Grand Canyon

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Grand Canyon National Park

Translocation of Humpback Chub to Grand Canyon Tributaries and Related Nonnative Fish Control Activities: 2011-2013 Report

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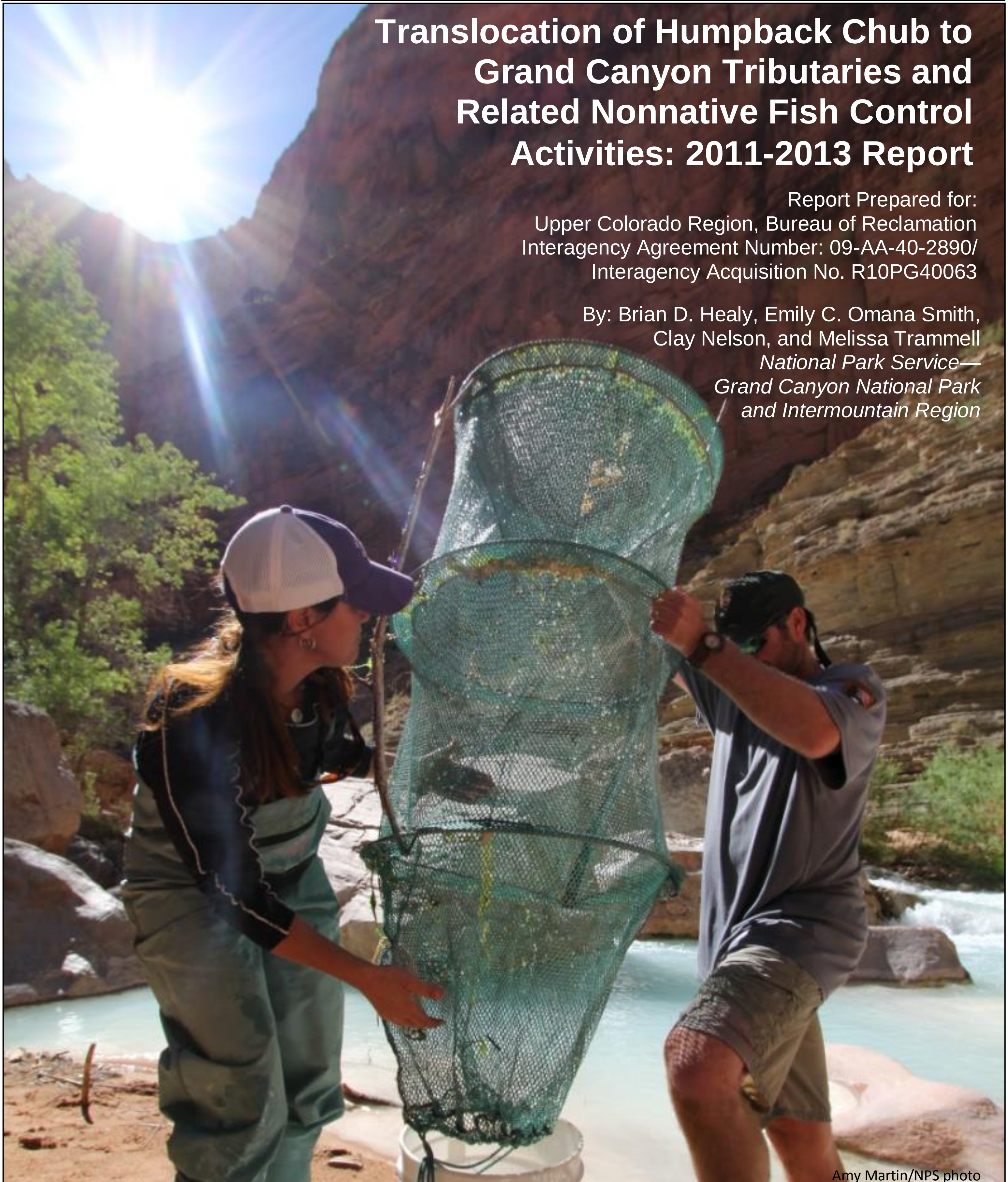
By: Brian D. Healy, Emily C. Omana Smith,
Clay Nelson, and Melissa Trammell
National Park Service—
Grand Canyon National Park
and Intermountain Region



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EXECUTIVE SUMMARY

The Humpback Chub (*Gila cypha*), is a federally endangered cyprinid fish species, endemic to the Colorado River basin, with its largest remaining population occurring in nine aggregations within Grand Canyon National Park (GCNP), Arizona (Valdez and Ryel 1995, reviewed in Coggins et al. 2006). Despite recent increases in abundance (Coggins and Walters 2009), the Grand Canyon population remains threatened by habitat modifications related to the construction and operation of Glen Canyon Dam and introduced nonnative fish species. Translocations of Humpback Chub and associated nonnative fish control were established as conservation measures in Biological Opinions on the operations of Glen Canyon Dam (U.S. Fish and Wildlife Service, USFWS, 2008, USFWS 2011). The result of these efforts conducted between 2010 and 2013 are the focus of this report.

Translocations of Humpback Chub from the Little Colorado River to Shinumo and Havasu creeks were conducted between 2009 and 2013 to meet the intent of the conservation measures and to contribute towards the restoration of native fish communities in GCNP. Nonnative Rainbow Trout control was conducted in Shinumo Creek to improve survival of translocated Humpback Chub, as well as for native fish community restoration. Monitoring metrics established for translocations included Humpback Chub survival, growth, abundance, evidence of reproduction, and presence in the adjacent Colorado River mainstem aggregation. The effectiveness of nonnative trout control efforts was measured using trends in native and nonnative abundance and population size structure, as well as trends in survival of native species. A summary of monitoring metrics and a comparison to data from the Little Colorado and Colorado rivers is provided in Table I.

Emigration, or the rate of movement out of Shinumo Creek, of translocated Humpback Chub, was assessed using a fixed, remote PIT-tag antenna array installed near the mouth of Shinumo Creek. Emigration rates were highest immediately after release of Humpback Chub during all years and also appeared to be related to higher flows that occur during spring runoff and during summer monsoons. Approximately half (51%) of all Humpback Chub were found to have emigrated from Shinumo Creek through January 9, 2013; however, questions related to antenna detection efficiencies remain. No fixed antenna array could be installed at Havasu Creek, so emigration rates could not be assessed directly at Havasu Creek. However, based on mark-recapture-based estimates of apparent survival and abundance, emigration rates in Havasu Creek may be similar to those found for Humpback Chub in Shinumo Creek. Abundance estimates during May 2013 suggest approximately 27% of the 2011 cohort, and 38% of the 2012 cohort remained in Havasu Creek.

Annual apparent survival rate estimates (i.e., proportion/rate of Humpback Chub remaining and surviving over a year) of Humpback Chub ranged from 0.18 (95% confidence interval: 0.08 – 0.32) in 2010 in Shinumo Creek to 0.51 (95% C.I.: 0.44 – 0.87) for the 2011 cohort translocated to Havasu Creek. Apparent survival varied over time for Humpback Chub translocated to Shinumo Creek, but remained constant over time in Havasu Creek.

Table I. Evaluation criteria and monitoring results for Humpback Chub translocation projects in Grand Canyon National Park.

Indicator (Benchmark)	**Colorado River**	**Little Colorado River**	**Shinumo Creek**	**Havasu Creek**
Annual Retention or Apparent Survival (≥20% of translocated fish, first year after release)	28 – 75% [b] (depending on year)	NA	2009: 19% (14-26) 2010: 18% (8-32) 2011: 46% (34-55)	2011: 51% (45-57) 2012: 37% (29-46)
Juvenile Survival (monthly rate)	0.97[a]	0.91 [a]	Mean (all cohorts) = 0.89 (range 0.79 – 0.94, time-dependent model)	0.95 (2011 cohort) 0.92 (2012 cohort)
Growth rates (annual)	27 mm [c]	52-58 mm [d]	2009:33 mm 2010: 37 mm 2011: 65 mm	2011: 91 mm 2012: 67 mm
Contribution to aggregation	NA	NA	39 translocated fish (73% of all captures, 2013)*	14 translocated fish (47% of all captures 2013)*
Reproduction	NA	NA	No evidence	Yes (ripe adults, presence of juveniles)
Recruitment to mature size	NA	NA	No evidence	No evidence

*Preliminary GCMRC/USFWS/NPS (NPS-Shinumo Only) unpublished data.
[a] Yaculick et al. 2014.
[b] Finch et al. 2013.
[c] Valdez and Ryel 1995.
[d] Robsinson and Childs 2001

Humpback Chub growth rates were comparable to, or greater than, published growth rates found for juvenile Humpback Chub in the Little Colorado River, and greater than growth rates found for Humpback Chub in the Colorado River (Table I). Annual growth was highest in Humpback

Chub translocated to Havasu Creek in 2011 (91 mm), Havasu Creek in 2012 (67 mm), and Shinumo Creek in 2011 (64 mm), and lowest in the Shinumo Creek 2009 cohort (39 mm).

Evidence of reproduction of translocated Humpback Chub was found in Havasu Creek in 2012 and 2013. Ripe, spawning male Humpback Chub were captured in May 2012, and ripe male and female Humpback Chub, as well as untagged juvenile Humpback Chub were captured during in May 2013. No evidence of reproduction was found in Shinumo Creek, despite the presence of mature-sized Humpback Chub (i.e., >199 mm total length); however, a large proportion of fish captured in the nearby mainstem aggregations had been translocated. This information, combined with growth rate data, suggests that both Shinumo and Havasu creeks provide an adequate rearing or "grow-out" opportunity for juvenile Humpback Chub, at a minimum, which would result in augmented aggregations. Additional translocations and monitoring are planned to continue to both Shinumo and Havasu creeks under the adaptive management strategy developed in the Comprehensive Fisheries Management Plan (NPS 2013).

Results of Shinumo Creek nonnative fish control were evaluated using trends in native and nonnative fish abundance and size-structure, as well as survival of Humpback Chub. Electrofishing effort was concentrated upstream of translocation areas, while angling and netting were mainly used to remove trout from translocation areas and downstream to the mouth (approximately 2.8 km). Since 2009, a total of 2,207 Rainbow Trout were removed from Shinumo Creek using angling and netting gear, and 3,362 were removed using electrofishing equipment. Trout densities were reduced between summer 2011 and winter 2012, but rebounded with a strong cohort in June 2012 (likely a "compensatory response"). Abundance of Bluehead Sucker increased in the lower reaches downstream of translocation areas and Speckled Dace increased throughout Shinumo Creek as Rainbow Trout densities were reduced. Of the three cohorts translocated to Shinumo Creek (2009, 2010, and 2011), the highest annual survival for translocated Humpback Chub occurred when Rainbow Trout densities were lowest (2011), which also coincided with high spring runoff. No significant trend in Bluehead Sucker from electrofishing data was evident; however small Bluehead Suckers may not be sampled effectively with electrofishing equipment, and thus, a strong 2011 year class was only later detected through net-sampling (September 2013). Additional monitoring and analysis are needed to continue to assess trends in native and nonnative fish as a result of nonnative trout control efforts.

Electrofishing equipment has the potential to injure individual native fish, particularly during repeated efforts. Negative, population-level impacts were not observed in trends in native fish between 2010 and 2013; however, a compensatory response in Rainbow Trout was observed following a reduction in overall trout density. Continued Rainbow Trout control and monitoring are necessary to assess the effects of these projects on the native fish community.

INTRODUCTION

The Humpback Chub (*Gila cypha*) is a federally endangered cyprinid fish species endemic to the Colorado River basin, with its largest remaining population found in Grand Canyon National Park (GCNP), Arizona (reviewed in Coggins et al. 2006). Humpback Chub are 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 is the only aggregation known to be maintained by local reproduction (Valdez and Ryel 1995; but see Valdez and Masslich 1999). Despite recent increases in abundance (Coggins and Walters 2009), the Grand Canyon population remains threatened by habitat modifications related to the construction and operation of Glen Canyon Dam and introduced nonnative fish species (U.S. Fish and Wildlife Service [USFWS] 2011). Further, the perpetuation of the Humpback Chub in Grand Canyon relies almost solely on reproduction occurring within the Little Colorado River, which exposes the entire population to potential anthropogenic disturbances occurring throughout the Little Colorado River watershed outside of the park (e.g., chemical spills).

Translocations of juvenile Humpback Chub from the Little Colorado River to other Colorado River tributaries within GCNP is one option proposed to attempt to establish a second spawning aggregation in Grand Canyon (Valdez et al. 2000), as well as meet National Park Service (NPS) mandates for species conservation (NPS 2006) and contribute towards goals and objectives within the Comprehensive Fisheries Management Plan for GCNP (NPS 2013), including the restoration of native fish communities. Translocations and associated nonnative fish control in tributaries also contribute to partially fulfilling the Bureau of Reclamation's commitment to implement conservation measures established under the 2008 and 2011 Biological Opinions for the operation of Glen Canyon Dam (USFWS 2008, 2011). These conservation measures include translocation of Humpback Chub to Shinumo, Havasu, and Bright Angel creeks in GCNP.

Control of nonnative fish species is an important pre-cursor to translocations in all three tributaries to minimize predation risk to translocated fish, but particularly in Bright Angel Creek, where large populations of nonnative rainbow (*Oncorhynchus mykiss*) and brown (*Salmo trutta*) trout are present (Carothers and Minckley 1981, Otis 1994, Omana Smith et al. 2012). In addition, NPS management policies (NPS 2006) directs park resource managers to remove exotic species already present within NPS units when control is feasible and prudent, and the exotic species interferes with natural processes and perpetuation of native species or natural habitats. Both species of introduced trout present in GCNP are known to prey upon native fish (Spurgeon 2012, Whiting et al. 2014), including endangered Humpback Chub (Yard et al. 2011). Mechanical control methods used to remove nonnative trout are considered experimental. An evaluation of these methods is needed to refine and adapt techniques as necessary, and to monitor the impact of the control methods upon native species (NPS 2013).

OBJECTIVES

The initially proposed translocation experiment involved the translocation of wild, young-of-year Humpback Chub from the Little Colorado River to Shinumo, Havasu, and Bright Angel creeks, with associated monitoring, over a period of five years (2009-2014). Three initial translocations were planned for Shinumo Creek (Grand Canyon Wildlands Council and SWCA 2006) and Havasu Creek (Trammell et al. 2012). Objectives of translocations may vary by tributary, and under the adaptive management framework established in the recently completed Comprehensive Fisheries Management Plan (NPS 2013), desirable outcomes may include: 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 (NPS 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, NPS 2013).

Data are available to assess criteria *a* through *d* for 2009, 2010, and 2011 cohorts translocated to Shinumo Creek, while an assessment of reproduction and recruitment (criteria *e through f)* is ongoing. Similarly, insufficient data are available to assess the Havasu Creek translocation against all success criteria. However, all available post-translocation monitoring data through May 2013 for Humpback Chub translocated to Havasu Creek in 2011 and 2012 are evaluated and presented in this report.

To assess the effectiveness of nonnative trout control activities at Shinumo Creek, trends in abundance and size structure for both native and nonnative fish species, as well as survival of native fish were evaluated. If effective, removal of Rainbow Trout from Shinumo Creek would be expected to result in decreased abundance of Rainbow Trout, with a corresponding increase in survival, recruitment, and abundance of native species in the fish community. However, a compensatory response in young-of-year survival of trout and consequently, an increase in trout abundance may occur as a result of control efforts (see Meyer et al. 2006), possibly negatively impacting native species, negating any positive response in their abundance.

The water chemistry in Havasu Creek precluded the use of electrofishing equipment to sample Rainbow Trout, and thus, no targeted nonnative trout control efforts were conducted there. Nevertheless, nonnative trout were removed when they were captured during netting efforts, and netting catch data are also summarized in this report. The results of winter nonnative trout control conducted in Bright Angel Creek in 2010-2011 to prepare for a potential future translocation of Humpback Chub are summarized in a separate report (see Omana Smith et al. 2012), and a report on nonnative trout control conducted during the 2011-14 seasons is in preparation (Nelson et al., in prep).

METHODS

Study Area

Humpback Chub translocation, baseline sampling, and nonnative fish control activities occurred in three tributaries of the Colorado River, including the Little Colorado River, and Shinumo and Havasu creeks, within the boundaries of GCNP (Figure 1). A description of the physical characteristics of all three study tributaries is summarized in Table 1, including data provided in Valdez et al. (2000), Grand Canyon Wildlands Council & SWCA (2006), and Voichick and Wright (2007).

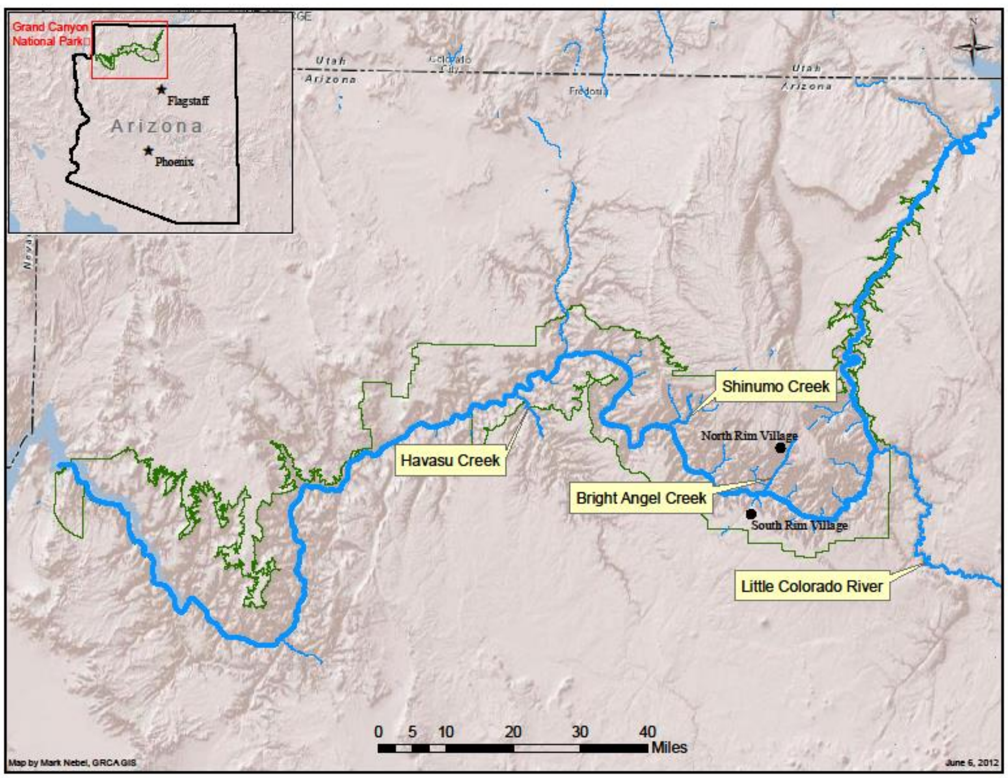

Figure1. The Little Colorado River, Shinumo Creek, and Havasu Creek are located in Grand Canyon National Park (green boundaries).

Shinumo Creek

Shinumo Creek is a small (wetted channel width 3.9 meters, range 3.0 – 5.8 meters), clear, spring-fed perennial tributary to the Colorado River with water temperatures ranging from 2 – 25°C in the lower reaches of the creek, approximate baseflow of 0.25 cubic m/sec (9 cubic feet per second), and a gradient of approximately 5% (NPS, unpublished data). The Shinumo Creek riparian zone consists of riparian plants including tree and shrub species such as Fremont cottonwood (*Populus fremontii*), coyote willow (*Salix exigua*), seep willow (*Baccharis salicifolia*), brickellia (*Brickellia longifolia*), and grasses such as California satintail (*Imperata brevifolia*) (M. McMaster, Invasive Plant Biologist, GCNP, personal communication, June 5, 2012).

Prior to Humpback Chub translocations, the fish community of Shinumo Creek consisted of native Speckled Dace (*Rhinichthys osculus*) and Bluehead Sucker (*Catostomus discobolus*), as well as Rainbow Trout (*Oncorhynchus mykiss*) (NPS unpublished data, 2005) introduced to Shinumo Creek beginning in the 1920s (Williamson and Tyler 1932).

Havasu Creek

Havasu Creek is most similar to the Little Colorado River in hydrology, water chemistry, and habitat (Valdez et al. 2000), and is one of the larger tributaries (baseflow approx. 60 cubic feet per second) to the Colorado River in GCNP. Havasu Canyon is dominated by riparian plant species including tree and shrubs species such as velvet ash (*Fraxinus velutina*), catclaw acacia (*Acacia greggii*), Fremont cottonwood (*Populus fremontii*), honey mesquite (*Prosopis glandulosa*) Emory's Baccharis (*Baccharis emoryi*), seep willow (*Baccharis salicifolia*), greythorn (*Ziziphus obtusifolia var. canescens*) and forbs such as canyon grape (*Vitis arizonica*) scarlet monkey flower (*Mimulus cardinalis*), common maidenhair (*Adiantum capillus-veneris*) and grasses including bush muhly (*Muhlenbergia porteri*) and smilo grass (*Piptatherum miliaceum*) (M. McMaster, Invasive Plant Biologist, GCNP, personal communication, June 5, 2012).

Juvenile Humpback Chub Collection and Translocation

In cooperation with the U.S. Bureau of Reclamation (BOR), U.S. Fish and Wildlife Service (USFWS) and USGS-Grand Canyon Monitoring and Research Center (GCMRC), juvenile Humpback Chub were collected in July and November 2010, November 2011, July 2012, and July and November 2013 for translocation the following year from the Little Colorado River, the primary spawning area for the species within the Lower Colorado River basin (Valdez and Ryel 1995). Young-of-year (YOY) Humpback Chub were targeted for collections to minimize the risk of impacting recruitment of the Little Colorado River aggregation (Pine et al. 2013). Initial collection efforts were focused in July prior to the onset of monsoonal storms and flooding, and when YOY Humpback Chub would be large enough to be captured using mini-hoop nets. November collection trips were undertaken when an insufficient number of Humpback Chub were captured during July, or when July trips were cancelled due to potential flooding. A detailed description of Humpback Chub collection and transport from the Little Colorado River, parasite and disease treatment, flow training, and tempering and release of juvenile Humpback Chub into Shinumo Creek during 2009 and 2010 is provided in GCWC (2010) and Healy et al. (2011), respectively. In summary, helicopter-supported collection trips to the Little Colorado River were conducted in 2010, 2011, and 2012 to collect Humpback Chub to be divided between Shinumo and Havasu creeks in 2011(approximately 300 each), 2012 (approximately 300 for Havasu Creek only), and 2013 (approximately 200 for Shinumo Creek, 300 for Havasu Creek). An additional 200 YOY Humpback Chub were also collected each year for incorporation into the refuge population established at the USFWS Southwestern Native Aquatic Resources & Recovery Center (SNARRC), formerly the Dexter National Fish Hatchery & Technology Center, in Dexter, New Mexico. Young-of-year fish less than 80 millimeters (mm) were targeted for collection during July trips. During the November collection trips, the maximum size was increased to 130 mm to account for interim growth.

Once collected, Humpback Chub were held in live wells in the Little Colorado River until they could be flown to the canyon rim in coolers and transferred to USFWS or Arizona Game and Fish Department (AZGFD) hatchery staff for transport to either the SNARRC (2010, 2012, and 2013) in Dexter, New Mexico, or the AZGFD's Bubbling Ponds Native Fish Facility (2011) in Cornville, Arizona. Once at the hatchery, Humpback Chub were quarantined and treated for parasites and diseases following standard protocols and kept over winter as described in GCWC (2010). Prior to translocation, Humpback Chub were provided flow-training, injected with passive integrated transponder (PIT) tags (12 mm, 134.2 kHz tags), measured (mm), and weighed (g). The average size at tagging, tag dates, release dates, and number of Humpback Chub released into Shinumo and Havasu creeks between 2009 and 2012 are summarized in Table 1.

Table 1. Summary of average size, tag dates, release dates, and number of Humpback Chub released into Shinumo and Havasu creeks from 2009-2013.

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

On the day of translocation, Humpback Chub were transported to Grand Canyon National Park's South Rim heli-base by hatchery personnel, divided into 1-2 aerated 120 quart coolers and flown internally by National Park Service helicopter to a landing area near the translocation site in Shinumo Creek, or to the rim above the release point at Havasu Creek. Since no suitable landing area was found near the release point adjacent to Havasu Creek, NPS heli-base personnel transferred the coolers to an external cargo net, and then transported the coolers and fish to awaiting fisheries staff at the release site via long-line sling-load. Translocation dates are shown in Table 1.

Humpback Chub were released into several large pools and a glide area in Shinumo Creek located approximately 2.8 kilometers above the confluence with the Colorado River in 2009-2011, and into pools and a glide approximately 1.5 kilometers upstream of the original release site in 2013. In an effort to minimize rapid emigration of newly translocated Humpback Chub from Shinumo Creek, which occurred during translocations in 2009-2011 (Spurgeon 2012), a "soft" release technique was implemented in 2013, in which a block net was set below the release pool and glide to allow chub to further acclimate following translocation. After a period of 3 days the block net was removed and the fish were free to disperse. In the 2011- 2013 Havasu Creek translocations, Humpback Chub were released into one large pool in Havasu Creek located approximately 5.6 kilometers upstream from the Colorado River on NPS land.

Mortality during collection, transport, hatchery rearing and disease treatments, and tempering and release of the fish was generally low, occurring during collection, transport from the Little Colorado River, and hatchery treatment. For example, out of 589 juvenile or YOY Humpback Chub collected during July and October Little Colorado River collection efforts in 2009, 5 mortalities occurred from collection to translocation (GCWC 2010). No immediate Humpback Chub mortality has been observed during any tempering or release in Shinumo Creek (2009-2013) or Havasu Creek (2011-2013), or during subsequent monitoring (2 trips per creek per year). The highest mortality observed associated with these Humpback Chub translocation activities occurred during hatchery rearing, disease treatment, and PIT tagging activities in 2011, which resulted in mortality of approximately 10% of collected fish.

Fish Handling During Monitoring

All fish captured in either Shinumo or Havasu creeks were handled using the standardized methods for Grand Canyon Fisheries Research 2012 (Persons et al. 2012). All captured fish were identified, and with the exception of Speckled Dace, were examined for sexual condition and parasites, measured for total length and fork length in millimeters, and weighed in grams (when possible). Subsets of Speckled Dace captured were measured for total length (mm), weighed (g) and examined for sexual characteristics before release; others were counted and released. All native fish > 150 mm in total length were scanned for the presence of a PIT tag; if no tag was located, fish received a new tag. Native fishes were released after data collection. Nonnative fish were euthanized and their stomachs were inspected for evidence of piscivory. All nonnative fish were prepared for beneficial use when possible, consistent with ongoing National Historic Preservation Act, Section 106 consultations with Traditionally Associated Indian Tribes, or disposed of away from recreational areas. Fish were handled in a manner to allow for human consumption whenever practicable; however, high heat during summer months and the hiking distance between sampling areas and camp precluded safe consumption of fish in some cases.

Shinumo Creek Field Data Collection

Fish community monitoring and nonnative trout control activities took place in Shinumo Creek during May, June, July, and September of 2009 (Grand Canyon Wildlands Council 2010), followed by June and September monitoring occasions in 2010 (Healy et al. 2011) and 2011, 2012, and 2013 (Table 2). Electrofishing to remove nonnative trout was also conducted in February of 2012 and 2013. For monitoring purposes, the creek was divided into six reaches beginning at the mouth of Shinumo Creek to a waterfall impassable to upstream fish movement located approximately 150 meters from the creek's confluence with the Colorado River (reach -1), and extending upstream of the 2009-2011 translocation reach (reach 5). In 2009-2011 Humpback Chub were translocated into reach 4, which was bounded on the upstream end by a series of cascades that may have served as an impediment to upstream movement by Humpback Chub (GCWC 2010). In June of 2013, 200 additional Humpback Chub were translocated into a pool approximately 1 kilometer (km) upstream of the original release pool. Reaches 1 through 4 were approximately 800, 1175, 600, and 250 meters long, respectively, and were delineated based on the presence of a sufficient number of pools to sample with mini-hoop nets, and for logistical ease (GCWC 2010, Spurgeon 2012). Prior to translocations (i.e. in May and June 2009), nonnative trout control efforts were conducted using backpack electrofishing equipment, focusing on reaches 1-4. However, once the first Humpback Chub were released into Shinumo Creek on June 15, 2009 (Table 1), only netting gears were permitted by the USFWS to monitor fishes in these reaches. Therefore, during sampling trips between September 2009 and September 2012, electrofishing gear was only used above the then-translocation reach in reach 5, and only after three hoop nets were set above the translocation pools and Humpback Chub captures did not exceed 10% of population estimates (see Healy et at. 2011). Trout control in the lower reaches occurred primarily by angling; however, trout were also incidentally captured and removed during fish monitoring activities with mini-hoop nets, minnow traps, and occasional seining.

Table 2. 2011-2013 trips, dates, activities, and associated trip reports for Humpback Chub translocation and monitoring, or associated nonnative fish control activities in Havasu (HAV) and Shinumo (SHI) creeks, Grand Canyon National Park, and the Little Colorado River (LCR).

Year	Tributary	Trip Dates	Activity	Trip Report
2011	HAV	June 23-29	Monitoring; HBC translocation on June 28	Healy et al. 2011
2011	HAV	October 7-13	Monitoring	Sponholtz et al 2011
2011	LCR	November 3-9	HBC collection & Chute Falls translocation	--
2011	SHI	June 14-27	Electrofishing and monitoring; HBC translocation on June 21	Healy et al 2011
2011	SHI	September 4-17	Electrofishing and monitoring	Healy & Omana 2011
2012	HAV	May 5-14	Monitoring; 2nd HBC translocation on June 13	Nelson et al 2012a
2012	HAV	October 15-21	Monitoring	Nelson et al 2012d
2012	LCR	July 9-13	HBC collection & Chute Falls translocation	Stone 2012
2012	SHI	February 22- March 5	Electrofishing and monitoring	Omana Smith & Healy 2012
2012	SHI	June 15-25	Electrofishing and monitoring	Nelson et al 2012b
2012	SHI/ Shinumo Inflow	September 4-16	Electrofishing and monitoring; Colorado River hoop-netting	Nelson et al 2012c
2013	HAV	May 6-15	Monitoring; 3rd HBC translocation on May 14	Healy & Nelson 2013
2013	HAV	October 7-13	Monitoring- *cancelled due to government shutdown*	--
2013	LCR	July 8-12	HBC collection	Peterlein 2013
2013	LCR	October 13-18	HBC collection & Chute Falls translocation- *cancelled due to government shutdown*	--
2013	LCR	November 4-8	HBC collection & Chute Falls translocation	--

2013	SHI	February 20-March 8	Electrofishing and monitoring	Nelson & Healy 2013
2013	SHI Shinumo Inflow	June 9-22	Monitoring; 4th HBC translocation on June 15; Colorado River hoop-netting	Nelson et al 2013
2013	SHI Shinumo Inflow	September 4-17	Monitoring; Colorado River hoop-netting	Nelson et al 2014

Two sampling passes were completed using baited (Aquamax ™ Grower 600 Carnivorous Species fish food) mini hoop-nets (50 x 100 cm, 6 mm nylon mesh, single 10 cm throat) and minnow traps (3.18 mm mesh, 25 x 25 x 43 cm) during both June and September sampling trips in reaches 1-4 in 2010 (Healy et al. 2011, Spurgeon 2012) and 2011- 2013 (Table 3) for the purposes of estimating abundance of native fish over time. Prior to 2010 (i.e. June, July, and September 2009), a single pass of hoop-netting and minnow trapping was conducted to determine catch-per-unit effort (CPUE) and presence/absence of Humpback Chub and other species (GCWC 2010). In addition, during all trips, a single night of netting was conducted in the reach below Shinumo Falls (reach -1) to determine presence/absence of Humpback Chub and other fishes. Data were collected on all captured fishes as described above (*Fish Handling During Monitoring*). For mark-recapture studies in 2010- 2013, Speckled Dace and Bluehead Sucker less than 150 mm in TL were marked on the first (“mark”) pass using a left or right pelvic fin clip in June and September trips, respectively. All fishes greater than 150 mm TL were scanned for the presence of a PIT tag, and implanted with one if none was detected. All translocated Humpback Chub were tagged with PIT tags prior to translocation.

Table 3. Sampling regime for Shinumo Creek, Grand Canyon National Park, June 2011 through September 2012.

	Stream Reach				
Sampling Day	**1**	**2**	**3**	**4**	**5**
Day 1	Set nets	Set nets	-	-	Set/ Check nets
Day 2	Mark	Mark	Set nets	Set nets	Check nets /Depletions*
Day 3	-	-	Mark	Mark	Depletions
Day 4	Set nets	Set nets	-	-	Depletions
Day 5	Recapture	Recapture	Set nets	Set nets	Depletions
Day 6	-	-	Recapture	Recapture	Depletions

**Depletion sampling only occurred following hoop netting (condition of ESA Section 10 permit).*

Relative to the sampling effort in Shinumo and Havasu creeks, limited sampling has occurred in the mainstem Colorado River Humpback Chub aggregations since the inception of tributary translocation projects in 2009. Three trammel and hoop netting trips, led by USGS-GCMRC and USFWS, were conducted during September 2010, 2011, and 2012 that included sampling in the Shinumo Inflow and Havasu Inflow aggregations. During September 2012, a pilot mark-recapture study was initiated at the Shinumo Inflow, when NPS fisheries staff set approximately 60 baited hoop nets between Bass Rapid (River Mile 108.4) and Shinumo Rapid (River Mile 109.3; the Shinumo Inflow) during a "mark" pass, which was followed by a similar effort by USGS-GCMRC and USFWS the following week (recapture pass). In June and September 2013 NPS continued mainstem sampling between Bass and Shinumo rapids, setting 60 baited hoop nets in a single pass per trip. The primary objective of the Shinumo Inflow sampling was to determine the contribution of the translocated Humpback Chub to the Shinumo Inflow aggregation (Valdez and Ryel 1995) of Humpback Chub. Hoop-netting was conducted over 3 nights concurrently with sampling in Shinumo Creek in September 2012, and June and September 2013.

Table 4. Sampling regime for Shinumo Creek, Grand Canyon National Park, June and September 2013.

	Stream Reach				
Sampling Day	**1**	**2**	**3**	**4**	**5**
Day 1	Set nets	Set nets	-	-	
Day 2	Mark	Mark	Set nets	Set nets	
Day 3	-	-	Mark	Mark	Set (Sept. Only)
Day 4	Set nets	Set nets	-	-	Mark (Sept. Only)
Day 5	Recapture	Recapture	Set nets	Set nets	
Day 6	-	-	Recapture	Recapture	Set
Day 7					Mark/Recapture

Emigration of Humpback Chub from Shinumo Creek was estimated based on data from two remote full duplexing PIT tag antennas installed approximately 150 meters upstream of Shinumo Falls (Figure 2). Data were accessed via satellite or through manual uploads during sampling trips, and included PIT tag number, date, time, antenna number (1 or 2), as well as stream stage and temperature (recorded very hour). Emigration of Humpback Chub from Shinumo Creek was determined using the order of detection on the antenna array such that a fish last detected at the downstream antenna (Antenna 2; Figure 2) was assumed to have emigrated from Shinumo Creek (Spurgeon 2012). As described in Spurgeon (2012), stream stage height and temperature were also recorded continuously at the antenna array to assess whether these variables had an influence on emigration.

Figure 2. Remote full duplexing PIT tag antennas in Shinumo Creek. Antenna 1 (right) is upstream of 2.

Single- and multiple-pass electrofishing was conducted at multiple stations in reach 5 to control Rainbow Trout and assess the effectiveness of nonnative control efforts in reducing Rainbow Trout populations and benefitting native fish populations. Beginning in 2013, electrofishing was discontinued during the June and September sampling trips, and efforts were re-focused in February, minimizing the potential for heat-related stress to fish and crews and maximizing crew efficiency, as well as enabling more efficient "beneficial use" of euthanized nonnative trout. Multiple-pass electrofishing, allowed for the collection of data to generate population estimates for each station through "depletion" estimators. Since the focus of these efforts was to remove trout from Shinumo Creek to improve Humpback Chub survival as well as benefit native species, part of the final sampling day on each trip was focused on single-pass electrofishing to capture and remove as many trout as possible. It was assumed that a sufficient number of multiple-pass depletion stations were sampled to meet the monitoring objectives, and that a greater number of trout could be captured using a single pass over longer stations than multiple passes over fewer, shorter stations.

To minimize the risk of injury to native species, including Humpback Chub with electrofishing equipment, several steps were taken, including mitigations as stipulated by the USFWS (Endangered Species Act, Section 10, Permit # TE819473, see Healy et al. 2011). Electrofishing at Shinumo Creek was generally conducted over shorter reaches to minimize time and stress to captured fish held in buckets while the survey continued prior to processing (average station length = 58 meters). All stations during 2011-2013 sampling were block-netted on both upstream and downstream ends using 30-foot x 6-foot seines with 1/8 -1/4 inch mesh to meet the assumption of "closure" of the sampling area, or no immigration or emigration to/from the reach between passes (i.e, assumption of a "closed" population). At the beginning of each 2011-2013 sampling trip, Smith-Root LR-20B (400 watt) backpack electrofishing units were set at 250 volts, and fish response was monitored. In each case fish response was determined to be minimal (i.e., settings were ineffective) and settings were changed to 350 volts, with a 30% duty cycle and output frequency of 35 Hertz (Hz). Captured fish were continually monitored for gear-related injuries while in buckets. The survey team consisted of two side-by-side electrofishing unit operators, 3-4 netters, and 1-2 bucket tenders. This crew configuration allowed for coverage of the entire stream width.

Data were collected on all captured fishes as described above (*Fish Handling During Monitoring*). Native fishes were released alive below the downstream block net following data collection. All Rainbow Trout were transferred to live wells until the end of the day; they were then euthanized, carried back to camp, and prepared for beneficial use, following consultation with Traditionally Associated Indian Tribes (Section 106, National Historic Preservation Act). In cases where fish had died or the air temperatures were too great to safely save trout for human consumption, they were distributed in the creek area away from recreational areas.

Havasu Creek Field Data Collection

Field sampling methods for monitoring Humpback Chub translocation activities in Havasu Creek are summarized by Trammell et al. (2012). The section of Havasu Creek on NPS-managed lands between the confluence with the Colorado River and Beaver Falls (approximately 3.25 miles/5.2 km) was divided into 3 reaches of approximately equal length and numbered downstream to upstream (i.e. reach 1 is near the confluence with the Colorado River). As described in the Trammell et al. (2012) monitoring plan, single-pass post-translocation monitoring trips were conducted in October 2011 and 2012 using hoop nets and minnow traps to collect data to estimate growth and survival for translocated Humpback Chu, although a trip planned for October 2013 was cancelled due to the temporary shutdown of the federal government. Sampling occurred over 3 nights using twenty baited mini-hoop nets (50 x 100 cm, 6 mm nylon mesh, single 10 cm throat) and minnow traps (3.18 mm mesh, 25 x 25 x 43 cm) each night. Trap nets were baited with Aquamax ™ Grower 600 Carnivorous Species fish food. Nets were set in pool habitats during the late afternoon and retrieved early in the morning to minimize interference with recreational visitors. Two-pass mark-recapture trips were also conducted in May 2012 and 2013 to facilitate annual population estimates for native species. During these trips, a mark pass was performed as during October sampling trips, followed by a recapture pass three days later in each reach. This rest period was planned to allow fish to recover from possible handling stresses and to reduce the influence of modified fish behavior between sampling efforts.

Data were collected on all captured fishes as described above (*Fish Handling During Monitoring*). Untagged Humpback Chub, Bluehead Suckers, and Flannelmouth Suckers >150 mm in total length were tagged with PIT tags. All native fishes were released back into Havasu Creek alive and nonnative fish were examined for PIT or Floy tags and fin clips, euthanized, their stomach contents examined for presence or absence of fish prey items, and disposed of away from recreation areas.

In October 2011 mobile PIT tag scanners were tested from the pool below Beaver Falls to the mouth of Havasu Creek. Two mobile PIT tag scanning units, operated in a similar fashion to backpack electrofishing units, were swept through various types of habitat (i.e., pools, riffles, backwaters, runs) moving downstream to scan for tagged Humpback Chub and other PIT tagged fish. Two-thirds of reach 3, all of reach 2, and ¾ of reach 1 were scanned. The units were equipped with GPS to record the location of all detected PIT tags. In addition, the wands of the two units were also baited with Aquamax ™ Grower 600 Carnivorous Species fish food and left in the pool below Beaver Falls for approximately 2 hours. Baited wands (2) were again tested in May 2012 in pools directly below Beaver Falls.

Data Analysis

Shinumo Creek Fish Population Estimation

Mark-recapture Population Estimates

Abundance estimates were generated for native species within and downstream of translocation reaches on each 2011-13 sampling trip using closed-population mark-recapture estimation methods. Population estimates for Humpback Chub, Bluehead Sucker, and Speckled Dace were generated for reaches 1-4 using closed-population mark-recapture models (full likelihood parameterizations of Otis et al. 1978, summarized in Cooch and White 2011), and information-theoretic model selection procedures in Program MARK (Akaike Information Criteria scores, AIC scores, White 2008). Data for PIT-tagged Bluehead Suckers, as well as those <150 mm that were fin-clipped on the first pass, were pooled for a single population estimate for June and September sampling occasions in 2011 trips. During 2012 and 2013 sampling, mark-recapture population estimates for Speckled Dace were only conducted in June.

Electrofishing Depletion Population Estimates

Population estimates for fish captured using electrofishing gear in reach 5 were generated using analytical methods described by Saunders et al. (2011). Capture probability biases associated with depletion sampling for salmonids due to size-selectivity of the gear and behavioral responses to electrofishing can result in low population estimates (see Peterson et al. 2004). The advantage of methods described by Saunders et al. (2011) is that heterogeneity in individual fish capture probability, and thus sources of bias, can be accounted for by including covariates such as fish length, as well as site-related information in the analysis (Huggins closed-capture data type; White 2008). In addition, capture probabilities can be estimated by pass, and data can be pooled from multiple sites to estimate capture probability parameters in the models (Saunders et al. 2011).

Various pre-determined closed population models, using combinations of covariates for individual fish (e.g., total length), and those related to the samples (e.g., month, year, pass), were assessed in Program MARK (White and Burnham 1999), using AIC scores to select the most parsimonious model for estimating capture probability and abundance of Rainbow Trout and Bluehead Sucker. Speckled Dace capture probability and abundance were estimated using similar methods; however, the fish size covariate could not be included in the population estimation models since not every individual was measured. An estimate of abundance of each fish species from all multiple-pass stations was estimated for June and September trips during 2011-2013 sampling efforts. Abundance and confidence interval estimates were then standardized to the number of fish per 500 meters (density).

Translocation Success Criteria

Translocation success criteria were evaluated for both Shinumo and Havasu Creek Humpback Chub translocation projects to the extent that data were available through monitoring events in 2011, 2012, and 2013. Analyses of some criteria, including survival of Humpback Chub released into Shinumo and Havasu creeks in 2013 (criteria *b*), and reproduction/recruitment criteria (criteria *e –f*) are preliminary and confounded by emigration, in the case of Shinumo Creek (Spurgeon 2012), or are too soon to fully evaluate, respectively. Nevertheless, available data are presented.

Retention/Emigration

An evaluation of the timing and magnitude of emigration of Humpback Chub from Shinumo Creek following 2009, 2010, and 2011 translocations through April 2012 is summarized in Spurgeon (2012), using data collected from the remote PIT-tag antenna system. More recent data, through January 9, 2013, are included in this report. Population estimates based on mark-recapture sampling (described above) and sampling conducted downstream of the antenna in the Colorado River (USFWS, GCMRC, and NPS, unpublished data) or in Shinumo Creek below Shinumo Falls are also used to assess the retention of Humpback Chub in Shinumo Creek as well as antenna detection efficiency.

Methods for determining retention of Humpback Chub in Havasu Creek differ from Shinumo Creek as the installation of a PIT tag antenna system was determined to be infeasible there due to the lack of a sufficient power source, maintenance concerns, and the potential for impact to visitor experience. Population estimates based on two-pass mark-recapture sampling during May sampling events were used to assess retention of Humpback Chub.

Survival

Monthly and annual apparent survival estimates were calculated for each cohort of translocated Humpback Chub following the methodology described in Spurgeon (2012). In summary, mark-recapture data were incorporated into a series of time-dependent and time-independent Cormack-

Jolly-Seber (CJS, Lebreton et al. 1992) models, including an individual covariate for fish total length at the time of translocation, to estimate survival and capture probabilities. Models were analyzed and ranked using AIC in Program MARK (White 2008), and results of the most parsimonious model are presented. The apparent survival estimates using this method represent the probability of fish remaining within our sampling area (Shinumo or Havasu creeks) and surviving. Program MARK provides an output of monthly survival rates, which were then expanded to survival between sampling intervals, defined as "summer" (3 months, June to September) or "winter" (9 months, September to June), and annual rates (e.g., annual apparent survival = monthly survival ^12; Cooch and White 2011).

Growth of Humpback Chub

A comparison of growth rates between translocated Humpback Chub and growth rates of juvenile Humpback Chub in the source population in the Little Colorado River was used to assess rearing potential for translocated fish in Havasu and Shinumo creeks. The average of length measurements taken during tagging events in the hatchery prior to translocations, and the average size of translocated Humpback Chub recaptured during sampling event, by translocated cohort, was plotted along a von Bertalanffy growth curve developed for juvenile Humpback Chub in the Little Colorado River (Robinson and Childs 2001) for comparison. Because growth rates in Humpback Chub are expected to decline with age (Valdez and Ryel 1995, Coggins and Pine 2010), individual fish were assigned age-classes (age 1+ at translocation < 145 mm TL, age-2+ at translocation ≥ 145 mm TL) based on analysis of length-frequency histograms derived from measurements taken by SNARRC or AGFD hatchery staff less than a month prior to translocation. Growth rates found in fish translocated to Havasu and Shinumo creeks were also compared to estimated growth rates for fish found in the Colorado River, determined by recaptures of PIT tagged Humpback Chub (e.g., Valdez and Ryel 1995, Finch 2013).

Annual absolute growth rates (growth per year) for individual Humpback Chub translocated to Shinumo Creek in 2009, 2010, and 2011 were determined by Spurgeon et al. (*in prep.*) using lengths taken during tagging in the hatchery, and post- translocation recaptures. The time each cohort spent in the hatchery following tagging, prior to release, was 13, 28 and 47 days for the 2009, 2010, and 2011 cohorts, respectively. Recapture data from the mainstem Colorado River collected during GCMRC and USFWS Humpback Chub aggregation monitoring trips in September 2010 and 2011 (USGS-GCMRC/USFWS unpublished data) and NPS-GCMRC trips in 2012 and 2013 were also used for growth analysis.

Contributions of Translocated Fish to Mainstem Aggregations

Humpback Chub capture data in the mainstem Shinumo Inflow reach (NPS, USGS-GCMRC/USFWS) were examined for the presence of recaptured, PIT-tagged fish translocated to Shinumo and Havasu creeks to determine whether contributions to the mainstem had occurred.

Nonnative Trout Control Evaluation and Trends

To evaluate the effectiveness of nonnative trout control in Shinumo Creek, trends in abundance, species composition, and size structure for each species were analyzed. In the past, catch-per-unit effort (CPUE), for electrofishing (number of fish per 100 seconds of electrofishing), hoop-netting, and minnow trapping (number of fish per hour of fishing effort) was used to evaluate abundance trends (Healy et al 2011). However variance was high, and thus CPUE proved to be of little value for evaluating trends. No angling or electrofishing was conducted in Havasu Creek, so only netting catch data are reported. Population estimates calculated from mark-recapture netting and electrofishing depletion sampling were relied upon for trend analysis in Shinumo Creek. In addition, for electrofishing in Shinumo Creek, the cumulative removal efficiency (% of trout removed, all passes) was estimated using average capture probabilities (q) estimated using Program MARK for each trip (all sites and passes combined) for the models used to estimate abundance incorporating fish length as a covariate with: % of trout removed = $1- (1-q)^3$.

RESULTS

All cohorts of Humpback Chub translocated to Shinumo Creek in 2009 – 2011 and 2013, and to Havasu Creek in 2011 and 2012, were represented in recapture data collected during monitoring events conducted in both streams in 2011-2013. The single 2013 post-translocation monitoring trip planned for Havasu Creek in October had to be cancelled due to the federal government shutdown, and thus, no data to assess the 2013 cohort are available for this report. In Shinumo Creek and the adjacent inflow area of the Colorado River, a total of 222 unique individual translocated Humpback Chub were recaptured during all NPS sampling trips in 2013, ranging in size from 102 to 299 mm TL (average= 188 mm TL). One Humpback Chub without a PIT tag was encountered during all Shinumo Creek sampling trips; a tag was detected in all other Humpback Chub captured within Shinumo Creek. One-hundred fifty-nine unique, translocated fish were recaptured in Havasu Creek during the single sampling event in 2013, ranging in size between 144 and 283 mm TL (average= 207 mm TL). In addition, 15 Humpback Chub that were likely not translocated were captured in Havasu Creek in 2013. These mostly untagged fish ranged in size from 121 and 340 mm TL (average= 269 mm TL); some of these were captured and tagged prior to the first translocation in 2011.

Translocation Evaluation

Humpback Chub Retention/Emigration

<u>Shinumo Creek</u>

A total of 456 of 902 (51%) Humpback Chub released were determined to have left Shinumo Creek using data collected by the remote PIT tag antenna system through January 9, 2013, with 120 (26% of all emigrants) of the fish emigrating within the first 10 days of their release into the creek (also see Spurgeon 2012). The antenna array was not operational for a number of days between the end of December 2009 and February 2010 due to power loss. In general, larger numbers of emigrants were detected during the summer monsoon season, and during the spring months 9-11 months following release, with the lowest emigration occurring during the cooler months (Figure 3). However, by comparing PIT tag detections at the antenna system and PIT tags from Humpback Chub translocated and then captured in the Colorado River (USGS-GCMRC/USFWS unpublished data) or in Shinumo Creek below Shinumo Falls downstream of the array (NPS, unpublished data), antenna detection efficiency was estimated to be less than 68% in 2012. Based on capture data, only 58 of 85 translocated Humpback Chub encountered below Shinumo Falls were determined to have dispersed from the creek using antenna data.

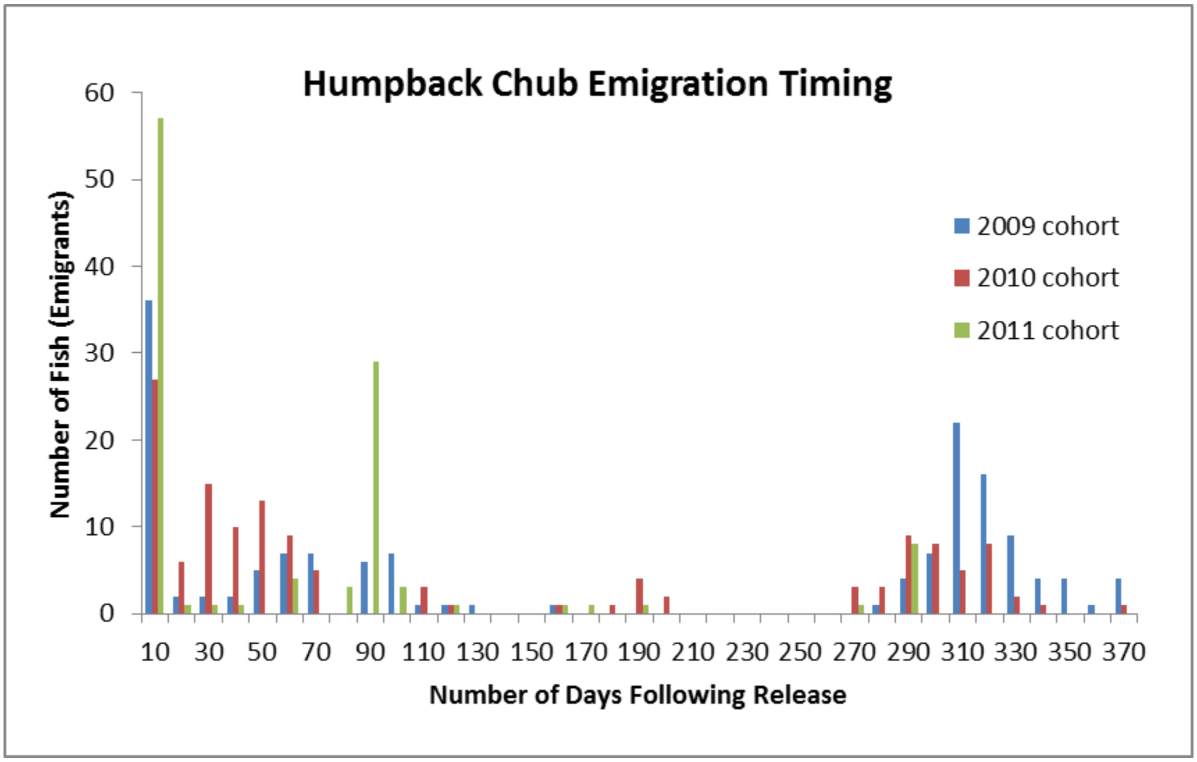

Figure 3. The number of Humpback Chub emigrants, by day, from the day of translocation in June 2009, 2010, and 2011, through the first year, by cohort, as detected by the antenna array at Shinumo Creek, Grand Canyon National Park.

Humpback Chub population estimates based on mark-recapture sampling could be calculated in June and September of each year beginning in June 2010 (through September 2013). Population estimates varied between trips (Table 5; Figure 4). The lowest estimates were in June of the year following the translocation for each cohort, which varied between 22 (June 2010) and 158 (June 2012) individuals, while the highest estimates were found during the fall of the year following translocations (approx. 3 months).

Table 5. Humpback Chub population (N), standard error (SE), confidence interval, and capture probability estimates based on analysis of mark-recapture data collected during 2010 and 2011 sampling trips in Shinumo Creek, Grand Canyon National Park.

			95% Confidence Intervals		Capture Probability	
Trip	**N**	**SE**	**Lower**	**Upper**	**Mark**	**Recapture**
June 2010	22	1.8	21.0	32.9	0.77	0.25
Sept. 2010	79	6.8	72.4	103.4	0.65	0.16
June 2011	38	1.3	38.0	46.9	0.85	0.31
Sept. 2011	322	93.3	219.9	629.8	0.31	0.54
June 2012	158	19.1	133.4	213.7	0.48	0.37
Sept. 2012	122	15.1	102.9	166.7	0.48	0.52
June 2013	64	5.4	58.7	83.8	0.67	0.47
Sept. 2013	208	22.1	180.9	274.2	0.52	0.48

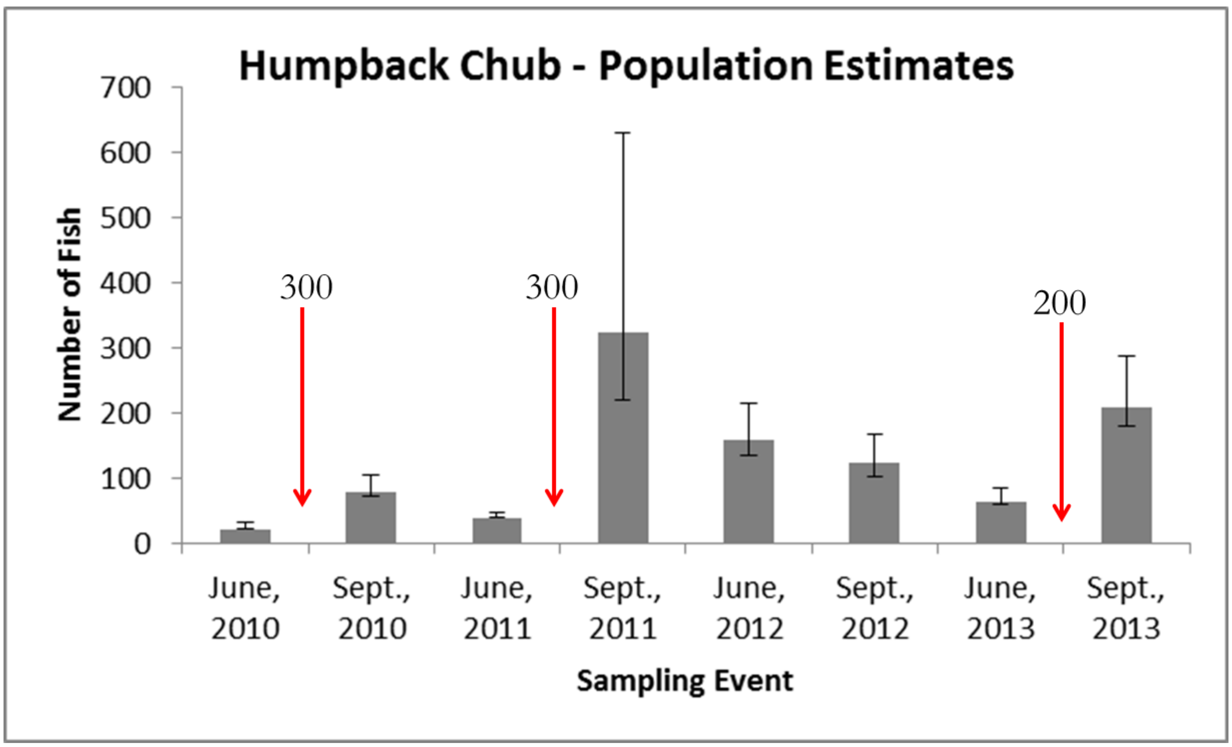

Figure 4. Humpback Chub population estimates based on mark-recapture sampling in Shinumo Creek between June 2010 and September 2013. Error bars indicate 95% confidence intervals for the population estimates, and numbered red arrows indicate the number of fish translocated relative to the timing of sampling events.

Havasu Creek

The retention of Humpback Chub translocated to Havasu Creek can only be evaluated for the 2011 and 2012 cohorts through May of 2013, because data collected following the 2013 translocation have not yet been analyzed. Nevertheless, 158 unique Humpback Chub out of 543 (29%) released in June 2011 (59 fish) and May 2012 (99 fish) were recaptured during the May 2013 monitoring event. Of these, 93 fish (59%) were > 199 mm total length. Lacking a PIT tag antenna, emigration rates could not be estimated. In October 2011, 16 unique, translocated Humpback Chub were also detected with experimental mobile PIT tag scanning units. Eight of these fish were not captured during netting efforts, bringing the total number of Humpback Chub detected during October 2011 to 105 (43%). However, the mobile antenna survey proved to be labor intensive, and due to limited detection range, few fish were detected relative to the number detected during netting, and it was not repeated after October 2011.

Population estimates based on annual mark-recapture sampling in Havasu Creek are shown in Table 6, and Figure 5. Non-translocated Humpback Chub were also captured during monitoring events, including 2 untagged juveniles that were likely the result of reproduction in Havasu Creek. Estimates were calculated for non-translocated Humpback Chub as well. The number of non-translocated Humpback Chub did not change between 2011 and 2012, however 27% and 38% of the 2011 and 2012 translocated cohorts, respectively, remained as of May 2013.

Table 6. Humpback Chub population (N), standard error (SE), confidence interval, and capture probability estimates based on analysis of mark-recapture data collected during 2012 and 2013 sampling events in Havasu Creek, Grand Canyon National Park.

			95% Confidence Intervals		Capture Probability	
Trip	**N**	**SE**	**Lower**	**Upper**	**Mark**	**Recapture**
May 2012	117	6.7	110.0	139.1	0.68	0.69
May 2013	179	8.4	168.3	203.5	0.68	0.68

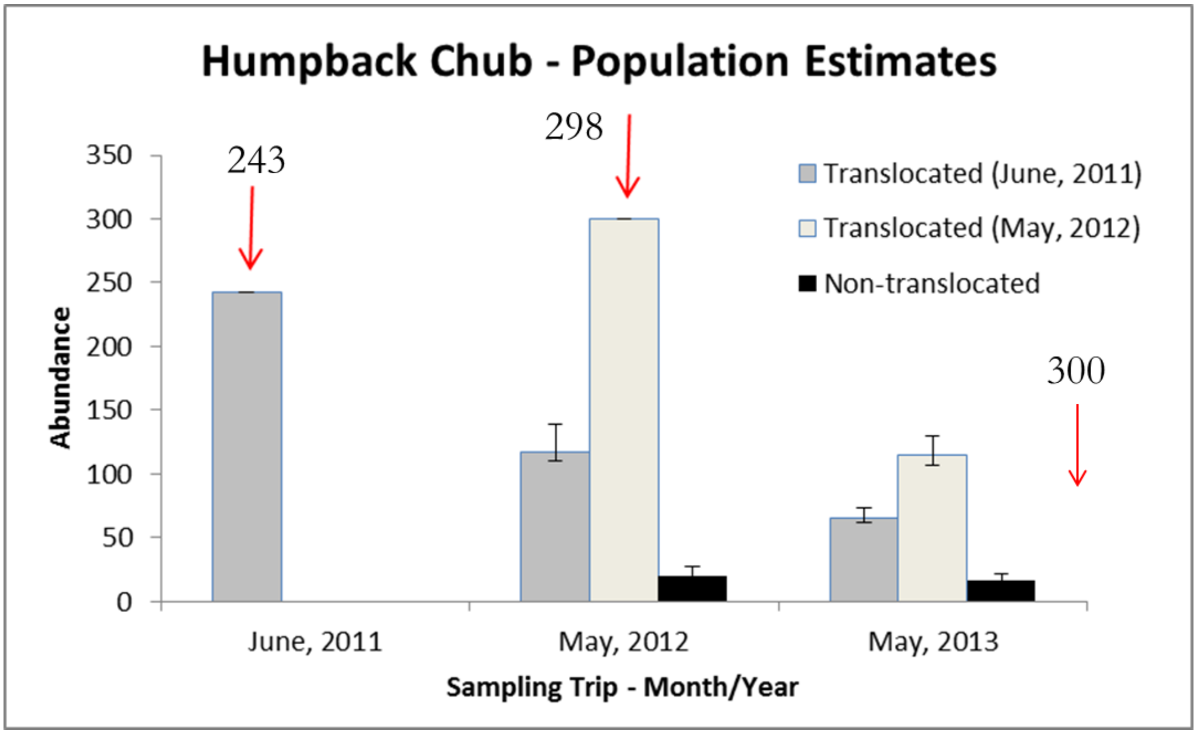

Figure 5. Humpback Chub population estimates by translocated cohort, and for non-translocated fish, based on mark-recapture sampling in Havasu Creek in May 2012 and May 2013. Error bars indicate 95% confidence intervals for the population estimates, and numbered red arrows indicate the number of fish translocated relative to the timing of sampling events. Bars without error bars are the total number of fish translocated on the last day of the monitoring trip.

Survival of Translocated Humpback Chub

The most parsimonious models selected for apparent survival of Humpback Chub at Shinumo were those incorporating the total length covariate for the 2009 and 2011 cohorts (i.e., survival varied with total length), which also varied with time. The model selected for the 2010 cohort indicated that survival varied with time. The model selected for Havasu Creek included a constant survival rate across time, and no total length covariate. Annual apparent survival estimates for the first year after translocation ranged from 0.18 (95% confidence interval: 0.08 - 0.32) for the 2010 Shinumo Creek cohort, to 0.51 (95% C.I.: 0.44 – 0.57) for the 2011 Havasu Creek cohort (Figure 6). The 2011 cohorts for both streams had significantly higher survival than the 2009 and 2010 cohorts translocated to Shinumo Creek.

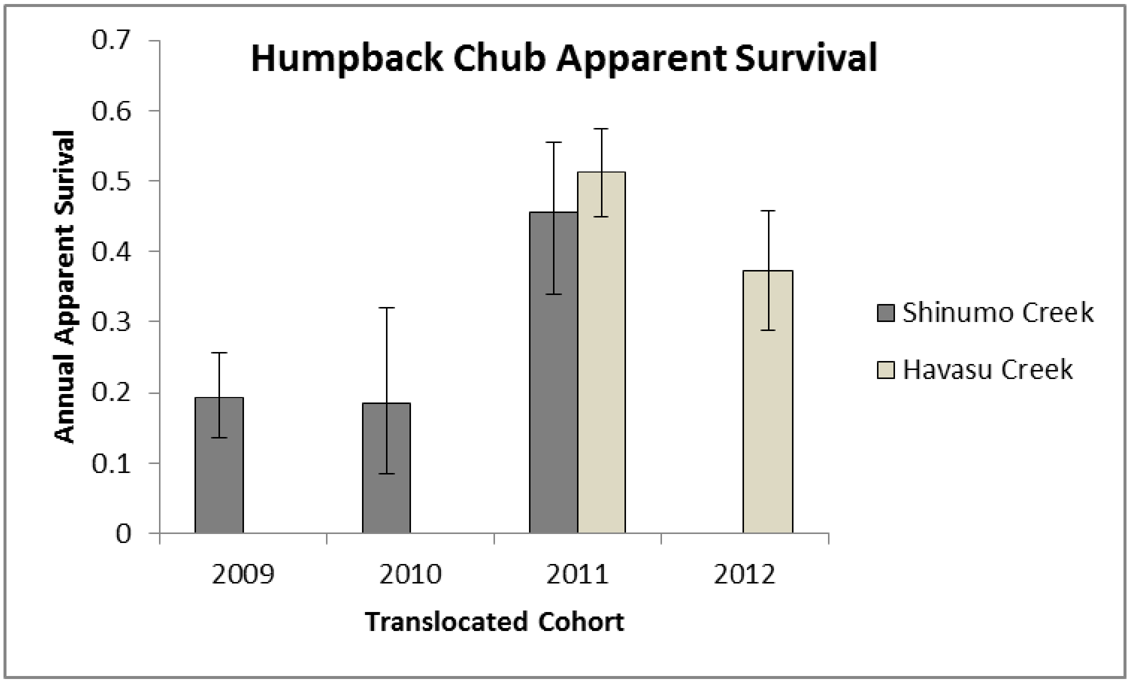

Figure 6. Apparent annual survival of cohorts of Humpback Chub translocated to Shinumo and Havasu creeks, between 2009 and 2012, Grand Canyon National Park. Apparent survival estimates are for the first year following translocation of each cohort.

Apparent survival rates of Humpback Chub translocated to Shinumo Creek varied between sampling intervals over time, generally increasing from the winter of 2009-2010 through the summer of 2012 (Figure 7). The precision of the most recent estimate (Summer 2013), which was based on fewer sampling events relative to earlier intervals, was relatively low. Summer and winter apparent survival did not differ significantly (Figure 7).

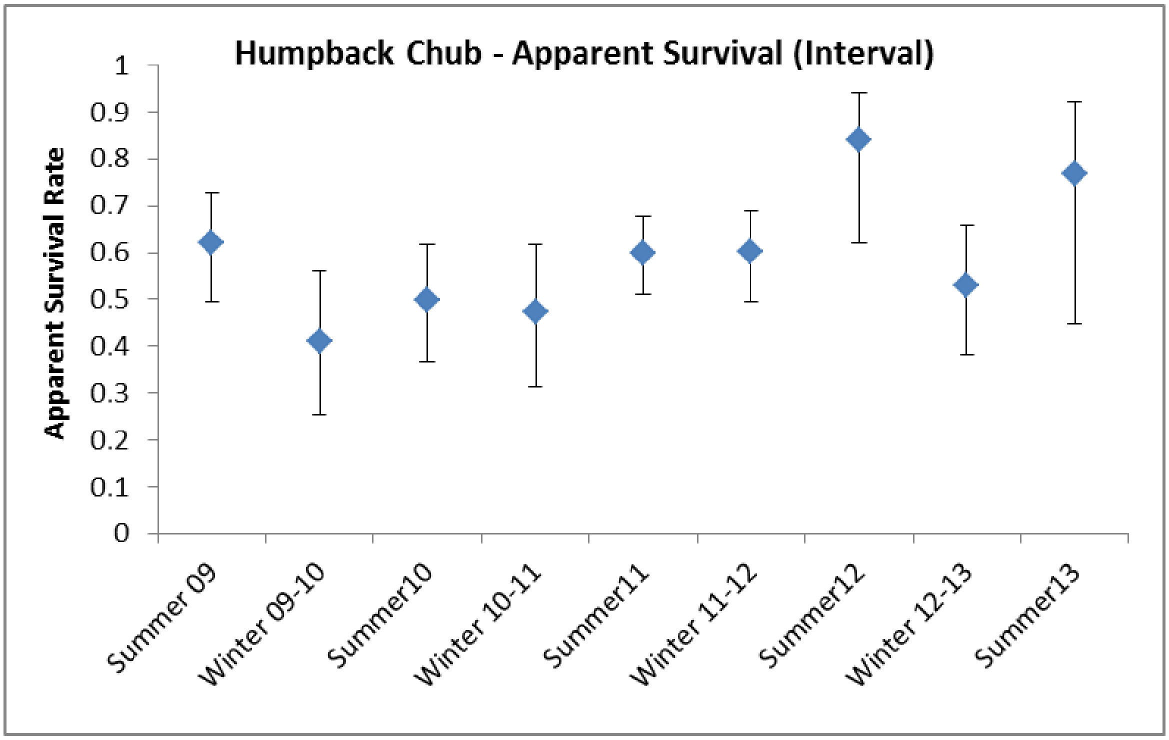

Figure 7. Apparent survival of Humpback Chub translocated to Shinumo Creek (all cohorts), Grand Canyon National Park, by interval (between sampling periods), during summer (June – September), and winter (September – June).

Growth of Translocated Humpback Chub

Shinumo Creek

Based on the mean size of cohorts of the same age (in months) recaptured in Shinumo Creek, compared to a growth curve developed for juvenile Humpback Chub in the Little Colorado River (Robinson and Childs 2000), Humpback Chub in Shinumo Creek met or exceeded Little Colorado River growth rates (Figure 8). In June of 2010 and 2013, following hatchery-rearing over the winter, Humpback Chub were tagged and released at a larger size than would be expected for age-1+ fish of the same age that would have remained in the Little Colorado River. By the September sampling events of each year, translocated fish had maintained their size advantage; however, the difference between the size of translocated cohorts and the Little Colorado River fish decreased over the first winter following translocation. When tagged and measured 47 days prior to release, the 2011 cohort was approximately the same size as would be expected for the same cohort in the Little Colorado River; however, summer (May to September) growth rates exceeded those for the Little Colorado River (Figure 8). By September, following two summers of growth in Shinumo Creek, the 2010 and 2011 cohorts maintained a size advantage over fish of the same age in the Little Colorado River (Figure 8).

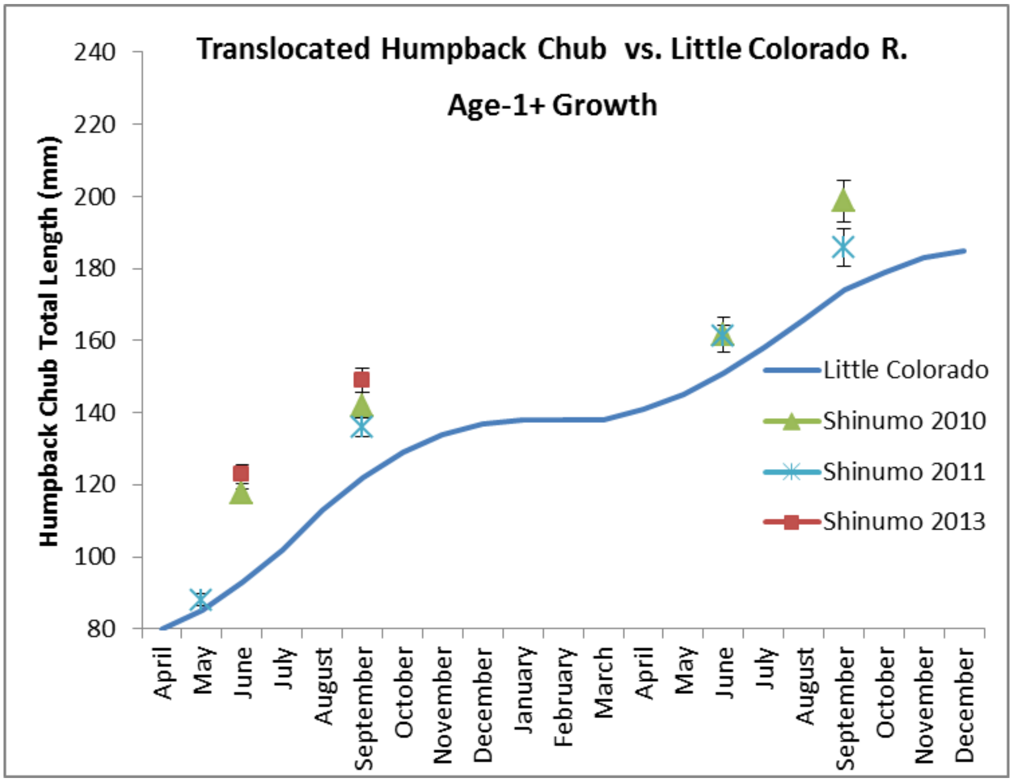

Figure 8. Average total length (mm) of Humpback Chub, by translocation cohort, at the time of PIT-tagging prior to release (May or June), and based on recaptures on each monitoring trip in Shinumo Creek, compared to average length by age (month) in the Little Colorado River as indicated by the growth curve developed by Robinson and Childs (2001). Error bars indicate 95% confidence intervals. NOTE: The 2009 cohort exhibited similar growth as the 2010 cohort, and thus, were excluded from this plot.

Annual absolute growth of Humpback Chub translocated to Shinumo Creek, based on PIT tag recaptures, was found to average 33 mm for the 2009 cohort (n = 21, range 16-48 mm) and 36 mm for the 2010 cohort (n = 38, range 19-53 mm) (Spurgeon *et al. in prep.*). Annual growth of the 2011 cohort exceeded that of both the 2009 and 2010 cohort, averaging 65 mm (range 43 – 95 mm). Valdez and Ryel (1995) calculated mean annual 30-day (mm/30day) growth rates from recaptured PIT-tagged fish as 2.3 mm for similarly sized fish to those in Shinumo Creek (150-200 mm TL). When converted to annual absolute growth (2.3 x 12 months = 27.6 mm) for comparison, growth of Humpback Chub was less in the Colorado River than in Shinumo Creek (27.6 mm vs. 33, 36, or 65 mm in Shinumo Creek).

Havasu Creek

Despite a decline in growth rates over the fall and winter in Havasu Creek (Figure 9), total annual growth for the 2011 and 2012 cohorts averaged 91 (range 49 to 137 mm) and 67 mm (range 22 to 97 mm), respectively, in the first year (time of PIT-tagging prior to release, to the following May). Exceptional growth of the 2011 cohort continued through May 2013. Of 58 fish translocated in 2011 recaptured in May 2013, 52 were greater than >199 mm TL (average size: 228 mm TL), and average total growth over 2 years was 143 mm. Growth rates of these cohorts exceeded growth in the Little Colorado River (Figure 9, see Robinson and Childs 2001) and Colorado River (see Valdez and Ryel 1995).

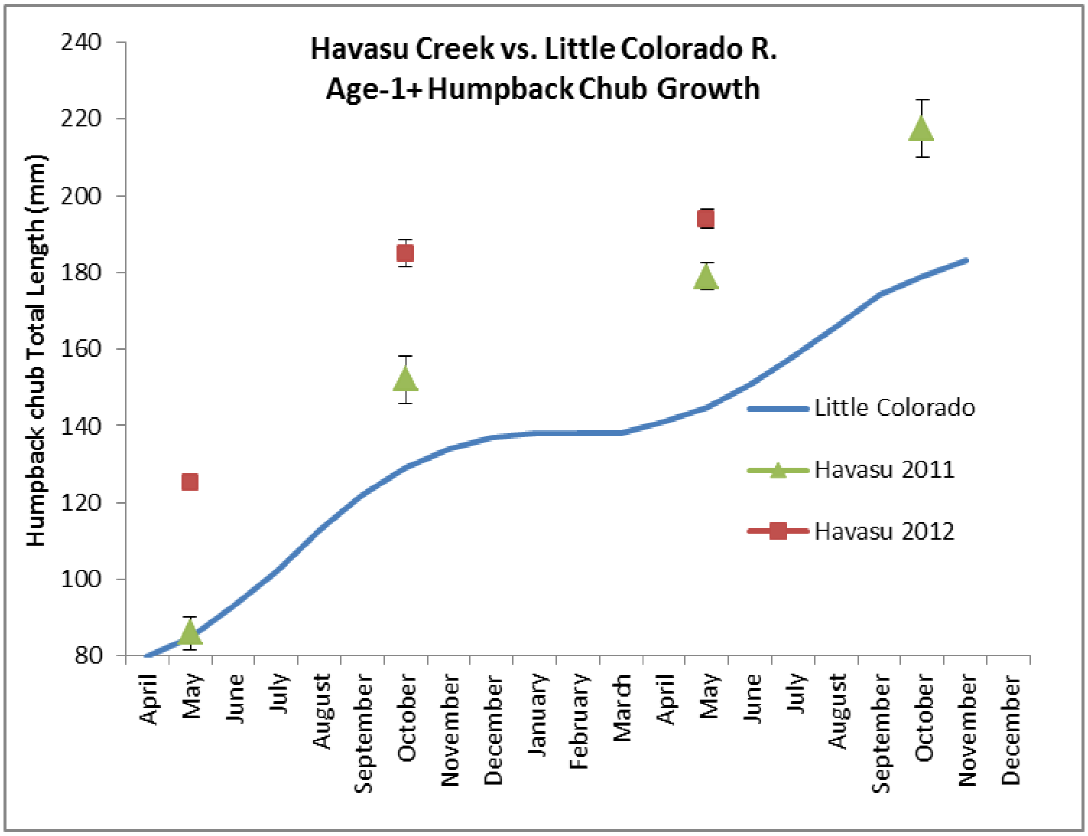

Figure 9. Average total length (mm) of Humpback Chub, by translocation cohort, at release (May or June) and based on recaptures on each monitoring trip in Havasu Creek, compared to average length by age (month) in the Little Colorado River as indicated by the growth curve developed by Robinson and Childs (2001). Error bars indicate 95% confidence intervals.

Contributions of Translocated Fish to Mainstem Aggregations

In 2010, 24 unique individuals representing both the 2009 (8 fish) and 2010 (16 fish) cohorts that had been translocated to Shinumo Creek were recaptured in the mainstem, including 9 over 200 mm (TL; USGS-GCMRC/USFWS unpublished data). One of these fish was captured at river mile 128.2, which is almost 20 miles downstream of the mouth of Shinumo Creek. At least one fish translocated in 2009 was also detected on USGS-GCMRC PIT-tag antenna arrays in the Little Colorado River in 2012 (W. Persons, USGS-GCMRC, personal communication).

During the September 2011 aggregation monitoring trip, translocated fish were captured in both the Shinumo and Havasu creek inflow aggregations, including 36 fish that had been translocated to Shinumo Creek and 7 that had been released in Havasu Creek in June. In the Shinumo aggregation, all 12 fish captured that had been released in 2009, and 9 of 15 released in 2010 exceeded 200 mm TL (a total of 21 fish > 200 mm TL). Nine and 7 subadult (< 200 mm TL) fish translocated to Shinumo and Havasu creeks in 2011, respectively, were captured in the mainstem. In summary, translocation projects contributed at least 24 and 43 Humpback Chub to mainstem aggregations in 2009 and 2010 (65 unique individuals). In 2013, 53 unique Humpback Chub were captured in the Shinumo Inflow aggregation, of which 39 (73.5%) had been translocated to Shinumo Creek, representing all translocated cohorts with the exception of the 2013 cohort (Table 7). Also in 2013, 14 Humpback Chub that had been translocated to Havasu Creek were captured in the Havasu Inflow aggregation (USGS-GCMRC/USFWS, preliminary, unpublished data).

Table 7. Unique Humpback Chub captured in the Shinumo Creek Inflow aggregation, by translocation cohort, and sampling year.

	Shinumo Aggregation Captures by Cohort				
Sampling Year	**2009**	**2010**	**2011**	**2013**	**Total Captures**
2010	15	8	0	0	23
2011	12	15	9	0	36
2012	13	19	24	0	56
2013	11	8	20	0	39
Total by Cohort	**51**	**50**	**53**	**0**	**154**

Reproduction and Recruitment

No evidence of reproduction in the Humpback Chub population translocated to Shinumo Creek had been detected through September 2013, despite the presence of at least 55 adult-sized fish in the Creek (i.e., fish >199 mm TL). However, mature spawning Humpback Chub were captured in Havasu Creek during May 2012 (ripe males only), and May 2013 (ripe females and males). In addition, 2 untagged, juvenile fish (total length = 121 and 127) were captured in Havasu Creek during May 2013, which were likely the result of reproduction in Havasu Creek during 2012. Ninety-three adult fish (>199 mm TL) were captured in Havasu Creek during the single monitoring trip in 2013. In June 2013, on the run-out river trip following monitoring activities at Shinumo Creek, three NPS fisheries staff searched the margins of Havasu Creek near the translocation pool and downstream for larval Humpback Chub; none were detected.

Nonnative Trout Control Evaluation and Abundance Trends

Nonnative Rainbow Trout were targeted for removal at Shinumo Creek. No sampling was conducted in Havasu Creek specifically for the purpose of controlling nonnative fish but Rainbow Trout were humanely euthanized if they were captured during netting efforts. A total of 155 Rainbow Trout were captured and removed from Havasu Creek over 5 sampling events (average of 31 per trip).

In addition to Humpback Chub survival, described above, additional measures used to assess the effectiveness of nonnative fish control efforts in Shinumo Creek are described below. These include Rainbow Trout abundance and size structure, and native species abundance and size structure. The analysis of trends in Bluehead Sucker survival is ongoing and incomplete.

Shinumo Creek Trout Control

Trout control efforts were conducted mainly by backpack electrofishing in Shinumo Creek; however, trout were also captured with netting or angling gear and removed from the creek. In 2011-2013, three-pass depletion electrofishing was conducted over an average of 580 meters (range: 431- 807 meters) of Shinumo Creek during trips in June, September, or February (Table 8, see Appendix A). Between one and 11 single-pass trout control stations were sampled during these same trips (Table 8, see Appendix A). Electrofishing effort was limited by flooding and high turbidity during the September 2012 sampling event. In addition, electrofishing operations were limited to areas upstream of Humpback Chub release points, and thus, no trends in Rainbow Trout in reaches 1-4 could be quantified.

Table 8. Electrofishing effort in Shinumo Creek 2011-13.

Sampling Trip	3 pass depletion stations / total meters (m)	Number of single pass (trout control) Stations
June 2011	8 / 431 m	10
September 2011	9 / 537 m	11
February 2012	8 / 709 m	8
June 2012	9 / 516 m	8
September 2012	8 / 444 m	1*
February 2013	8 / 807 m	4

*Electrofishing effort was limited by flooding.

The total number of trout removed via angling, netting, and electrofishing equipment, by year, is displayed in Table 9. Angling effort varied widely between trips, and due to varying skill levels of anglers, and a lack of a standardized protocol, catch-per-unit effort for angling was not quantified. Flooding during the September 2013 monitoring trip also precluded effective angling.

Table 9. Summary of numbers of nonnative Rainbow Trout removed from Shinumo Creek, Grand Canyon National Park, between 2009 and 2013, by reach and gear type.

	All Reaches	**Translocation Reach**	**Upstream of Translocation Areas**
Reach/Trip	Number of Trout Removed Angling/ Netting	Number of Trout Removed (Electrofishing)	Number of Trout Removed (Electrofishing)
May/June 2009 (pre-trans.)	292	694	0
2009 (post-trans.)	45	0	0
2010	391	0	538
2011	260	0	498
2012	302	0	916
2013	917	0	716
TOTAL:	**2,207**	**694**	**2,668**

For estimating capture probabilities and abundances of Rainbow Trout, the best-fitting model chosen using AIC selection methods was one that included an individual covariate for trout total length, while assuming equal capture probability across passes and monitoring events. Models including covariates to account for the effect of electrofishing on the behavior of trout (i.e, differences in capture probability between the first and consecutive passes), or site-level covariates (year and month of sample) lent minimal additional power to capture probability and abundance estimation procedures. The capture probability for a single pass for Rainbow Trout was 0.55, which cumulatively resulted in an average of 90.9% of the trout removed from these depletion stations (95% C.I. = 86.1 – 94.2). Rainbow Trout density estimates (number of trout/500 meters) declined between June 2010 and February 2012 (Figure 10). By June 2012, there was a significant five-fold increase in the Rainbow Trout density estimate, which approximated the abundance observed in June 2010 (Figure 10). Subsequent density estimates fluctuated in September 2012 and February 2013, remaining near June 2010 levels (Figure 10).

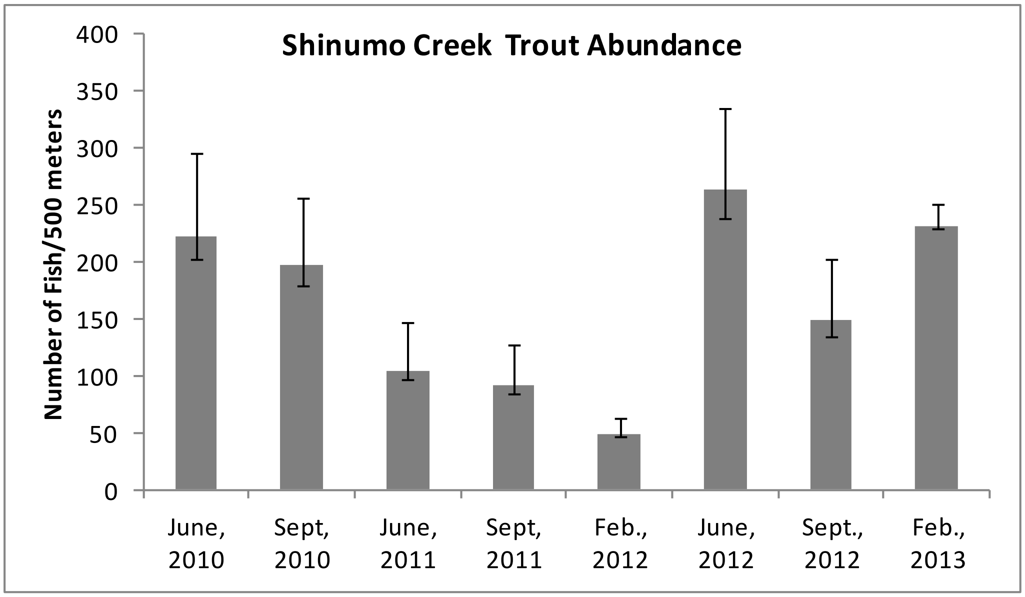

Figure 10. Rainbow Trout population estimates based on multiple-pass depletion sampling using backpack electrofishing equipment in Shinumo Creek, Grand Canyon National Park, 2010-2013. Error bars indicate 95% confidence intervals for the population estimates.

The size structure of Rainbow Trout captured during electrofishing activities in Shinumo Creek shifted toward smaller fish during June sampling events from 2010 to 2012 (Figure 11). The distribution of Rainbow Trout in June 2010 was predominantly fish with a total length greater than 150 mm (73.4%). In June 2011, 85.7% of Rainbow Trout were greater than 150 mm (Figure 11), but by the following June (2012), 13.7% of Rainbow Trout were greater than 150 mm total length (Figure 11). As of the latest electrofishing sampling event in 2013 (February), the size structure of Rainbow Trout remained skewed towards smaller size classes, but had shifted to larger fish as the cohort grew (Figure 12).

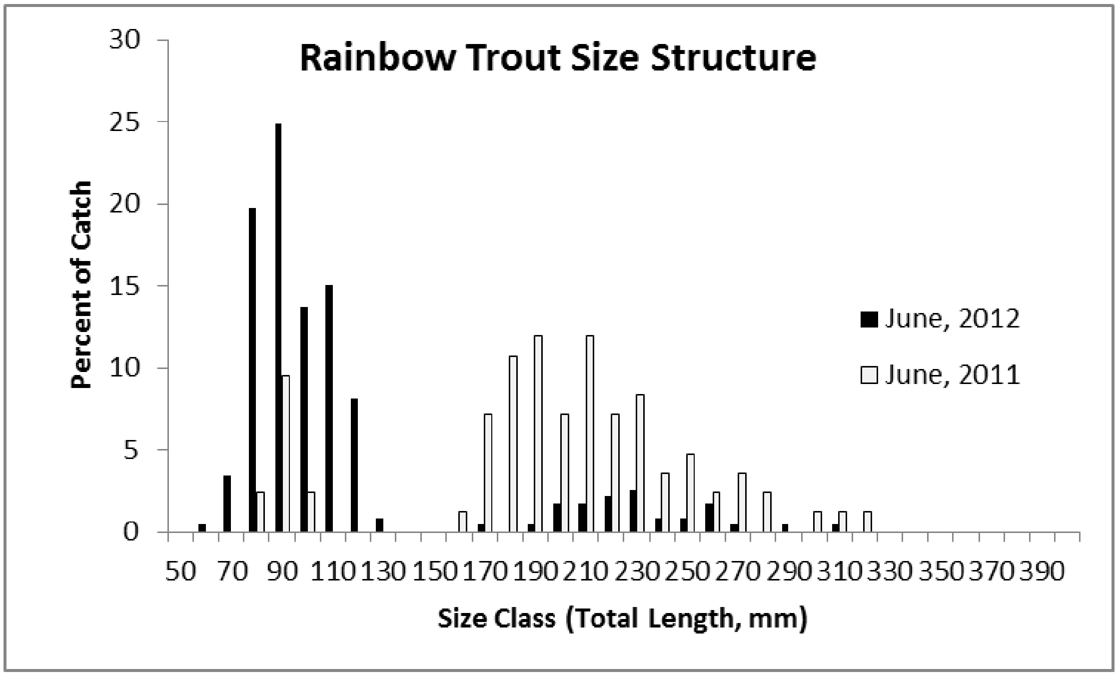

Figure 11. Rainbow Trout length frequency histograms for June sampling trips in Shinumo Creek, Grand Canyon National park, 2011- 2012.

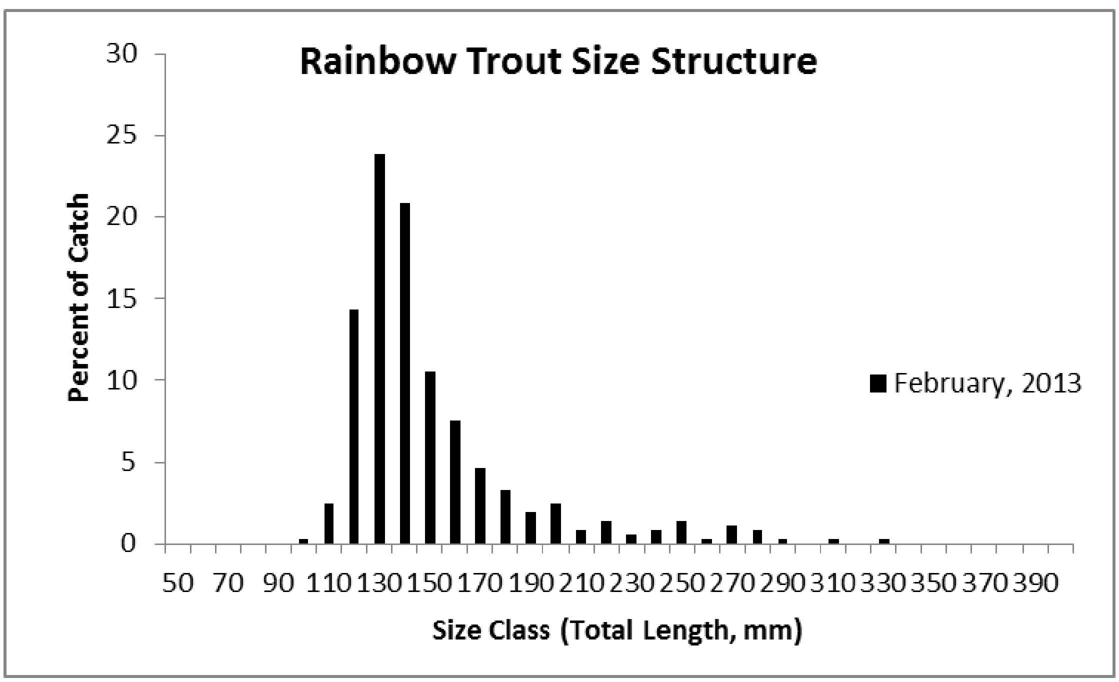

Figure 12. Rainbow Trout length frequency histogram for the latest electrofishing sample (February 2013) from Shinumo Creek, Grand Canyon National Park.

Native Fish Population Trends

Bluehead Sucker were not captured from one of station during each monitoring effort in 2010 and 2011, and therefore those stations were removed from the depletion analysis; however, the assumed estimate of zero for those stations were incorporated into reach-scale average density estimates. The model that best explained variation in capture probability for Bluehead Suckers between 2010 and 2012 incorporated the total length covariate and a constant capture probability among all trips and depletion sampling passes. Approximately equal support (i.e., model likelihood of 1.0 vs. 0.93) was found for the models incorporating a behavioral and a total length effect, as the model incorporating the individual Bluehead Sucker total length covariate alone, and the results from the "behavior and total length" model are displayed for the February 2013 sampling event (Figure 13). Capture probability estimates for Bluehead Sucker incorporating the behavior effect were 0.60 for the first pass and 0.76 for consecutive passes for 2013, and a constant 0.54 capture probability for 2010-2012. Bluehead Sucker density estimates for sampling occasions ranged from 62 to 126 individuals per 500 mm of Shinumo Creek, but no statistically significant change in abundance for Bluehead Sucker could be discerned across all eight sampling occasions (i.e., no trend was evident; Figure 13).

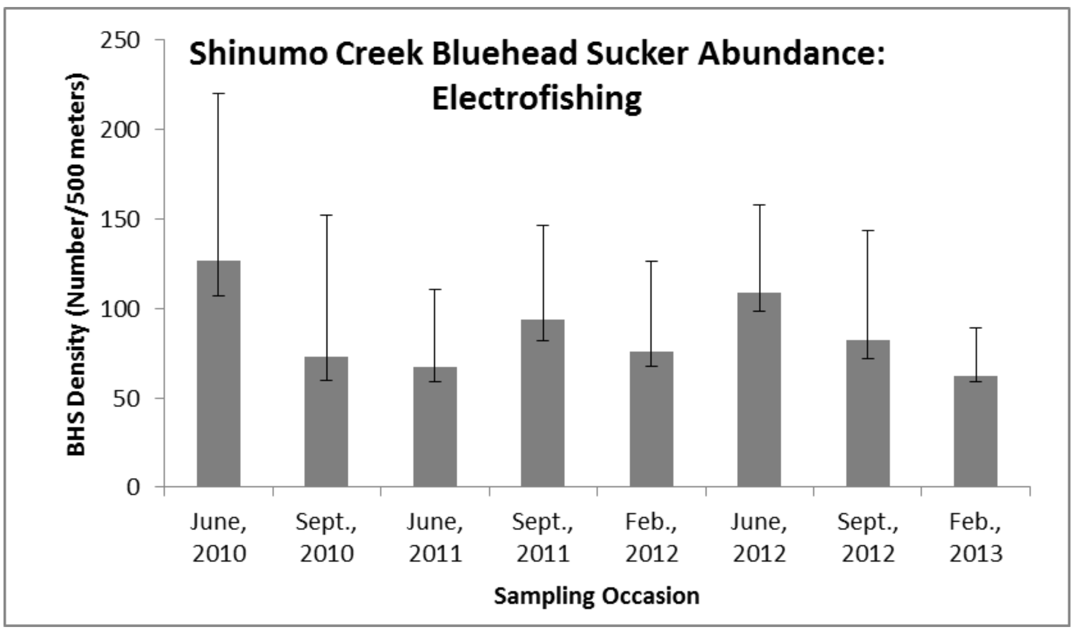

Figure 13. Bluehead Sucker population estimates based on mark-recapture sampling using mini hoop-nets and minnow traps in Shinumo Creek, Grand Canyon National Park, 2010-2013. Error bars indicate 95% confidence intervals for the population estimates.

A more limited set of models could be assessed for estimating Speckled Dace abundances and capture probabilities due to the lack of individual fish measurements. Measuring all individual Speckled Dace captured in the field would be prohibitive based on time constraints. Therefore individual covariates were not included during model selection procedures, as they were for

Bluehead Sucker and Rainbow Trout. Nevertheless, models incorporating effects of the year, month sampled, station, individual monitoring trip, and behavior across sampling passes were assessed. Separate analyses were conducted to model capture probabilities for 2010 and 2011 (June and September), 2012 (February, June, September), and 2013 (February) trips. Best-fitting models varied by analysis grouping, including assumed equal capture probability across passes, but with differing capture probabilities at individual stations (i.e, "station effect") for 2010 and 2011 trips, trip-specific models were selected for 2012 trips, and a constant capture probability across all stations and passes was selected as the top model for February 2013. Capture probabilities averaged 0.39, 0.27, and 0.28 for analysis groupings. Speckled Dace population estimates ranged from 1588 to 3236 individuals per 500 meters of stream in Shinumo Creek across all sampling events. A slight increasing trend in Speckled Dace abundance was observed (Figure 14).

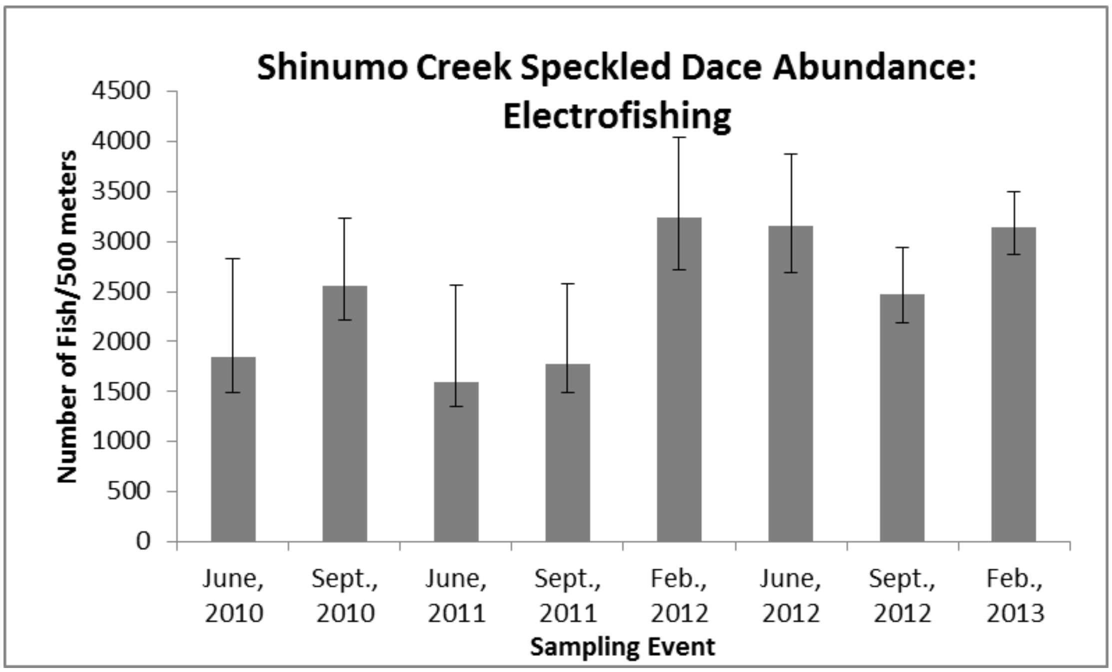

Figure 14. Speckled Dace population estimates based on multiple-pass depletion sampling using backpack electrofishing equipment in Shinumo Creek, Grand Canyon National Park, 2010-2013. Error bars indicate 95% confidence intervals for the population estimates.

Shinumo Creek Mark-Recapture Population Estimates

Mark-recapture population estimates were calculated for Bluehead Sucker and Speckled Dace, in addition to Humpback Chub (above), to monitor trends in native species abundance in reaches 1-4 of Shinumo Creek where Humpback Chub are expected to disperse following translocation.

The most parsimonious model for mark-recapture analysis of Bluehead Sucker captures chosen using AIC scores in MARK included the model incorporating differing capture probabilities across sampling events, and a constant recapture probability (AIC weight 0.77, model likelihood

= 1.0). Population estimates were possible for Bluehead Sucker on all netting trips, except for September 2010 when a low number recaptures and low capture probabilities precluded the calculation of a population estimate. No marked Bluehead Suckers were captured on the second pass in September 2010. A significant decline between June of 2010 and 2011 was evident in Bluehead Sucker, however abundance has increased since 2011 (Figure 15).

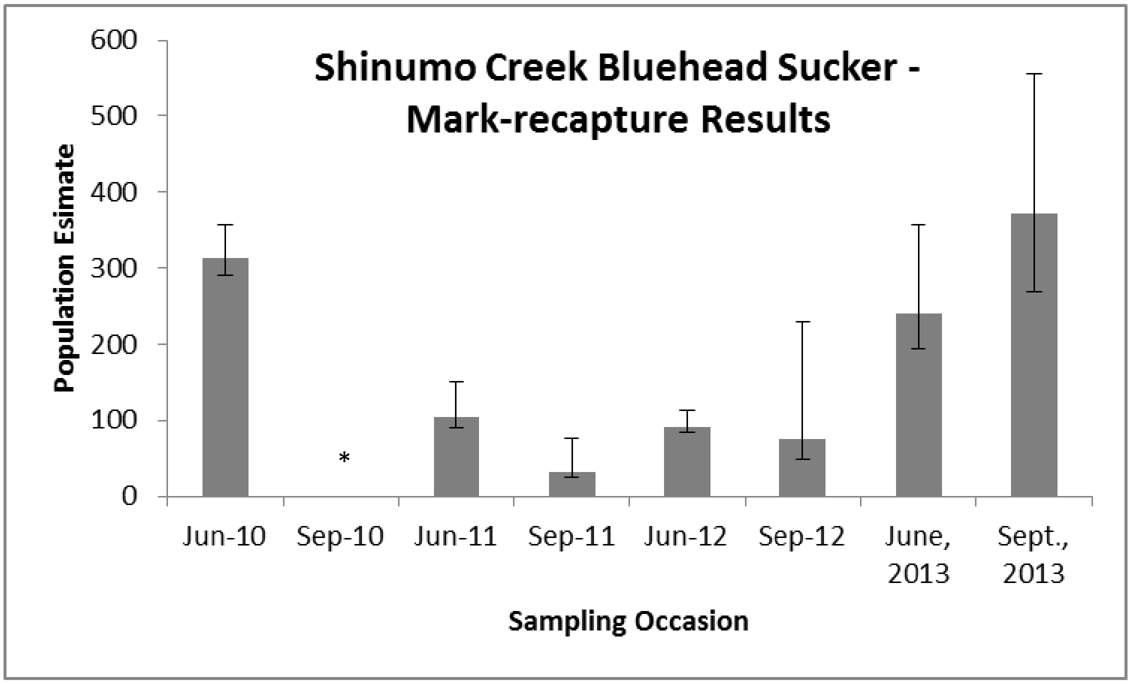

Figure 15. Bluehead Sucker mark-recapture population estimates for reaches 1-4 of Shinumo Creek, Grand Canyon National Park, 2010-2013. Error bars indicate 95% confidence intervals for the population estimates. *NOTE: No estimates could be calculated for September 2010 sampling event due to low (or lack of) numbers of recaptures on the second sampling pass.

The size structure of the Bluehead Sucker population in Shinumo Creek changed as abundance increased. The change reflected increased recruitment since 2011 (Figure 16), as a large cohort between 120 and 180 mm was detected during September 2013.

Mark-recapture sampling for Speckled Dace was conducted in the lower reaches (reach 1-4) during translocation monitoring trips beginning in June of 2010. The effort proved to be laborious and time-intensive and was restricted to the June samples beginning in 2012. In addition, in some cases a mark (i.e. fin clip) was observed during the second pass, but there was a question about whether it was a new mark or one from a previous sampling session. These fish were also not included in the analysis. For this report, mark-recapture modeling was conducted using data grouped for trips during June 2010 through September 2011, and then separate analyses were conducted for June 2012 and June 2013. Capture and recapture probabilities varied between 0.16 and 0.32. Speckled Dace abundance ranged from a low of 4,632 in June

2010 to 13,326 in September of 2011, with significant increases in abundance between June to September 2010, and June to September 2011 (Figure 17). Abundance declined between September 2011 and June 2013.

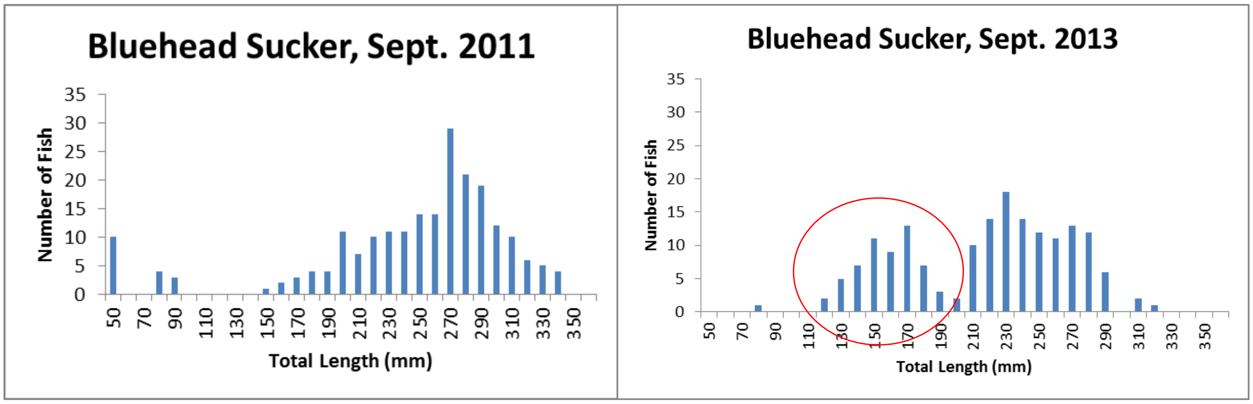

Figure 16. Bluehead Sucker length frequency histogram from September 2011 and 2013 sampling in Shinumo Creek, Grand Canyon National Park. Red circle indicates evidence of recruitment.

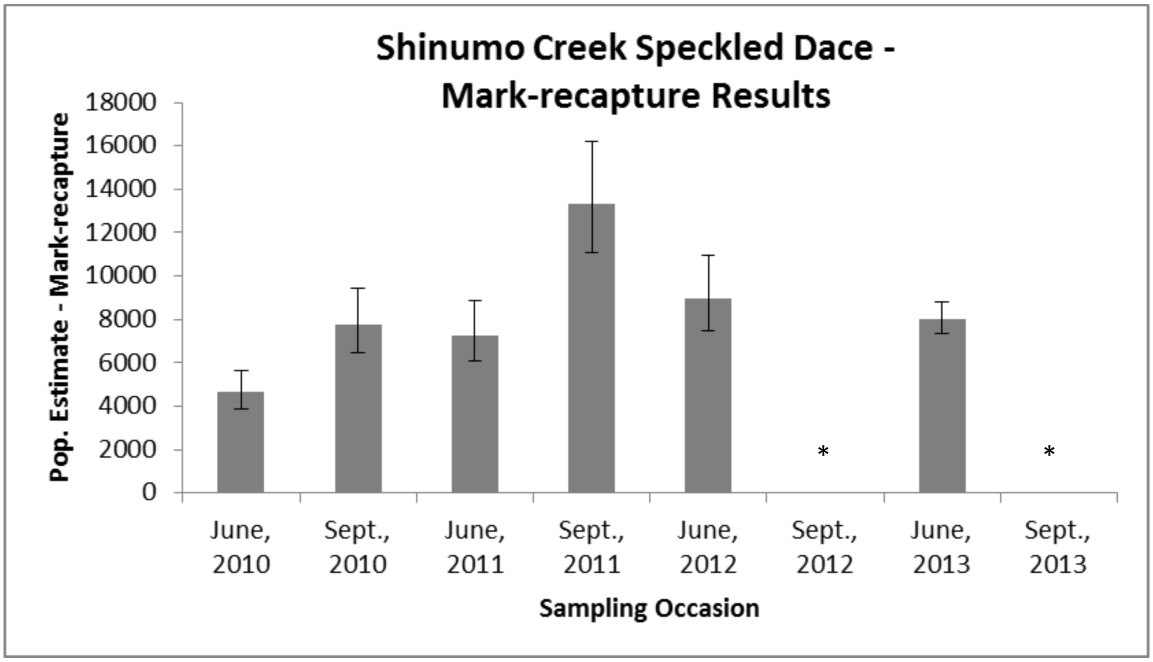

Figure 17. Speckled Dace mark-recapture population estimates for reaches 1-4 of Shinumo Creek, Grand Canyon National Park, 2010-2013. Error bars indicate 95% confidence intervals for the population estimates, and asterisks (*) indicate sampling trips when mark-recapture was not attempted for Speckled Dace.

DISCUSSION

In addition to partially fulfilling the Bureau of Reclamation obligation to meet the intent of conservation measures established in Biological Opinions for the operation of Glen Canyon Dam (USFWS 2011), Humpback Chub translocations are measured against goals and objectives recently established in the Comprehensive Fisheries Management Plan for GCNP (NPS 2013). Indicators, including retention of translocated fish, survival, growth, reproduction, and recruitment, are used to establish the outcomes for each translocation project.

The desired outcome for translocation projects in GCNP is the establishment of additional viable spawning populations of Humpback Chub outside of the Little Colorado River in order to meet park goals and objectives (NPS 2013). An additional outcome of translocations, which also partially meets the goal of restoring the distribution and abundance of Humpback Chub, and eventually may lead to the desired condition of population redundancy in Grand Canyon, is for translocations to provide for a suitable rearing opportunity for juvenile fish (NPS 2013). Translocation projects are evaluated using growth, survival, and retention in translocation streams, documented reproduction and recruitment, and the contribution of translocated fish to adjacent mainstem aggregations. Retention of less than 20% of translocated fish in receiving streams or adjacent aggregations would signify the failure of the project.

Thus far, initial translocations through 2013 have met several of the criteria that would indicate translocation projects to Havasu and Shinumo creeks provide suitable rearing or “grow-out” opportunities for juvenile Humpback Chub. A comparison of monitoring data and evaluation criteria are provided in Table 10. Growth and survival rates are comparable to those of juvenile Humpback Chub in the Little Colorado River, and growth rates exceed those found for Humpback Chub inhabiting the Colorado River (Table 10). Relatively high growth rates are likely the result of warmer seasonal temperatures compared to the Colorado River (see temperature data in Voichick and Wright 2007), as well as a more diverse and abundant food supply in these tributaries compared to the Colorado River. Macroinvertebrate data collected from Havasu, Shinumo, and Bright Angel creeks show a relatively high proportion and density of quality food items (i.e., mayflies, stoneflies, caddisflies; see Trammell et al. 2012, NPS and University of Missouri unpublished data, Whiting et al. 2014) that are generally lacking in the Colorado River (Cross et al. 2011, Kennedy et al. 2013). Humpback Chub emigrating from Shinumo and Havasu creeks captured in mainstem aggregations have comprised large proportions of the total catch of Humpback Chub, and thus have augmented mainstem aggregations. However, efforts to develop abundance trends in the mainstem have met with limited success due to the level of sampling effort needed to obtain sufficient recapture data.

Table 10. Indicators for evaluation of Humpback Chub translocation projects in Grand Canyon National Park, established in the 2013 Comprehensive Fisheries Management Plan (NPS 2013), compared to benchmarks in the Little Colorado and Colorado Rivers. NA = non-applicable.

Indicator (Benchmark)	**Colorado River**	**Little Colorado River**	**Shinumo Creek**	**Havasu Creek**
Annual Retention or Apparent Survival (≥20% of translocated fish, first year after release)	28 – 75% [b] (depending on year)	NA	2009: 19% (14-26) 2010: 18% (8-32) 2011: 46% (34-55)	2011: 51% (45-57) 2012: 37% (29-46)
Juvenile Survival (monthly rate)	0.97[a]	0.91 [a]	Mean (all cohorts) = 0.89 (range 0.79 – 0.94, time-dependent model)	0.95 (2011 cohort) 0.92 (2012 cohort)
Growth rates (annual)	27 mm [c]	52-58 mm [d]	2009: 33 mm 2010: 37 mm 2011: 65 mm	2011: 91 mm 2012: 67 mm
Contribution to aggregation	NA	NA	39 (73% of all captures, 2013)*	14 (47% of all captures 2013)*
Reproduction	NA	NA	No evidence	Yes (ripe adults, presence of juveniles)
Recruitment to mature size	NA	NA	No evidence	No evidence

*Preliminary GCMRC/USFWS/NPS (NPS-Shinumo Only) unpublished data.
[a] Yaculick et al. 2014.
[b] Finch et al. 2013.
[c] Valdez and Ryel 1995.
[d] Robsinson and Childs 2001

While aggregations have been found to contain a large proportion of translocated fish, emigration rates remain relatively high in Shinumo Creek (approx. 50% or more), with the largest pulses in emigration occurring over the days immediately following translocations, followed by emigration during monsoonal flooding or spring snowmelt runoff. Additional analyses are in progress to investigate the role of flooding or other factors influencing emigration. Nevertheless, due to antenna detection efficiency issues and uncertainties, it is likely that emigration estimated by the PIT tag antenna system is a minimum estimate. These Humpback Chub that leave translocation streams immediately do not gain the same potential advantage of warmer, food-rich, rearing habitats within the tributaries. To address the issue of high emigration rates immediately after release, an experimental “soft release” was conducted in Shinumo Creek in 2013. Block nets were placed at the downstream end of the release pool, which was also moved upstream from the mouth approximately 1-kilometer, for 3 nights following translocation. The assumption was that block nets may allow for additional time for Humpback Chub to acclimate to the receiving stream, and possibly reduce the flight response that had occurred upon release in previous years. Preliminary analysis of antenna data indicated that only 6 individual fish out of 200 that had been released in June2013 had been detected at the Shinumo Creek antenna through August 24, 2013 (NPS unpublished, preliminary data). This suggests that temporary block-netting may result in higher retention rates, at least in the short-term.

The objective of establishing a second spawning and recruiting population in Grand Canyon seems likely in Havasu Creek, where evidence of reproduction has been detected. Temperatures in Shinumo Creek appear to be sufficient for the development of gametes by adult chub, but evidence of spawning has not been detected through 2013. Nevertheless, monitoring for spawning and recruitment at both streams will continue. In addition, a subset (30-50) of untagged Humpback Chub that may be the offspring of translocated fish will be fin-clipped for genetic analysis, should more be encountered.

Nonnative trout control was initially implemented in Shinumo Creek to improve the survival of translocated Humpback Chub, but also to contribute towards NPS mandates for the restoration of native fish communities (see NPS 2006). Effectiveness was assessed using measures of abundance of native and Rainbow Trout, as well as survival of Humpback Chub and indicators of native fish recruitment (size structure) in Shinumo Creek. A significant declining trend in Rainbow Trout was evident beginning in September 2010, through February 2012, which was followed by a large cohort of trout that same year. This large cohort, likely occurring as a result of higher survival of young-of-year trout among lowered densities of adult trout as a result of trout control, was an expected compensatory response. Nevertheless, the apparent survival of the 2011 cohort of translocated Humpback Chub approximately doubled, and growth rates were higher, compared to the two previous years when trout densities were higher. Apparent survival of Humpback Chub remained high through the summer of 2012, even after Rainbow Trout abundance increased. However, Humpback Chub remaining in Shinumo Creek through 2012 would have been residents for a year or more, and would have outgrown the risk of predation by young-of-year Rainbow Trout, which comprised the vast majority of the remaining Rainbow Trout population. Smaller Rainbow Trout have been observed to primarily consume invertebrates, relative to other prey items, in Shinumo Creek (Spurgeon et al. 2014) and in another Grand Canyon tributary (Whiting et al. 2014); however, native fish were more common in larger rainbow trout (>200 mm total length) stomachs (Spurgeon et al. 2014).

The highest Speckled Dace abundance in the electrofishing reach, as well as in lower reaches sampled with nets, was found when trout densities were lowest, but no clear trend was found in Bluehead Sucker in the electrofishing reach. Nevertheless, Bluehead Sucker recruitment increased during the period of low trout densities. It is unclear to what year or years the larger cohort of Bluehead Sucker belonged, since it is unlikely that young-of-year or small juvenile suckers are sampled effectively with electrofishing or netting gears employed in Shinumo Creek. For example, depletion analyses of February 2013 electrofishing data showed that total length was an important driver of capture probability estimates for Bluehead Sucker, and capture efficiency of the smallest suckers captured (122 mm TL) was low (capture probability = 0.13), but also relatively uncertain (95% confidence interval = 0.01 – 0.60). Bluehead Suckers smaller than 150 mm TL are not PIT-tagged, so growth rates of juveniles in Shinumo Creek are unknown. However, it is possible that 2011 was the year in which a large cohort observed in 2013 was produced, based on growth equations developed by Robinson and Childs (2001) for Bluehead Sucker in the Little Colorado River. Robinson and Childs (2001) found that Bluehead Suckers would be 159 mm approximately two and a half years of age. The mode of the size distribution of the larger juvenile cohort found in September 2013 was between 150 and 170 mm (see Figure 16), suggesting this cohort was hatched in May or June 2011, if growth rates and the spawning season of Bluehead Sucker are similar between Shinumo Creek and the Little Colorado River. High spring runoff in 2011 (NPS, unpublished data) may have also contributed to higher abundances of native species; however, the mechanism is unclear. The evidence suggests that trout control efforts may have contributed to higher survival and growth rates of translocated Humpback Chub, as well as higher abundance and recruitment of Bluehead Sucker and Speckled Dace.

One concern raised among cooperating agencies involved in fisheries management within GCNP was that repeated electrofishing for trout control efforts would result in injuries to individual native fish, potentially leading to population-level declines in Shinumo or Bright Angel creeks. This concern was addressed in the adaptive management framework of the Comprehensive Fisheries Management Plan (NPS 2013). Monitoring does not indicate any significant declines in native fish abundance in the electrofishing reach and indicates instead that native fish abundance remained stable or increased, and native fish recruitment increased throughout all monitoring reaches as trout densities were reduced. However, no electrofishing was conducted downstream of translocation areas, where removal efforts focused on the use of angling (fly-fishing) techniques, or netting, which would have less potential for injury to native fish. The compensatory response observed in Rainbow Trout requires continued control efforts, and thus, the potential for injury to native fish remains a concern, and additional monitoring is needed.

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LITERATURE CITED

Carothers, S. W. and C. 0. Minckley. 1981. A survey of the fishes, aquatic invertebrates and aquatic plants of the Colorado River and selected tributaries from Lee's Ferry to Separation Rapid. Final Report to U. S. Bureau of Reclamation. 401 pgs.

Coggins, L.G., and W. E. Pine, III. 2010. Development of a temperature-dependent growth model for the endangered Humpback Chub using capture-recapture data. Open Fish Science Journal [online serial] 3:122–131. Available: www.bentham.org/open/tofishsj/openaccess2.htm. (January 2011).

Coggins, L.G., Jr., and Walters, C.J. 2009. Abundance trends and status of the Little Colorado River population of Humpback Chub; an update considering data from 1989-2008: U.S. Geological Survey Open-File Report 2009-1075. 18 pp.

Coggins, L.G., Pine, W.E., III, Walters, C.J., Van Haverbeke, D.R., Ward, D., Johnstone, H.C. 2006. Abundance trends and status of the Little Colorado River population of humpback chub. North American Journal of Fisheries Management (26):233–245.

Cooch, E., and G. White. 2011. Program MARK: a gentle introduction. 9th Edition. Program MARK software manual. 800+pages.

Cross, W. F., C. V. Baxter, K. C. Donner, E. J .Rossi-Marshall, T. A. Kennedy, R. O. Hall, Jr., H. A. Wellard Kelly, R. S. Rogers. 2011. Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon. Ecological Applications 21(6): 2016-2033.

Finch, C., W. E. Pine, III, and K. Limburg. 2013. Do hydropeaking flows alter juvenile fish growth rates? A test with juvenile Humpback Chub in the Colorado River. River Research and Applications (2013. Published online (wileyonlinelibrary.com) DOI: 10.1002/rra.2725

Grand Canyon Wildlands Council and SWCA Environmental Consultants. 2006. Humpback Chub translocation in Grand Canyon: feasibility, and experimental design, final report. Report submitted to NPS- Grand Canyon National Park, April1, 2006. 30 pages.

Grand Canyon Wildlands Council. 2010. Humpback Chub translocation into Shinumo Creek, Grand Canyon National Park, Arizona. Final report submitted to Grand Canyon National Park. 36 pages.

Healy, B. D., E. Omana Smith, J. J. Spurgeon, C. Paukert, J. Whittier, P. J. Sponholtz, and W. C. Leibfried. 2011. Translocation of Humpback Chub to Grand Canyon tributaries and related nonnative fish control activities: 2010 annual report. Report prepared for the Upper Colorado Region, Bureau of Reclamation IA Number: 09-AA-40-2890, and Colorado Plateau Cooperative Ecosystems Studies Unit (Coop. Agreement # H1200-09-0005). 93 pages.

Kennedy, T.A., Cross, W.F., Hall, R.O., Jr., Baxter, C.V., and Rosi-Marshall, E.J., 2013, Native and nonnative fish populations of the Colorado River are food limited—evidence from new food web analyses: U.S. Geological Survey Fact Sheet 2013–3039, 4 p., **http://pubs.usgs.gov/fs/2013/3039/.**

Lebreton, J., K. P. Burnham, J. Clobert, D. R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Monographs 62(1): 67-118.

Meyers, K. A., J. A Lamansky Jr., D. J. Schill. 2006. Evaluation of an unsuccessful brook trout electrofishing removal project in a small Rocky Mountain stream. North American Journal of Fisheries Management 26(4): 849-860.

National Park Service (NPS), U.S. Department of the Interior. 2006. Management Policies. Washington, D.C.: National Park Service. Available at http://www.nps.gov/policy/mp/Index2006.htm.

National Park Service (NPS), U.S. Department of the Interior. 2013. Comprehensive fisheries management plan: Grand Canyon National Park and Glen Canyon National Recreation Area. Environmental Assessment and Finding of No Significant Impact. Intermountain Region, National Park Service.

Omana Smith, E., B.D. Healy, W.C. Leibfried. 2012. Bright angel creek trout reduction project, winter 2010 to 2011 report, Natural Resource Technical Report NPS/GCNP/NRTR—2012/002, Grand Canyon National Park, Arizona.

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.

Otis, T. 1994 Selected aspects of the ecology of native and introduced fishes in two Colorado River tributaries in the Grand Canyon. M.S. thesis, University of Arizona, Tucson.

Persons, William R., D. Ward, L.A. Avery, and A.C. Butner. 2011. Standardized Methods for Grand Canyon Fisheries research 2011. Grand Canyon Monitoring and research center, U.S. Department of the Interior, flagstaff. 41 pp.

Pine, W. E. III, B. Healy, E. Omana Smith, M. Trammell, D. Speas, R. Valdez, M. Yard, C. Walters, R. Ahrens, R. Van Haverbeke, D. Stone, W. Wilson. *In press.* An individual-based model for population viability analysis of Humpback Chub in Grand Canyon. North American Journal of Fisheries Management.

Robinson, A. T. and M. R. Childs. 2001. Juvenile growth of native fishes in the Little Colorado River and in a thermally modified portion of the Colorado River. North American Journal of Fisheries Management 21:809-815.

Saunders, W. C., K. D. Fausch, G. C. White. 2011. Accurate estimation of salmonid abundance in small streams using nighttime removal electro-fishing: an evaluation using marked fish. North American Journal of Fisheries Management 31(2): 403-415.

Spurgeon, J. J. 2012. Translocation of Humpback Chub (*Gila cypha*) and food-web dynamics in Grand Canyon National Park tributary streams. Master of Science thesis, University of Missouri-Columbia. 84 pages.

Spurgeon, J. J., C. P. Paukert, B. D. Healy, C. A. Kelley, and D. P. Whiting. 2014. Can translocated native fishes retain their trophic niche when confronted with a resident invasive? Ecology of Freshwater Fish 2014: 1-11.

Spurgeon, J. J., C. P. Paukert, B. D. Healy, M. Trammell, D. Speas, E. Omana Smith. *In preparation.* Translocation of humpback chub into tributary streams of the Colorado River: implications for conservation of large-river fishes.

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/GCNP/NRR – 2012/586. National Park Service, Fort Collins, Colorado. 26 pages.

U.S. Fish and Wildlife Service (USFWS), U.S. Department of Interior. 2008. Final Biological Opinion for the Operation of Glen Canyon Dam. Bureau of Reclamation. Upper Colorado Region, Salt Lake City, Utah.

U.S. Fish and Wildlife Service (USFWS), U.S. Department of Interior. 2011a. Final Biological Opinion on the Operation of Glen Canyon Dam including High Flow Experiments and Non-Native Fish Control. Bureau of Reclamation. Upper Colorado Region, Salt Lake City, Utah.

Valdez, R.A., and R.J. Ryel. 1995. Life history and ecology of Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. BIO/WEST, Inc. Final report (TR-250-08) to the Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A. and W.J. Masslich. 1999. Evidence of reproduction by Humpback Chub in a warm spring of the Colorado River in Grand Canyon, Arizona. Southwest Nat. 44:384-387.

Valdez, R.A., S.W. Carothers, M.E. Douglas, M. Douglas, R.J. Ryel, K.Bestgen, and D.L. Wagner. 2000. Final research and implementation plan for establishing a second population of Humpback Chub in Grand Canyon. Grand Canyon Monitoring and Research Center, U.S. Department of the Interior, Flagstaff. 56 pp.

Voichick, N., and Wright, S.A., 2007, Water-temperature data for the Colorado River and tributaries between Glen Canyon Dam and Spencer Canyon, northern Arizona, 1988–2005: U.S. Geological Survey Data Series 251, 24 p.

White, G. C. 2008. Closed population estimation models and their extensions in program

MARK. Environmental and Ecological Statistics 15: 89-99.

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

Whiting, D. P., C. P. Paukert, B. D. Healy, J. J. Spurgeon. 2014. Macroinvertebrate prey availability and food web dynamics of nonnative trout in a Colorado River tributary, Grand Canyon. Journal of Freshwater Science 33(3): 872-884.

Williamson, R. R., and C. F. Tyler. 1932. Trout propagation in Grand Canyon National Park. Grand Canyon Nature Notes Volume VII, number 2. 15 pages.

Yackulic, C. B., M. D. Yard, J. Korman, and D. R. Van Haverbeke. 2014. A quantitative life history of endangered Humpback Chub that spawn in the Little Colorado River: variation in movement, growth, and survival. Ecology and Evolution (2014) open access journal.

Yard, M. D., L. G. Coggins, C. V. Baxter, G. E. Bennett, and J. Korman. 2011. Trout piscivory in the Colorado River, Grand Canyon: Effects of turbidity, temperature, and fish prey availability. Transactions of the American Fisheries Society 140(2):471-486.

Appendix A. Electrofishing sampling effort at Shinumo Creek, between June 2011, and February 2013.

Trip ID	Station ID	1st Pass Effort (Seconds)	Date	Sampling Protocol	Station Length (meters)
GC061211	5-1	1010	06/16/2011	3-pass depletion	50
GC061211	5-2	1512	06/16/2011	3-pass depletion	69
GC061211	5-3	1013	06/17/2011	3-pass depletion	50
GC061211	5-4	1186	06/17/2011	3-pass depletion	58
GC061211	5-5	1085	06/17/2011	3-pass depletion	50
GC061211	5-6	668	06/18/2011	3-pass depletion	50
GC061211	5-7	711	06/18/2011	3-pass depletion	51
GC061211	5-8	858	06/18/2011	3-pass depletion	53
GC061211	TC1	310	06/18/2011	Single Pass (Trout Control)	NA
GC061211	TC2	1414	06/19/2011	Single Pass (Trout Control)	NA
GC061211	TC3	748	06/19/2011	Single Pass (Trout Control)	NA
GC061211	TC4	1286	06/19/2011	Single Pass (Trout Control)	NA
GC061211	TC5	1124	06/19/2011	Single Pass (Trout Control)	NA
GC061211	TC6	265	06/19/2011	Single Pass (Trout Control)	NA
GC061211	TC7	1166	06/20/2011	Single Pass (Trout Control)	NA

GC061211	TC8	1441	06/20/2011	Single Pass (Trout Control)	NA
GC061211	TC9	965	06/20/2011	Single Pass (Trout Control)	NA
GC061211	TC10	1587	06/20/2011	Single Pass (Trout Control)	NA
GC090511	8	886	09/12/2011	3-pass depletion	64
GC090511	9	571	09/12/2011	3-pass depletion	42
GC090511	6	1242	09/12/2011	3-pass depletion	75
GC090511	7	823	09/12/2011	3-pass depletion	50
GC090511	5	1241	09/12/2011	3-pass depletion	81
GC090511	4	1120	09/12/2011	3-pass depletion	75
GC090511	3	905	09/12/2011	3-pass depletion	70
GC090511	1	986	09/12/2011	3-pass depletion	65
GC090511	2	832	09/12/2011	3-pass depletion	51
GC090511	TC 11	646	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC10	716	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC9	749	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC8	472	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC7	661	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC6	704	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC5	1270	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC4	886	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC3	402	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC2	397	09/12/2011	Single Pass (Trout Control)	NA
GC090511	TC1	601	09/12/2011	Single Pass (Trout Control)	NA
GC022012	1	1567	02/24/2012	3-pass depletion	100
GC022012	2	1563	02/24/2012	3-pass depletion	100
GC022012	3	1727	02/25/2012	3-pass depletion	100
GC022012	4	1501	02/25/2012	3-pass depletion	100
GC022012	5	1545	02/26/2012	3-pass depletion	101
GC022012	6	867	02/26/2012	3-pass depletion	52
GC022012	7	1501	02/27/2012	3-pass depletion	105
GC022012	8	914	02/27/2012	3-pass depletion	51
GC022012	TC1	1365	02/28/2012	Single Pass (Trout Control)	NA
GC022012	TC2	446	02/28/2012	Single Pass (Trout Control)	NA

GC022012	TC3	1604	02/28/2012	Single Pass (Trout Control)	NA
GC022012	TC4	1577	02/28/2012	Single Pass (Trout Control)	NA
GC022012	TC5	627	02/28/2012	Single Pass (Trout Control)	NA
GC022012	TC6	1589	02/29/2012	Single Pass (Trout Control)	NA
GC022012	TC7		02/29/2012	Single Pass (Trout Control)	NA
GC022012	TC8	1186	02/29/2012	Single Pass (Trout Control)	NA
GC06132012	EL1	749	06/17/2012	3-pass depletion	41.4
GC06132012	EL2	1334	06/17/2012	3-pass depletion	56
GC06132012	EL3	1492	06/18/2012	3-pass depletion	58
GC06132012	EL4	1299	06/18/2012	3-pass depletion	59.2
GC06132012	EL5	482	06/19/2012	3-pass depletion	62
GC06132012	EL6	520	06/19/2012	3-pass depletion	60
GC06132012	EL7	497	06/19/2012	3-pass depletion	56
GC06132012	EL9	937	06/20/2012	3-pass depletion	66
GC06132012	EL8	510	06/20/2012	3-pass depletion	57
GC06132012	TC1	482	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC2	555	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC3	508	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC4	505	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC5	390	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC6	591	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC7	702	06/21/2012	Single Pass (Trout Control)	NA
GC06132012	TC8	519	06/21/2012	Single Pass (Trout Control)	NA
GC090412	1	648	09/08/2012	3-pass depletion	69
GC090412	2	865	09/08/2012	3-pass depletion	53
GC090412	3	890	09/09/2012	3-pass depletion	56
GC090412	4	1032	09/09/2012	3-pass depletion	57
GC090412	5	767	09/09/2012	3-pass depletion	54
GC090412	6	875	09/10/2012	3-pass depletion	53
GC090412	7	903	09/10/2012	3-pass depletion	51
GC090412	8	-	09/10/2012	3-pass depletion	51
GC090412	TC-1	444	09/10/2012	Single Pass (Trout Control)	NA
GC022013	1	1705	02/26/2013	3-pass depletion	100
GC022013	2	1573	02/26/2013	3-pass depletion	98

GC022013	3	1878	02/27/2013	3-pass depletion	100
GC022013	4	1927	02/27/2013	3-pass depletion	100
GC022013	5	1806	02/28/2013	3-pass depletion	108
GC022013	6	1614	02/28/2013	3-pass depletion	100
GC022013	7	1904	03/01/2013	3-pass depletion	101
GC022013	8	1484	03/01/2013	3-pass depletion	100
GC022013	TC-1	1427	03/02/2013	Single Pass (Trout Control)	NA
GC022013	TC-2	2326	03/02/2013	Single Pass (Trout Control)	NA
GC022013	TC-3	2121	03/02/2013	Single Pass (Trout Control)	NA
GC022013	TC-4	1198	03/02/2013	Single Pass (Trout Control)	NA

Glossary

Aggregation –

Translocation –

Cohort –

Emigration –