geom_line()+geom_ribbon(data=openModelAll,
aes(ymin=lower,ymax=upper),alpha=0.3)
plotopen

#~~~~~~~~~~~
#Closed
closed.mnpcap<-mean(closedModel$Pass1pcap, na.rm=TRUE)

Bc = 1000
nc = 12
boot.samples.c = matrix(sample(closedModel$Pass1pcap, size = Bc * nc, replace = TRUE),
                      Bc, nc)
boot.statistics.c = apply(boot.samples.c, 1, mean)
hist(~boot.statistics.c,las=1, xlim=c(0.5, 1), xlab="Capture probability")
closedpcap.se = sd(boot.statistics.c)
closedpcap.se
mec = (10 * 2 * closedpcap.se)/10
closed.pcap.int<-closed.mnpcap + c(-1, 1) * mec
```

```
closedModel$n.hat<-closedModel$Pass1HBCcounts/closed.mnpcap
closedModel$upper<-closedModel$Pass1HBCcounts/closed.pcap.int[1]
closedModel$lower<-closedModel$Pass1HBCcounts/closed.pcap.int[2]

closedModel$Date<-as.Date(closedModel$Date)

plot(closedModel$n.hat~closedModel$Date, ylim=c(0, 500))
theme_set(theme_cowplot())
plotclosed<-
ggplot(data=closedModel,aes(x=Date,y=n.hat))+geom_point()+geom_line()+geom_ribbon(data=closedModel,
aes(ymin=lower,ymax=upper),alpha=0.3)

#combine bootstrapped p-caps from open and closed model abundance estimattes
hav_bootnhats<-rbind(closedModel,openModelAll)
#remove NAs
hav_bootnhats2<-subset(hav_bootnhats, n.hat>0)
#sorted all estimates by date
hav_bootnhats3<-hav_bootnhats2[order(hav_bootnhats2$Date),]

theme_set(theme_cowplot())
plotall<-ggplot(data=hav_bootnhats3,aes(x=Date,y=n.hat))+geom_line()+geom_ribbon(data=hav_bootnhats3,
aes(ymin=lower,ymax=upper),fill="gray",alpha=0.5)+labs(x="Date", y=expression(paste("Modeled abundance" ~"
"~ (italic(hat(n))))))+ geom_hline(yintercept = 200,linetype="dashed")
plotall
#plot of distribution of boostrapped estimates
hist(~boot.statistics.c,las=1, xlim=c(0.3, 1), xlab="Capture probability")
hist(~boot.statistics,las=1, xlim=c(0.3, 1), add=TRUE,col=rgb(1,0,0,1/4))
legend("topleft",title = " ", legend=c("Open model","Closed model"),col=c("pink", "gray"), pch=16, inset =
0.01,cex=.9, box.lty=0)
plot(n.hat~Date,data=hav_bootnhats2, type="l")
```

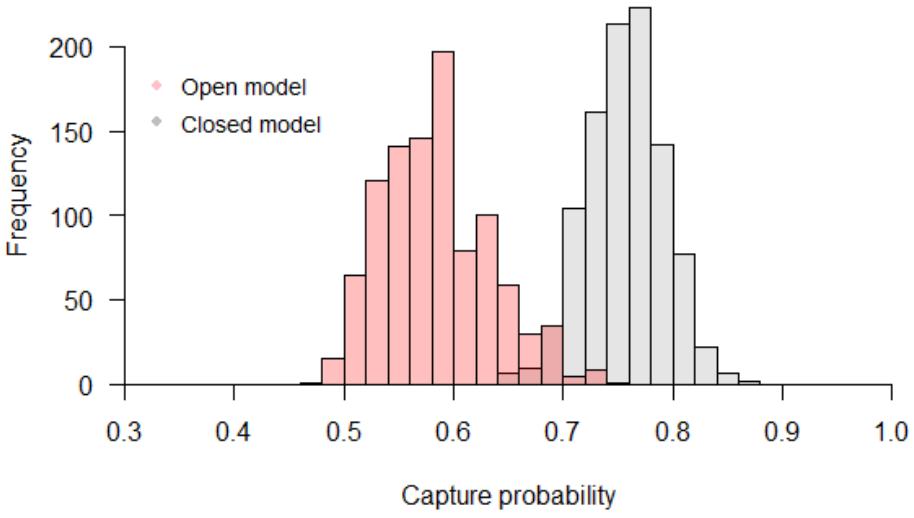

Figure A1. Distribution of bootstrapped capture probability estimates from open- and closed-population mark-recapture models.