Nearshore Ecology (NSE) of Grand Canyon Fish 2010 Progress Report

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Note: All information presented should be considered draft and subject to revision based on corrections and updates to field data and analytical approaches. This document is prepared as a courtesy to our cooperators.

List of abbreviations

Fish species – Common name

BBH – Brown bullhead
BKC – Black crappie
BNT – Brown trout
CCF – Channel catfish
CRP – Common carp
FHM – Fathead minnow
FMS – Flannelmouth sucker
GSF – Green sunfish
HBC – Humpback chub
PKF – Plains killifish
RBT – Rainbow trout
RSH – Red shiner
SPD – Speckled dace
STB – Striped bass
SUC – Unidentified sucker

Places

CR – Colorado River
LCR – Little Colorado River

Gear

EF – Boat electrofishing
HN – Hoopnets

Other

NSE – Nearshore Ecology Project
UF – University of Florida
GCMRC – United States Geologic Survey Grand Canyon Monitoring and Research Center
PIT – Passive Integrate Transponder, a tag type that provides a uniquely identifiable id to each fish
VIE – Visible Implant Elastomer, a tag type that provides a batch mark that identifies the trip, gear, and site a fish was collected

Nearshore Ecology Project 2010 Research Progress Report

The NSE project is designed to assess whether juvenile native fish survival and recruitment are influenced by planned flow experiments from Glen Canyon Dam that will occur during September and October 2009-2011. To make this assessment, our research is defined by three domains each informed by 2009 sampling and detailed in our original full proposal. Three key areas where this project seeks to fill existing information gaps are:

> *(1) Evaluating how steady flows influence juvenile native fish growth and survival,*
> *(2) Assess habitat use and movement of juvenile fish in response to steady flows, and*
> *(3) Identify the spatial source of juvenile native fish found in the mainstem.*

This report serves as a preliminary presentation of research results from 2010. These results focus on sampling, methodologies, and analyses to inform 2011 field efforts and primarily include catch-rate, movement, capture probability, and abundance estimates for juvenile humpback chub (HBC) as well as microchemical and isotopic water atlas development and assessment of otolith microchemistry techniques. All information presented should be considered draft and subject to revision based on corrections and updates to field data and analytical approaches through collaboration revisions between NSE core research team and GCMRC cooperators. A detailed final report will be prepared during 2012 as detailed in the original agreement.

Field Sampling Overview

Field efforts in 2010 included a total of four sampling trips, two trips prior to the steady flow experiment which launched during normal dam operations (launch dates of mid-July and mid-August), and two trips following the start of the steady flow experiment (experiment began September 1, trip launch dates early September and mid-October). Our sampling universe covered an area from Heart Island (just downstream of the Little Colorado River confluence, Figure 1) to an area just upstream of Lava Chuar rapid (about RM 65.5). Within this sampling universe, we established three sampling sites (Sites 1, 2, and 3) of approximately equal length (about 1500-m) with similar hydrologic features. Each Site was then subdivided further into individual spatially referenced 50-m segments (“habitat sub-unit”, HSU). We used slow-speed boat electrofishing (~9 seconds/m of shoreline) during night time to sample each HSU. Fish captured in each HSU were placed in a numbered bucket corresponding to the HSU to track catch spatially by HSU. All fish collected in each HSU were identified, measured (TL and FL)

and given one of two tag types following established fish handling protocols in Grand Canyon (W. Persons, GCMRC, *in-review)*. We examined all native fish for PIT tags and tagged HBC greater than 100-mm TL and all other natives greater than 150-mm TL with a PIT tag. All native fish less than 100-mm TL and fathead minnows received a Visual Implant Elastomer (VIE) mark that identified gear and Site (1, 2, or 3) the fish was captured (the marks are not unique to individual fish). The use of VIE marks was required because the smaller size fish are too small to mark with PIT tags. We sampled each site over multiple nights (3-4 passes) and kept track of the cumulative numbers of captures and recaptures of fish (all species and tag types). We used this mark-recapture information to estimate abundance for each site.

Sampling selectivity differs among gear type, and for a given species, or fish size, or habitat. In Site 1, besides slow shocking, we also employed hoopnets (standardized mini-hoopnets used by cooperating agencies for mainstem fish sampling, approximately 0.5-m in diameter, 1.0-m length, 6-mm mesh, and single 10-cm throat; n = 47 nets trip 1, n = 60 nets trip 2, n= 62 nets trips 3, and 4) to sample juvenile fish. Hoopnets were checked every 24-hours and were fished for 12-14 nights for each trip. All collected fish were processed similarly to the fish captured via electrofishing.

To assess fish movement patterns and habitat use directly we tagged a sub-set of juvenile humpback chub (N = 30 total, 10 per trip July-Sept, all between 180 and 220–mm TL) with sonic telemetry tags. Tags measured approximately 9.5 x 28-mm with a battery life of 60 days. We tagged approximately equal numbers in each of the first three river trips following a staggered-entry design due to short life of telemetry tags where small numbers (n=10) of fish are released on trips 1-3 to sustain a population of telemetered fish instead of releasing all telemetered fish on one trip. We tagged fish collected as part of the standardized EF and HN sampling described above and released the fish in approximately the same location as it was originally captured. We relocated telemetered fish using a boat mounted hydrophone approximately every 8 hours daily. When a fish was relocated, we triangulated its position and recorded the tag's unique number, spatial location, depth, distance to shore and habitat hydraulic type.

Water chemistry and isotope sampling

Water samples were collected in May, July, August, September, and October 2010. Acidified (1% HNO_3) samples were analyzed for trace elements with inductively coupled plasma optical emission spectrometry (ICP-OES) or inductively coupled plasma mass spectrometry (ICP-MS).

Our limit of detection for most elements was in the low parts per billion. Following completion of quality control samples, results were only accepted if relative standard deviation (standard deviation / mean * 100) < 10%. Unacidified samples were analyzed for stable isotopic ratios of Sr, O, H, and C. $^{87:86}$Sr was analyzed in the Department of Earth Sciences, Syracuse University, using thermal ionization mass spectrometry (TIMS). Oxygen (δ^{18}O) and hydrogen:deuterium (H:D) ratios were analyzed by isotope ratio mass spectrometry at the Center for Stable Isotope Biogeochemistry at the University of California at Berkeley. Carbon (δ^{13}C) ratios were analyzed at the Stable Isotope Facility at the University of California at Davis.

Movement and growth assessment from otoliths

The use of otolith chemistry as a natural marker is based on a predictable relationship between water and otolith chemistry such that fish movements between water masses with differing trace elemental chemistry is reflected in otolith composition. Based on 2009 results we now have a good idea of what unique otolith chemical markers discriminate native fish residency in the Little Colorado River and mainstem Colorado River. All otolith chemistry analyses have been conducted on a very limited number of native fish. With all fish, the lapillus otoliths were removed and polished to the core in order to permit retrospective otolith chemistry analysis over the life of the fish. In addition, we have also estimated age of young-of-year native fishes using otolith daily increment analyses.

A single analytical technique cannot be used to quantify all potential otolith chemistry markers. Therefore, we have used three different analytical methodologies to capitalize on the analytical strengths each technique offers. Laser-ablation inductively coupled plasma mass spectrometry (LA-ICPMS) is routinely used to quantify heavier trace elements in otoliths such as Sr, Ba, Mg, Mn, Ca, and Pb. This approach uses a high energy laser to remove otolith material that is swept into a mass spectrometer using a carrier gas flow. This technique assays specific sample locations on the otolith and permits the simultaneous analysis of multiple elements.

In addition to LA-ICPMS analyses, we have analyzed several otoliths using synchrotron-based scanning x-ray fluorescence microscopy (synchrotron SXFM) at the Cornell High Energy Synchrotron Source (CHESS) facility. This method uses focused high-energy x-ray radiation to elicit a characteristic, element-specific fluorescence from the otolith used to determine trace elemental concentrations. Although many of the elements that can be quantified using SXFM overlap with LA-ICPMS techniques, SXFM has the advantage of being non-destructive (i.e.,

material is not removed from otolith) and can produce fine scale analyses of the otolith (beam size ~15-25μm). Additionally, this technique lends itself to creating 2D surface maps of otolith chemistry. A suite of HBC, SPD, and FMS fish otoliths were analyzed using this technique.

Geologic and biological processes often result in shifts in natural isotopic abundances for some elements in the water. Given that these shifts are often recorded in otolith chemistry, we used secondary ion mass spectrometry (SIMS) to quantify oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotope ratios in otoliths. This technique bombards the surface of the otolith sample using a cesium ion beam to create oxygen and carbon ions. These ions are then separated by isotopic mass, and abundances are quantified using a very sensitive mass spectrometer. Given the high demand and high cost of SIMS instrument time (only 6 SIMS instruments exist in US), we have only been able to analyze a small number of native fish from 2009 and 2010 using the full suite of available microchemistry approaches. We are scheduled to analyze additional samples at University of Wisconsin SIMS facility during 2011.

Finally, a combination of light (brightfield, phase contrast, differential light microscopy) and scanning electron microscopy (SEM) were used to enumerate daily growth increments recorded in the otoliths. Samples were prepared as described above using otoliths from the limited number of native fish.

Results and Analyses to date

Catch and size frequency analyses

Across all eight trips (4 each in 2009 and 2010), in all sites, using both gears, we have collected over 25,000 fish from 15 identifiable species and a group of unidentifiable suckers (Table 1 and Table 2). Unidentified suckers were not retained due to concern that these may be HBC. The top three species caught (by number) were generally native HBC (6499 caught) and SPD (1512 caught) and nonnative fathead minnows (13764 caught). We focus the remaining results in this report on 2010 field season results for juvenile HBC as they are the endangered species of management interest in this system.

Size frequency analyses show that both gears (HN and EF) captured a wide size range of HBC but electrofishing generally captured smaller fish than hoopnets (Figure 2 and Figure 3). Total catch of all sizes of HBC was higher in hoopnets than from electrofishing (Figure 2) and the catch of small HBC (<100 mm TL) was similar between the hoops and electrofishing in 2010,

although EF generally caught smaller HBC. This similarity in the catch of small fish between the HN and EF during 2010 differs from the 2009 observation of much higher catches of small HBC in EF than in hoopnets.

Spatial distribution of catch, movement, and habitat use of HBC

To examine the spatial distribution of HBC catch, we created a plot of HBC catch by size class on habitat sub-unit (HSU; Figure 4). The HSU represents the spatial grid cell of each electrofishing transect sample. We structured this plot such that the HSUs for river right (sites 140-300) are found on the primary x-axis and the HSUs for river left (HSU 450-650) are found on the secondary x-axis (Figure 4). The catch in each of these grid cells (y-axis) then correspond to each x-axis such that catches close to zero for a given HSU are near the axis corresponding to that HSU (either primary or secondary x-axis) and non-zero catches are a greater distance away from the corresponding x-axis. Catches of HBC of all sizes by gear and trip were widely distributed throughout each site for electrofishing and a similar pattern is apparent for HBC in hoopnet samples in Site 1. We continue to work with GCMRC cooperators to link spatial catch information with habitat information available for each HSU to assess habitat use vs. availability.

To determine whether telemetered humpback chub were selecting or avoiding specific habitat hydraulic types the following log likelihood test statistic was constructed as

$$X^2_{L2} = 2\sum_{j=1}^{n}\sum_{i=1}^{l} Uij \log e[Uij / E(Uij)], \quad (1)$$

where, Uij is the amount of habitat type *i* used by fish *j.* A chi-square test statistic is used to assess whether habitats are selected with equal probability (alpha = 0.05). Following this test, a selection ratio then used to assess habitat selection as:

$$\hat{W}i = (\underline{U}i+) / (\pi i^* U++) \quad (2)$$

Where *Ui*+ is the amount of habitat type *i* used by all fish, πi is the proportion of available habitat in category l and U++ is the total amount of habitat used by all fish. This selection ratio measures the proportion of habitat used over the proportion of habitat available such that selection is indicated by values >1 and avoidance is characterized by values < 1. Values equal to 1 indicate no selection or avoidance (random habitat use). Approximate 95% Bonferroni adjusted confidence intervals were calculated to determine the probable range of W*i* estimates.

Assuming equal probability of detection in different hydraulic habitat types, our results suggest HBC select for eddy habitats while generally avoiding other habitat hydraulic types (e.g. run, glide, rapid; Figure 5 and Figure 6). No strong difference in selection was observed between the fluctuating flow regime and the steady flow regime. While backwater habitats may be considered a sub-type of eddy habitat, we treated backwaters as a separate category because of their managerial interest. An interesting observation is that backwater hydraulic types were used by telemetered humpback chub during periods of high turbidity. Selection of backwater areas was not included in this analysis because the proportional area of backwaters is extremely small compared to the availability of other habitat types causing the selection ratio to be strongly biased upward.

Movement of tagged fish

Movement patterns of VIE tagged HBC are detailed in Table 2 which identifies total catch in each site on each trip, and then recaptures in all other possible trip and site combinations. As a reminder, VIE tagged HBC are < 100-mm TL. Movement patterns of HBC within a trip were generally restricted to the site of tagging with the majority of recaptures occurring in the same site in which the fish was tagged. Recaptures of fish outside of the site they were originally tagged occurred both downstream and upstream (i.e., Trip 3, Site 1, 2 fish were recaptured in Site 3; Table 2). Highest marking rates were in Site 1 because of the additional sampling effort associated with fishing hoopnets in this site.

We used relocations of telemetered humpback chub to calculate daily movement rates (m/day, Figure 7). As a preliminary assessment, we used a basic t-test to test for differences in mean daily movement rates of telemetered humpback chub. The mean movement of telemetered humpback chub during the fluctuating flow regime was about 100 meters/day (n=176 relocations) and about 103 meters/day (n=367 relocations) for the steady flow regime (Figure 8 and 9). Daily movement did not vary significantly between flow regimes (P-value=0.44, df=537). We are continuing more detailed analyses of telemetered fish movement patterns, habitat selection, and home range estimation. Field work with telemetered fish will be discontinued in 2011.

Capture probability

We assessed capture probability of juvenile HBC in two different size classes (100-150-mmTL, and 151-200-mm TL) by trip (Figure 10) and found that across these attributes capture probabilities were generally low (about 5-14%). Graphs of capture probability by size class for HBC show capture probability is generally higher for the larger fish. We are currently working to incorporate turbidity as a covariate on capture probability.

Abundance

We are currently assessing a variety of approaches to estimating abundance. The simplest approach is to simply divide catch of HBC of different size classes by capture probabilities estimated for each trip and size class. For this report we used this approach and have provided abundance estimates for HBC <100-mm TL in Figure 11 for all trips in both 2009 and 2010. Figure 12 is a similar figure and shows abundance estimates for HBC between 100-200-mm TL. Similar patterns are seen across years with higher abundance usually estimated in Site 1 compared to the more downstream Site 2 and Site 3. Abundance estimates of HBC <100-mm TL were generally between 500-1000 fish per site and about 150-200 fish per site for HBC 100-150-mm TL. We anticipate revising these abundance estimates as we revise our approach to estimating capture probability and improve our methods for estimating abundance during 2011.

Survival

Our two tag types (VIE and PIT tags) provide two very different types of data for estimating annual survival. For VIE marked HBC (<100-mm TL) we followed the abundance of marked cohorts of fish through time. Table 2 demonstrates this approach as it is possible to follow the number of fish recaptured from a cohort of fish marked on a particular trip through time to see how long that cohort persists through time (i.e., from Trip 1, July 2009 through all other trips). The consistent number of fish recaptured from each cohort through time demonstrates high survival of these fish generally about 50-60% annually (example in Figure 13). We estimate survival of the PIT tagged fish differently because the PIT tagged fish have individually unique tags. These unique tags allow us to follow the fate of individual fish through time and estimate survival using Cormack-Jolly-Seber type models. We estimated survival using this approach for fish between 100-150-mm TL and then 150-200-mm. We found that annual survival for these two size classes was between about 50-80% (Figure 13). It is important to note that this approach to estimating survival is apparent survival as we are unable to separate out mortality from emigration. However, given our high fidelity rates identified in Table 2 emigration rates

may be low. We are continuing to refine our approaches to estimating survival for both the VIE and PIT tagged fish.

Growth

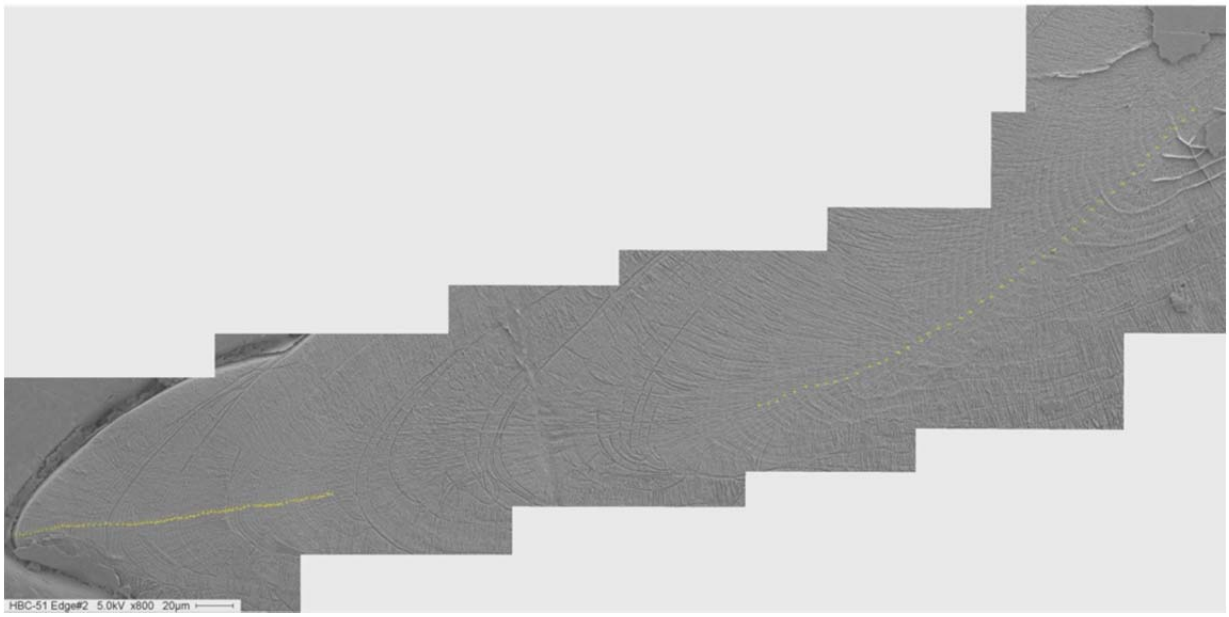
We estimated growth of juvenile HBC through recaptures of PIT tagged fish. Because PIT tags provide unique marks, when we recapture a fish we can review the previous capture information to determine how much the fish has grown over the period of time since its last capture. We assessed growth of juvenile HBC in both the mainstem Colorado and LCR during both fluctuating and steady flow conditions. To do this, we had to rely on recaptures of fish that were captured and recaptured in the LCR or in the mainstem exclusively during each flow treatment. Because of small sample sizes associated with recaptures of fish available for this growth assessment, we had to pool recaptures of fish that met our conditions between 2009 and 2010 field efforts and then we bootstrapped our estimates of growth 1000-times to create frequency distributions of growth under each location or flow treatment (Figure 15 and Figure 16). Growth of juvenile HBC from the mainstem Colorado was slower in September and October (steady flows) than in July and August (fluctuating flow, Figure 14) even though water temperatures were similar in these two time periods. LCR growth was generally faster (but highly variable) in July and August than in September-October (Figure 15). Figure 16 plots frequency distributions of all growth estimates on a single plot. We are hoping to use recapture information from cooperator sampling in the LCR (USFWS) to increase sample size of fish for growth estimation during 2011.

Movement and growth assessment from otoliths

In our 2009 progress report we provided extensive discussion on the approaches used to develop a water atlas of trace elements and isotopes throughout Grand Canyon. Using information from the water atlas and analyses of otoliths from larval and very small native fish from the LCR, we were able to identify the elemental and isotopic signature in the otolith that identifies the natal origins of an individual fish. Additionally, based on microchemistry signatures, we can now identify whether or not a particular fish has spent time in the Colorado River, LCR, or both. When combined with visual assessment of otolith growth rings (under various light and scanning electron microscopes) we are now able to create more complete movement and growth patterns of individual native fish. To demonstrate these approaches, we will follow the life history trajectory of a single 97-mm HBC that was collected in the LCR near

Boulders camp in July 2009. The format is atypical but necessary to best explain the images. A composite scanning electron microscope image of this fish's otolith after preparation follows.

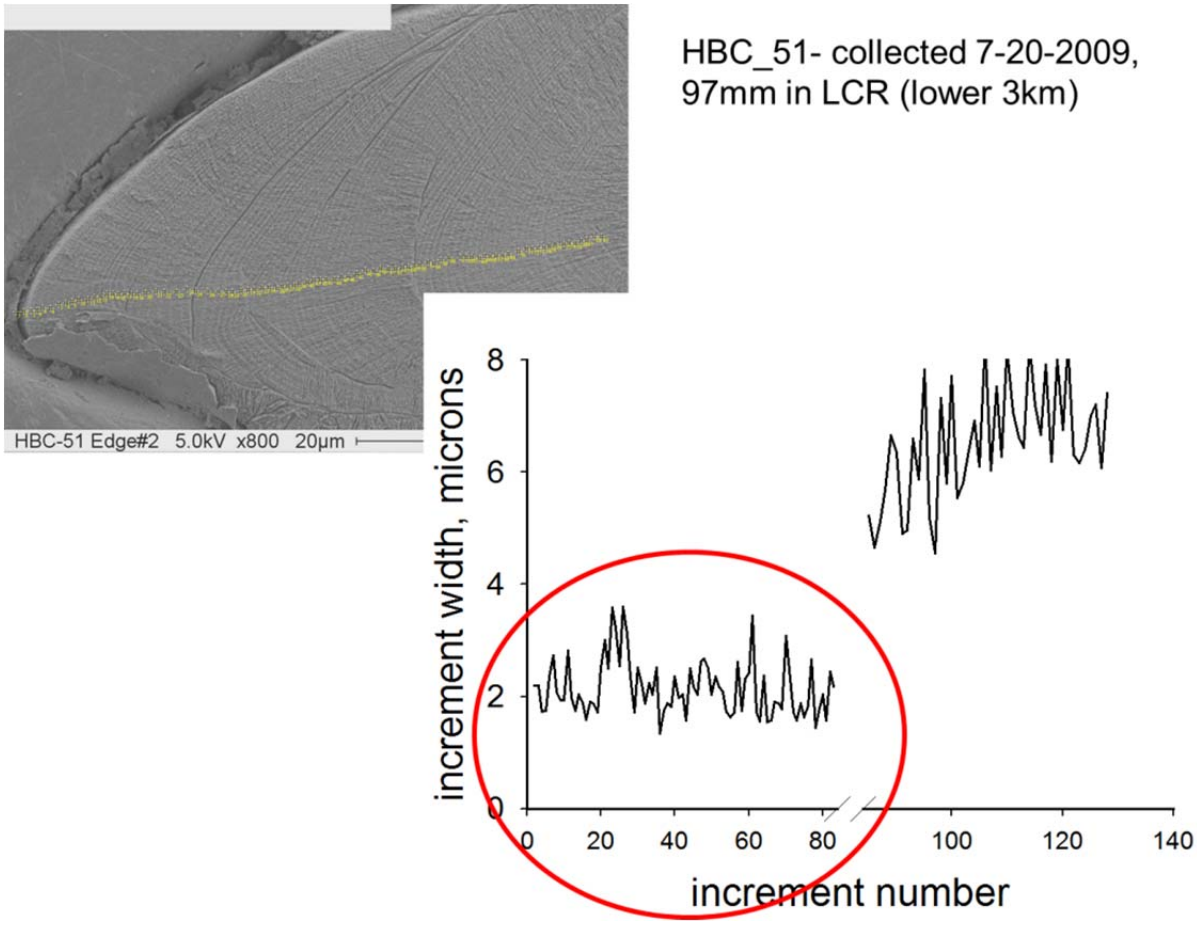
HBC 51- collected 7-20-2009, 97mm in LCR (lower 3km)



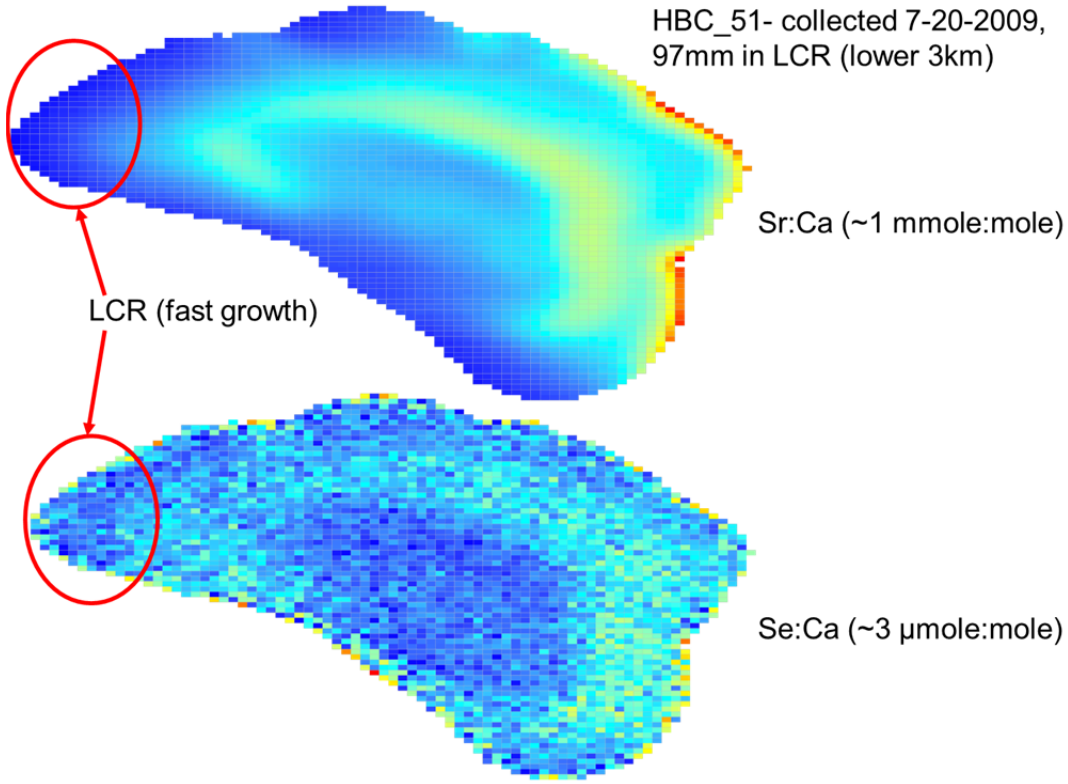
The top right of the image is near the otolith core which is the part of the otolith formed when the fish hatches from the egg. The bottom left region of this image is the outer edge of the otolith and corresponds to material added to the otolith just before the fish was collected. The yellow dots highlight daily growth increments ("rings") on the surface of the otolith that correspond to each day of the fish's life. The fish's age can be determined by counting the rings, analogous to counting the rings of a tree. As well, fish growth rates can be estimated by measuring the distances between increments. The region of the otolith between core and outer edge does not have any yellow marks because we are unable to resolve daily rings during this time of the fish's life.

Next, we will link fish growth and residency using otolith chemistry (mainstem vs. LCR) throughout the life of this fish. We start by zooming in on the outer edge of the otolith shown above (see image below). The yellow dots denote individual growth rings on the surface of this otolith and the corresponding graph shows the distances (in microns) between these rings. The

red circled region in the graph shows the incremental measurements for the first 80 rings reading from the left to right (outside edge of otolith towards the otolith core).

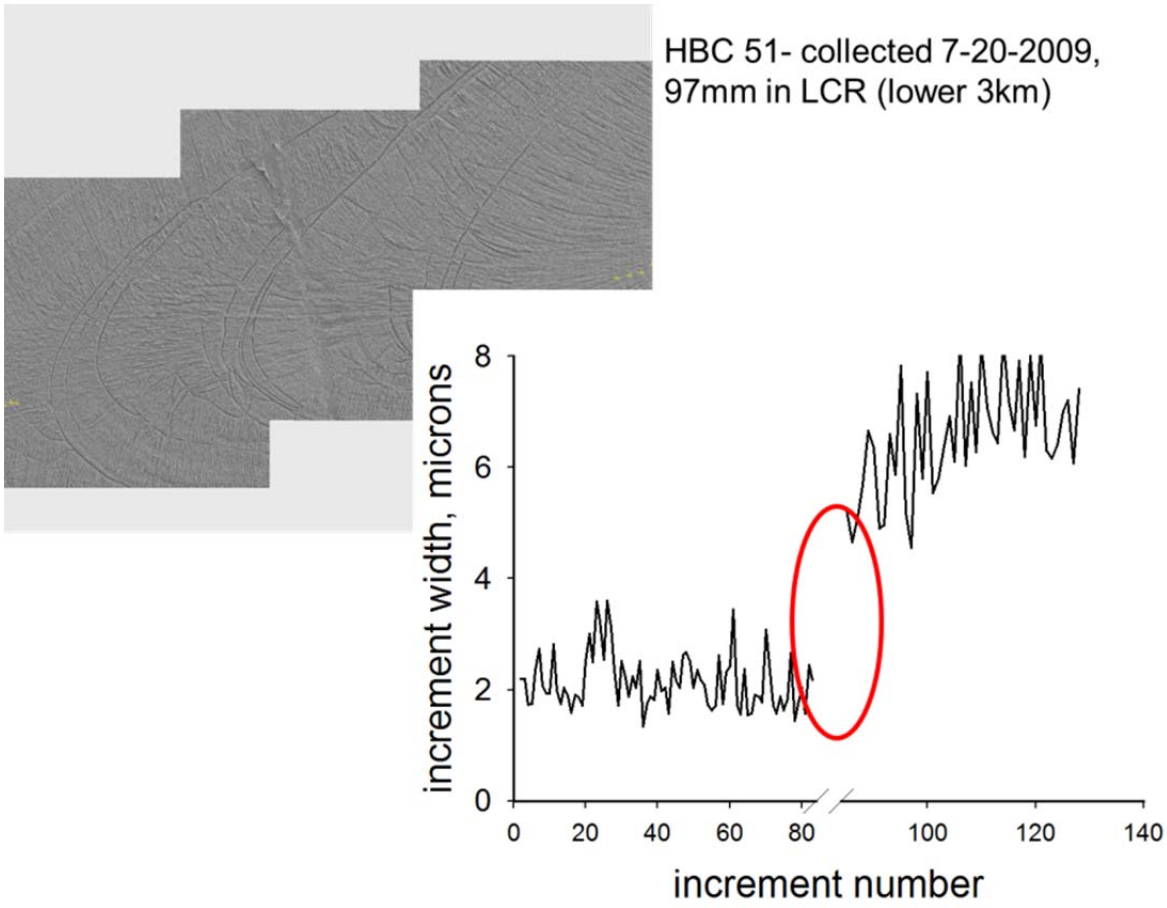


If we look at the same region (circled in red) of the Sr:Ca (top image) and Se:Ca (bottom image) elemental maps created using synchrotron based scanning x-ray fluorescence, then the microchemistry picture looks like this:



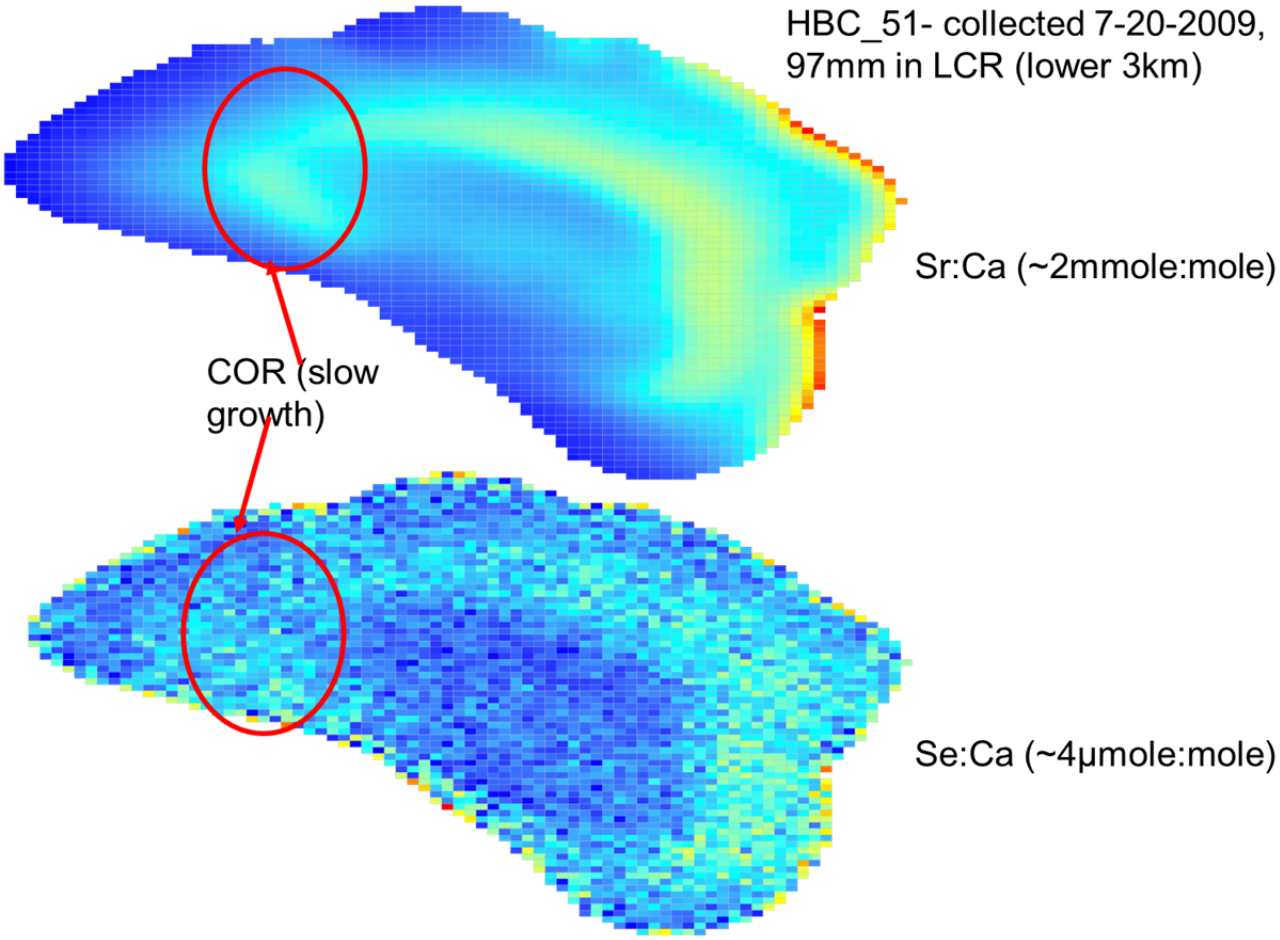
In all of the elemental maps shown, the lowest ratios are represented by dark blue coloration with increasing ratios denoted by lighter shades of blue. The highest ratios are given yellow and red coloration. Also, it should be noted that 3-4 pixels at the edge of these maps are not representative of the actual chemistry and reflect edge effects inherent to the x-ray fluorescence analytical technique. The measured ratios at the otolith edge correlate with water chemistry from the LCR. This confirms that this fish spent at least the previous few weeks before capture in the LCR. Furthermore, growth increment measurements suggest that fish growth was quite steady during this the LCR residency as indicated by incremental widths of rings.

We will now look a little further back into this HBC's life, closer to the center of the otolith, as we examine the region of the otolith surface where we could not distinguish regular growth increments.



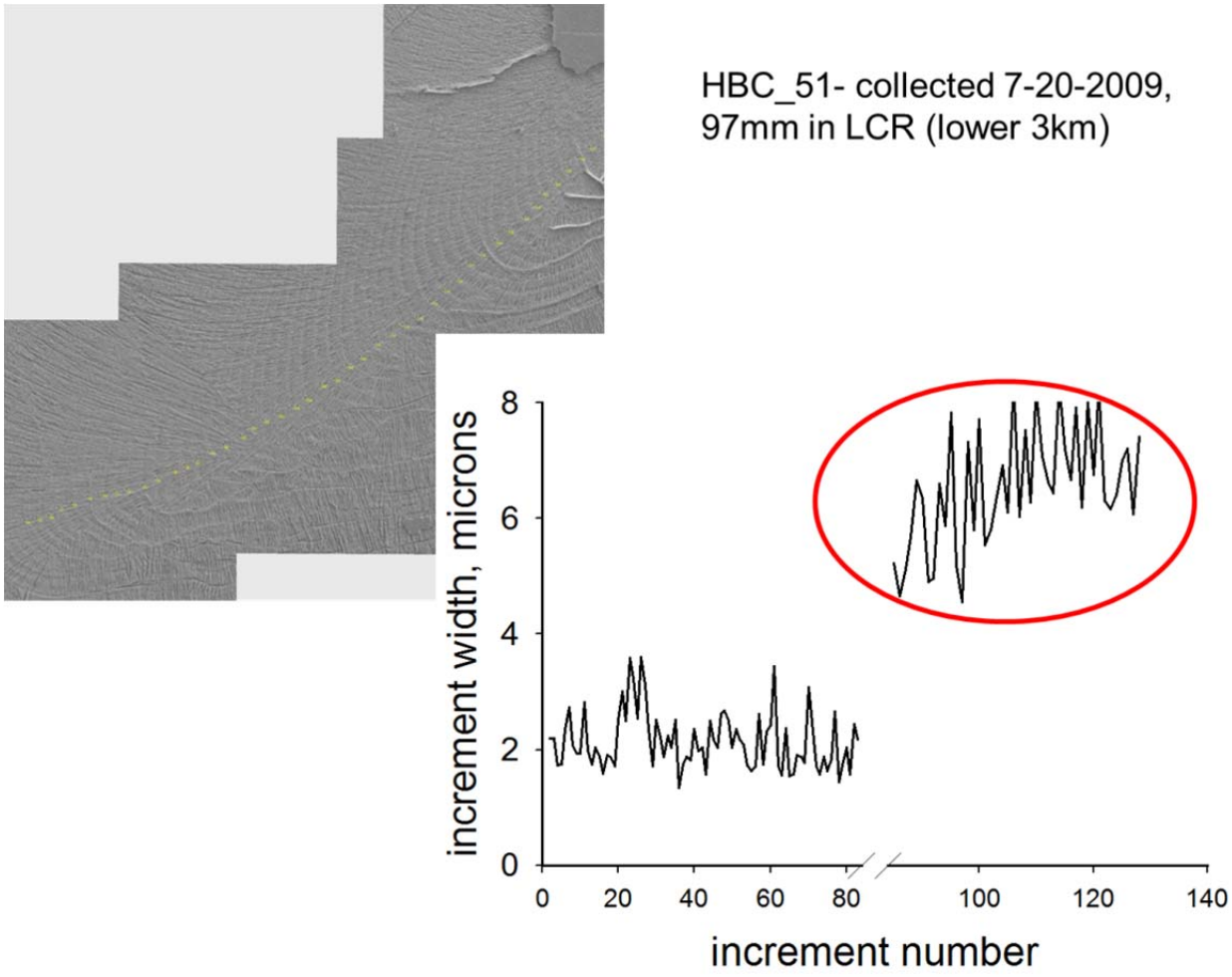
This is demonstrated in the above image where no consistently clear rings were visible on the scanning electron microscope image and measurement of growth increment widths were not possible (graph above- red circled region). In many fish species, a lack of discernable growth increments can be caused by slow growth rates.

If we examine the microchemistry picture of this region of the otolith we see an image that looks like this:



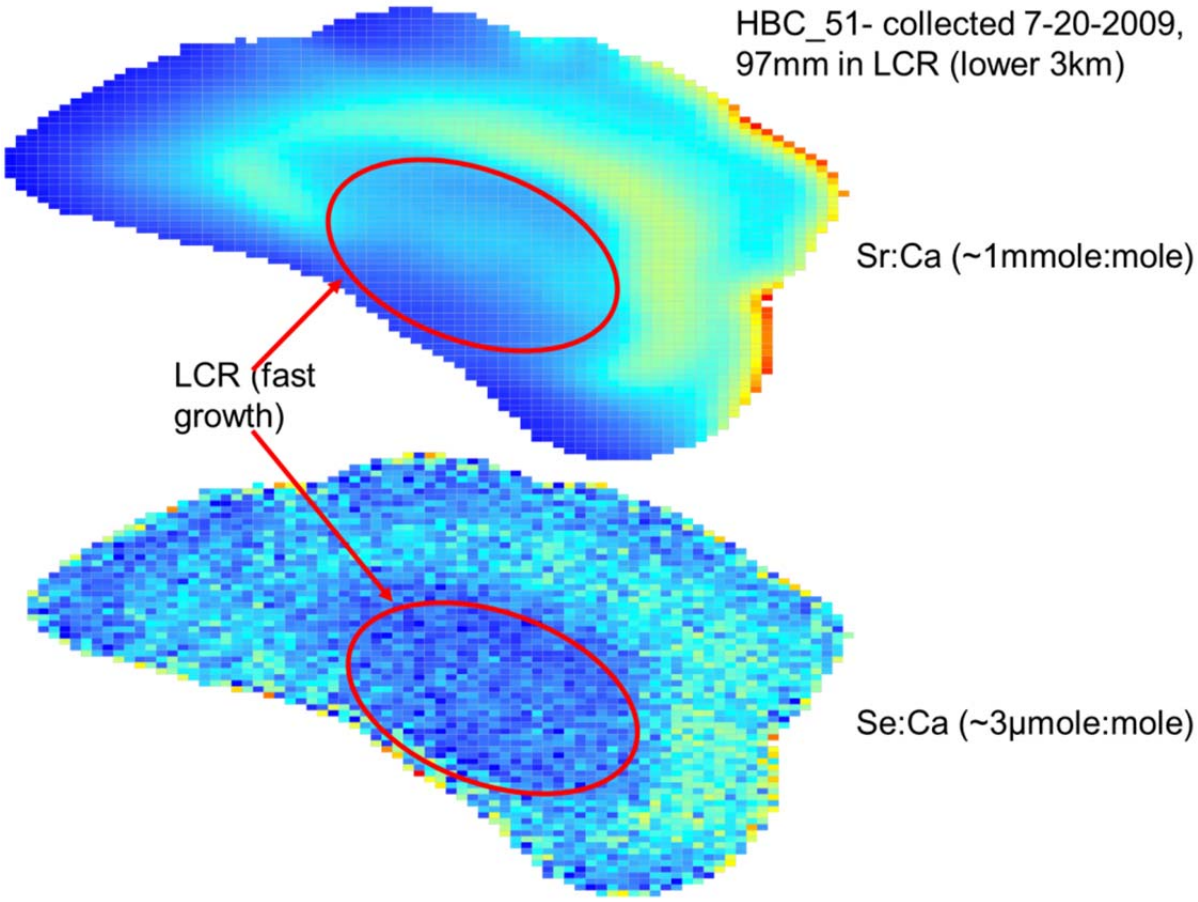
The Sr:Ca and Se:Ca ratios that (inside red circles) suggest that during this period of the fish's life, it inhabited a water mass with higher Sr:Ca and Se:Ca ratios. Based on our extensive water chemistry sampling, this is consistent with residency in the Colorado River. Because this shift in otolith chemistry correlates with a lack of distinguishable growth increments, it suggests that fish growth during this period was very slow. Again, this is consistent with residency in the colder waters of the Colorado River.

If we move further back in the life of this fish (closer to the otolith core our image looks like this:



In this region of the otolith, we can resolve growth increments (indicated by yellow dots in top left image) and we can measure the widths of these increments (red circle, bottom right image). Growth rates are much higher during this time.

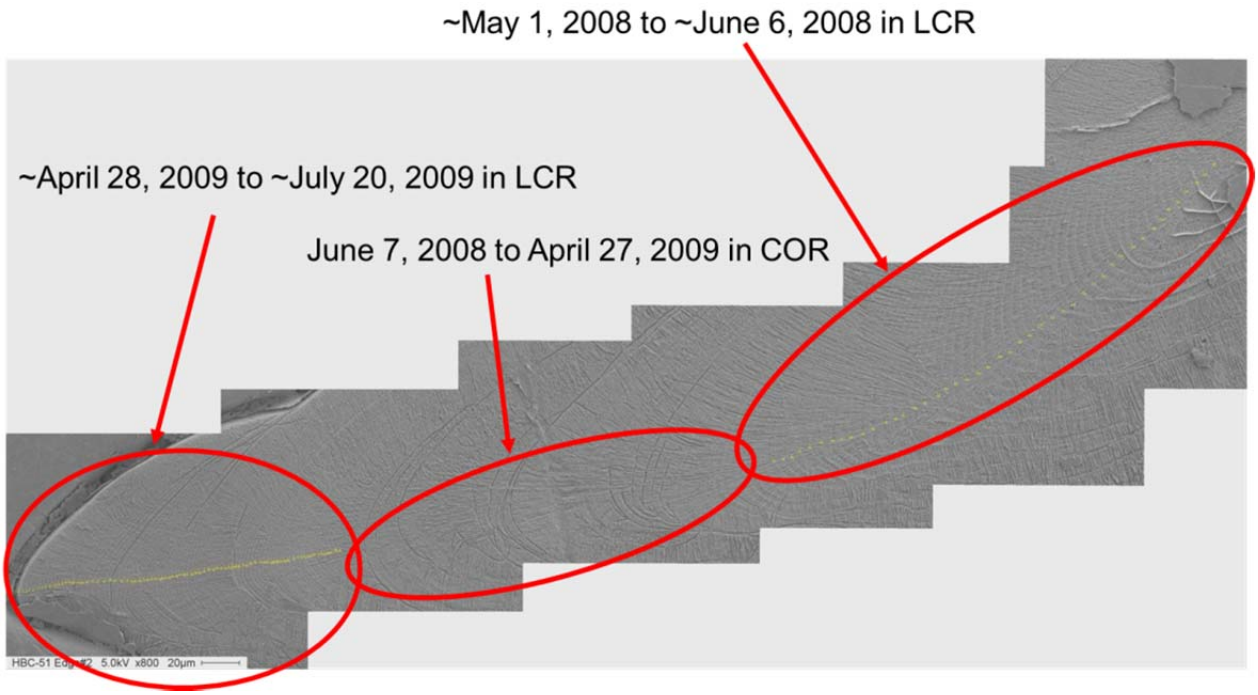
If we pair this with our microchemistry image:



As in previous images, Sr:Ca and Se:Ca elemental maps are shown and red circles denote the same region shown in electron microscope image above. Notice that Sr:Ca and Se:Ca ratios are lower in this region and similar to ratios measured at the edge of the otolith. This is consistent with LCR residency. As such, this fish originated from the LCR system.

If we count this visible rings on the surface of the otolith and subtract from the day of capture, and we assume that the fish was born on 1 May then the composite image of where this fish has lived becomes

HBC 51- collected 7-20-2009, 97mm in LCR (lower 3km)



This image demonstrates that this 97-mm TL HBC outmigrated from the LCR to the mainstem at a young age, survived a summer, winter, and spring in the mainstem Colorado River, and returned to the LCR during the spring of 2009 where it was collected in early summer (July). The exact age (and thus calculation of the actual birth date) cannot be determined because we are unable to count rings on the surface of the otolith while the fish is in the mainstem Colorado River because the growth rings are very tightly compressed. Again, otolith ring increment spacing is widely used as a measure of fish growth rate. In examining the otolith increment distances for this humpback chub we see that growth was faster in the LCR than in the mainstem, the same result found in assessing the growth rates from the tag recaptures. While knowing that HBC move between the mainstem and LCR is not new information, what *is* new is that we are documenting this for a small juvenile fish and we are demonstrating the age, in days, at which this fish emigrated from the LCR to the mainstem and that this fish survived an extended time in the mainstem before returning to the LCR. We are continuing this type of analyses for other juvenile HBC.

2011 Work plan

In 2011 we plan a similar field campaign as 2009-2010. We do not plan to conduct any additional telemetry studies and instead will dedicate additional resources to marking and recapturing more juvenile HBC in the LCR during July and August for growth rate assessments. For our otolith work we continue to work with existing samples for age and growth estimation as well as microchemistry analyses. We are finally scheduled to process a number of otolith samples on a SIMS machine at the University of Wisconsin in May 2011. We expect to have a revised analyses framework for estimating abundance and survival of native fish by the end of summer 2011. A recurring need is additional information on habitat availability within our study reach to help assess habitat selection in our telemetered fish. We continue to work with GCMRC to obtain this information.

Acknowledgements

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Table 1. Marks and recaptures of VIE marked humpback chub (<100-mm TL) across all trips and sites as part of the NSE project. How to read this table: The trip column designates each of the 8 NSE trips (July-October 2009 = Trips 1-4; July-October 2010 = Trips 5-8). Within each trip, fish are marked and released at a designated site (Sites 1-3). The M column represents the number of juvenile HBC VIE marked on each trip and site (< 100-mm TL). Each R column represents the number of fish recaptured on a given trip, at a given site (identified in the top row). As an example 190 HBC were marked on Trip 1, Site 1, and 23 of these fish were recaptured during T1S1 (Trip 1 Site 1 Recaptures), 38 fish first marked on Trip 1 Site 1 were recaptured in Site 1 on Trip 2 (one month later, designated as T2S1). This table demonstrates the high recapture rate of fish through time as well as the limited movement of tagged fish.

Trip#	Site#		T1 S1	T1 S2	T1 S3	T2 S1	T2 S2	T2 S3	T3 S1	T3 S2	T3 S3	T4 S1	T4 S2	T4 S3	T5 S1	T5 S2	T5 S3	T6 S1	T6 S2	T6 S3	T7 S1	T7 S2	T7 S3	T8 S1	T8 S2	T8 S3
		M	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Trip 1	Site 1	190	23	0	0	38	0	0	40	2	0	12	0	0	29	0	0	20	0	0	26	0	0	39	0	0
	Site 2	48	0	1	0	0	0	2	3	1	0	0	2	1	2	1	0	1	2	0	1	2	0	1	0	0
	Site 3	40	2	0	1	0	0	8	0	3	0	0	0	6	2	1	0	0	0	3	1	1	2	2	0	0
Trip 2	Site 1	220	-	-	-	23	0	0	46	2	0	12	0	0	26	0	0	20	0	0	22	2	0	52	1	0
	Site 2	34	-	-	-	0	3	2	0	5	0	0	1	4	0	2	0	0	4	0	1	3	0	0	2	0
	Site 3	53	-	-	-	0	0	8	0	1	1	0	0	7	0	0	2	0	0	3	0	0	1	0	0	0
Trip 3	Site 1	253	-	-	-	-	-	-	39	1	1	12	2	1	21	0	1	38	1	1	31	3	0	47	4	1
	Site 2	52	-	-	-	-	-	-	0	2	0	0	1	0	0	1	0	1	1	0	0	4	1	0	4	0
	Site 3	24	-	-	-	-	-	-	3	0	1	0	1	2	1	0	1	0	0	1	1	2	0	2	0	1
Trip 4	Site 1	93	-	-	-	-	-	-	-	-	-	5	0	0	11	0	0	6	0	0	8	1	0	18	0	0
	Site 2	9	-	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0
	Site 3	30	-	-	-	-	-	-	-	-	-	0	0	2	0	1	1	0	0	2	1	1	1	0	0	0
Trip 5	Site 1	161	-	-	-	-	-	-	-	-	-	-	-	-	18	0	1	30	0	0	29	3	0	38	2	0
	Site 2	21	-	-	-	-	-	-	-	-	-	-	-	-	2	0	0	0	0	0	0	0	0	2	0	0
	Site 3	21	-	-	-	-	-	-	-	-	-	-	-	-	0	1	3	0	0	2	0	1	1	0	1	2
Trip 6	Site 1	180	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	30	0	2	62	2	3	47	2	0
	Site 2	48	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	8	2	0	11	0	0	3	0
	Site 3	51	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	5	0	2	4	0	0	1
Trip 7	Site 1	369	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	66	1	2	127	6	1
	Site 2	112	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	13	3	0	9	3
	Site 3	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	4	0	0	5
Trip 8	Site 1	337	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	80	3	0
	Site 2	65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	10	0
	Site 3	32	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	2

Table 2. Catch of all fish species from each site and trip during the 2009 and 2010 field seasons using hoopnets and electrofishing. Species abbreviations are defined in the list of abbreviations at the beginning of this report.

	Jul-09				Aug-09				Sep-09				Oct-09			
Fish Species	Site			July 2009 Total	Site			August 2009 Total	Site			September 2009 Total				October 2009 Total
	1	2	3		1	2	3		1	2	3		1	2	3	
BBH	5	9	4	18	5	2	2	9	10	4		14	2	1		3
BHS	31	18	20	69	72	43	71	186	45	38	71	154	14	14	38	66
BKC										1		1				
BNT	6			6	1		2	3	2	2		4	3		1	4
CCF	2		1	3	4			4	1		1	2	2			2
CRP		1	1	2	3	6	1	10		1	1	2				
FHM	114	198	407	719	101	200	382	683	589	512	436	1537	778	881	2354	4013
FMS	21	21	54	96	77	67	80	224	86	28	19	133	68	9	20	97
GSF																
HBC	560	92	94	746	655	81	124	860	820	88	69	977	219	27	47	293
PKF									1			1		2	1	3
RBT	24	33	21	78	41	26	27	94	29	22	11	62	22	13	13	48
RSH					8	8	3	19	4	2	1	7	2	2	5	9
SPD	50	21	42	113	37	30	68	135	31	32	39	102	13	14	56	83
STB																
SUC	1	15	51	67	3	10	80	93	7	13	9	29	2	3	2	7
Grand Total	814	408	695	1917	1007	473	840	2320	1625	743	657	3025	1125	966	2537	4628

Table 2 continued.

	Jul-10				Aug-10				Sep-10				Oct-10		
Fish Species				July 2010 Total				August 2010 Total				September 2010 Total			
	1	2	3		1	2	3		1	2	3		1	2	3
BBH	7	2		9	3			3	6			6	2	1	1
BHS	26	12	6	44	85	29	68	182	42	81	44	167	53	40	17
BKC															
BNT		4	2	6		1		1	1			1	1		
CCF	2	3		5	2	2		4	4			4	1	1	
CRP	1	10	2	13	4	1	1	6	1	3		4	2		
FHM	167	445	447	1059	838	642	694	2174	410	617	637	1664	573	657	685
FMS	49	7	13	69	29	4	18	51	72	36	39	147	108	51	24
GSF													1		
HBC	381	48	44	473	601	90	87	778	894	209	60	1163	1045	127	37
PKF	3	4	2	9	7	22	36	65	2	15	17	34	4	16	8
RBT	69	70	92	231	37	33	33	103	47	67	19	133	82	58	39
RSH	1	4	5	10		2	7	9		1	19	20		2	2
SPD	176	102	68	346	121	46	38	205	154	97	36	287	105	91	45
STB		1		1											
SUC	1	2	4	7	1	6	48	55	3			3			
Grand Total	883	714	685	2282	1728	878	1030	3636	1636	1126	871	3633	1977	1044	858

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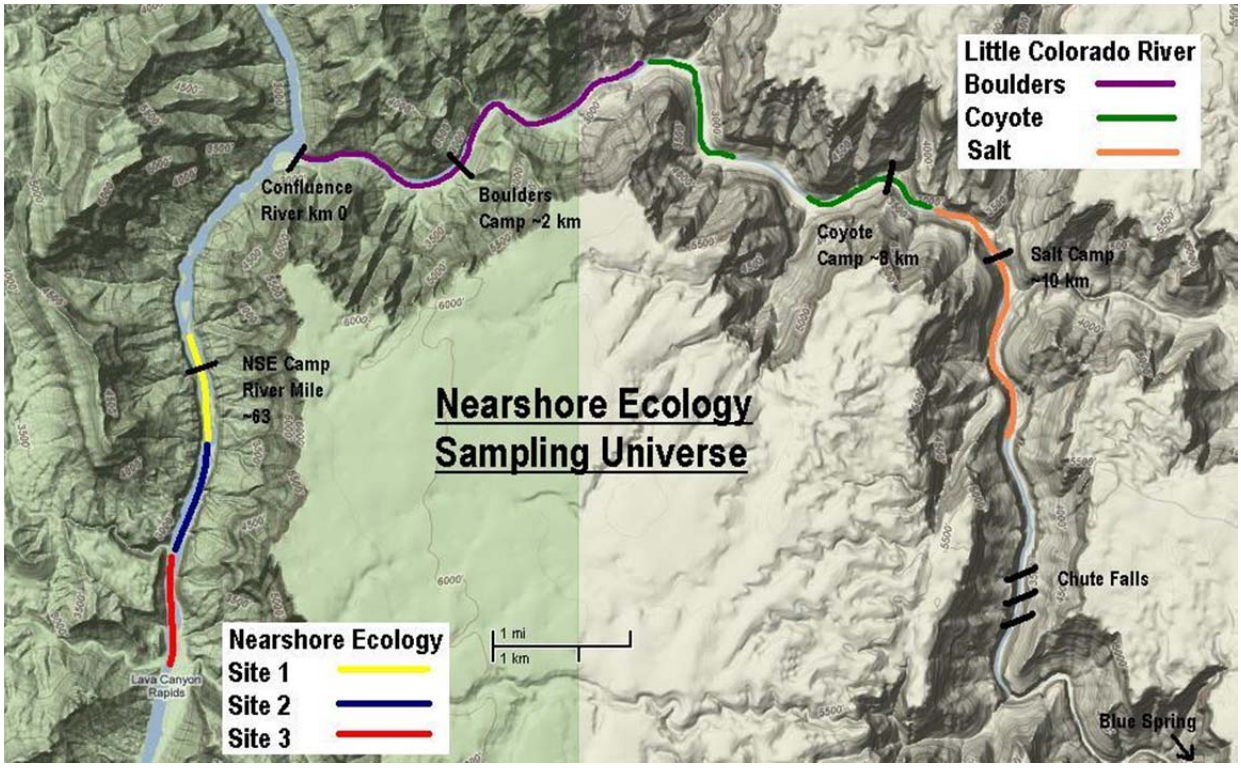

Figure 1. Map of the NSE sampling universe in the mainstem Colorado River and for comparison the USFWS sampling base camps in the Little Colorado River.

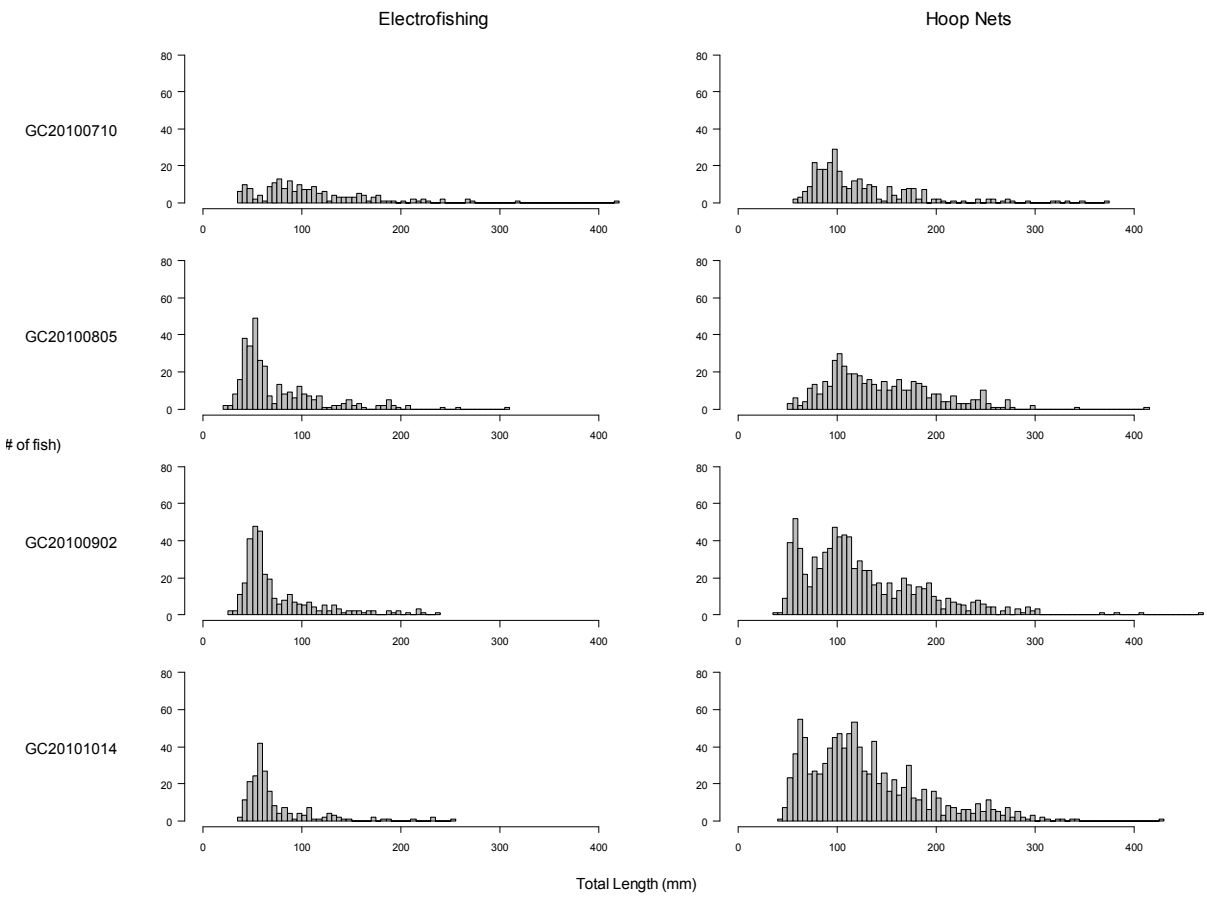

Figure 2. Length frequency distributions of humpback chub collected during 2010 NSE sampling trips (each row) by electrofishing (left column) and hoop nets (right column).

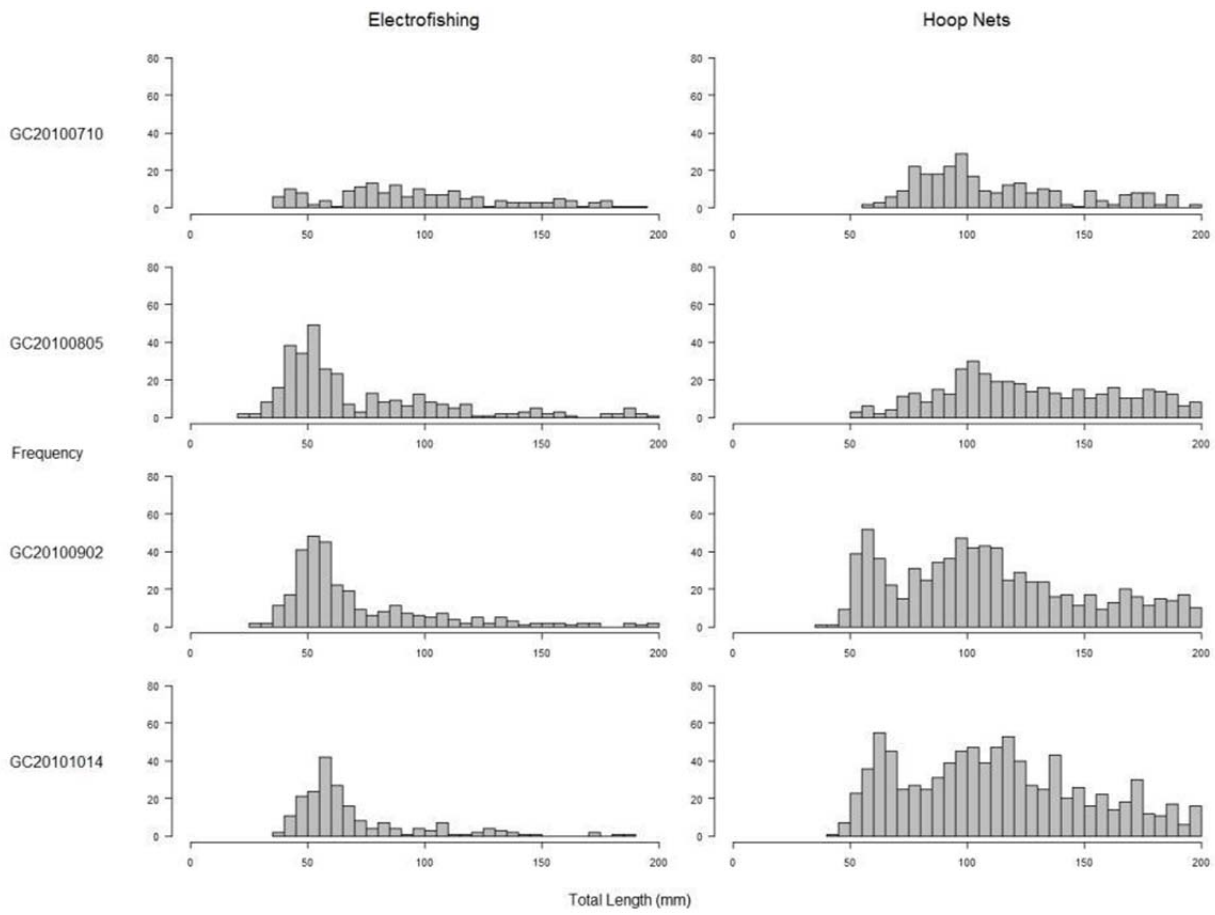

Figure 3. Length frequency distributions of humpback chub collected during 2010 NSE sampling trips (each row) by electrofishing (left column) and hoop nets (right column). This is the same figure as Figure 2, but the X-axis is truncated at 200-mm to make it easier to see the size structure of small fish collected in each gear.

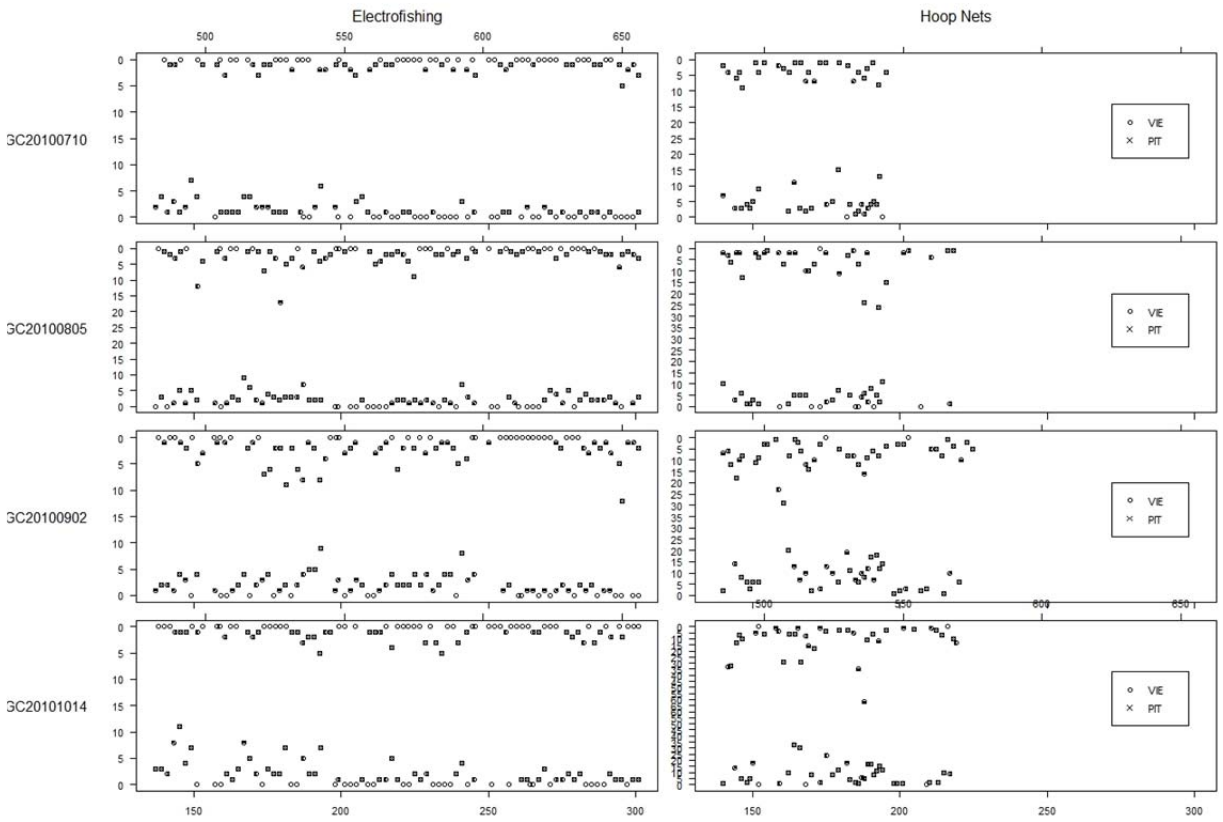

Figure 4. Spatial distribution of juvenile (<200-mmTL) humpback chub catch by HSU. HSUs from river right (sites 140-300) are found on the primary x-axis and the HSUs for river left (sites 450-650) are found on the secondary x-axis. The catch in each of these grid cells (y-axis) then correspond to each x-axis such that catches close to zero for a given HSU are near the axis corresponding to that HSU (either primary or secondary x-axis) and non-zero catches are a greater distance away from the corresponding x-axis. VIE marked HBC (<100-mm TL) are indicated with a circle and PIT tagged fish (100-mm TL) are indicated with an X.

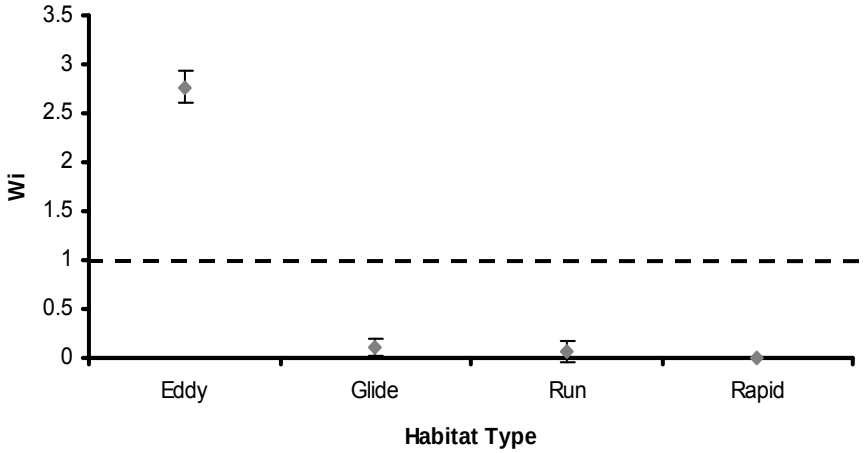

Figure 5. Mean habitat selection of telemetered sub-adult during a fluctuating flows from Glen Canyon dam during July and August, 2010. Dashed line equals no selection. Points above line indicate selection for certain habitat types; points below line indicate habitat avoidance. Error bars are ± 95% Bonferroni confidence intervals.

Figure 6. Mean habitat selection of telemetered subadult during steady flows from Glen Canyon dam during September and October, 2010. Dashed line equals no selection. Points above line indicate selection for certain habitat types; points below line indicate habitat avoidance. Error bars are ± 95% Bonferroni confidence intervals.

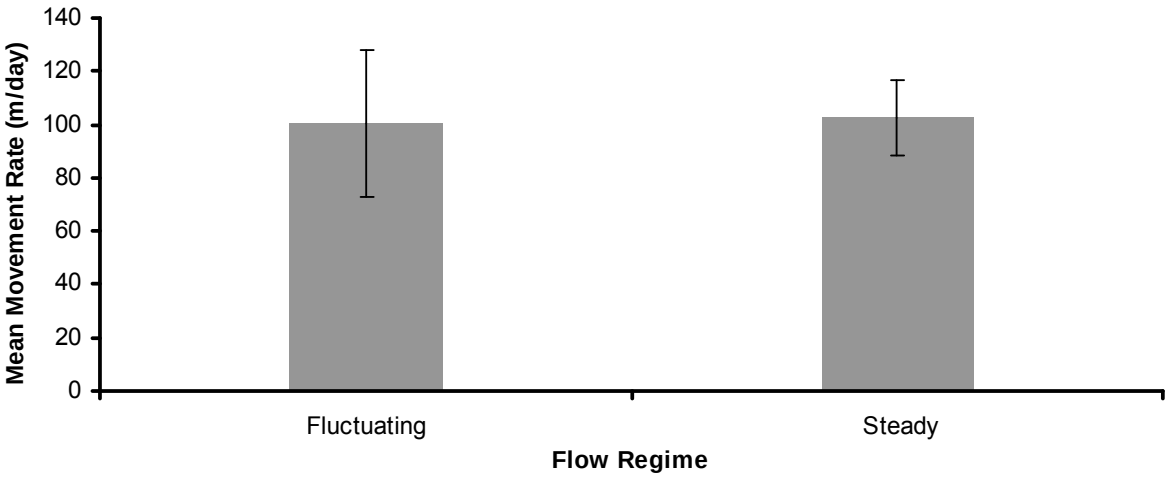

Figure 7. Mean daily movement rate (m/day) of telemetered humpback chub in contrasting flow regimes. Fluctuating flows occurred during July and August and steady flows occurred during September and October, 2010 Further analyses determine if daily movement of humpback chub can be predicted from a suite of covariates.

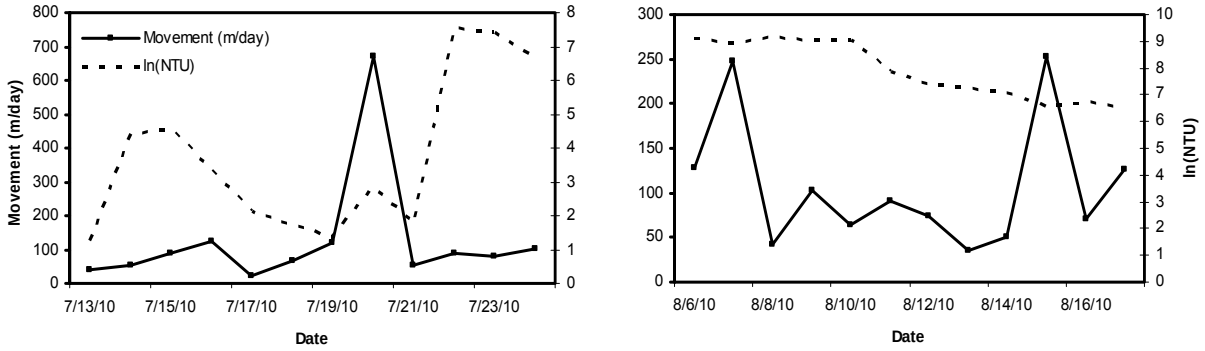

Figure 8. Trends in movement rate (m/day) of telemetered humpback chub and natural log of mean daily turbidity during fluctuating flows from Glen Canyon dam in July and August, 2010.

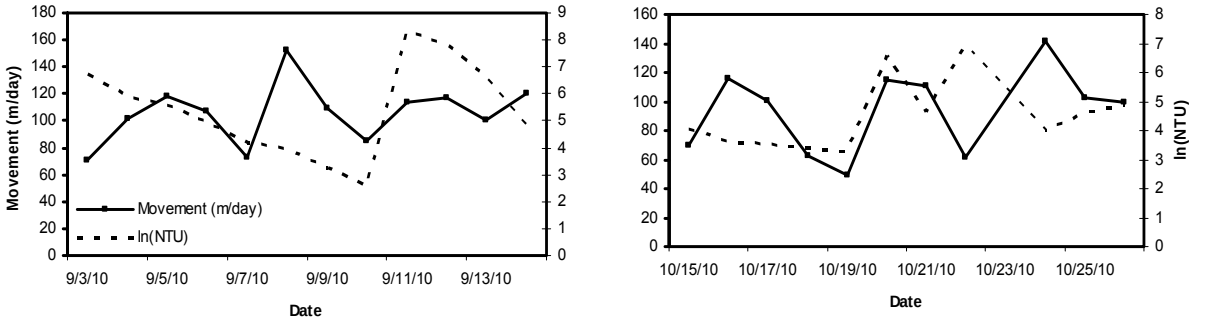

Figure 9. Trends in movement rate (m/day) of telemetered humpback chub and natural log of mean turbidity during steady flows from Glen Canyon dam during September and October 2010.

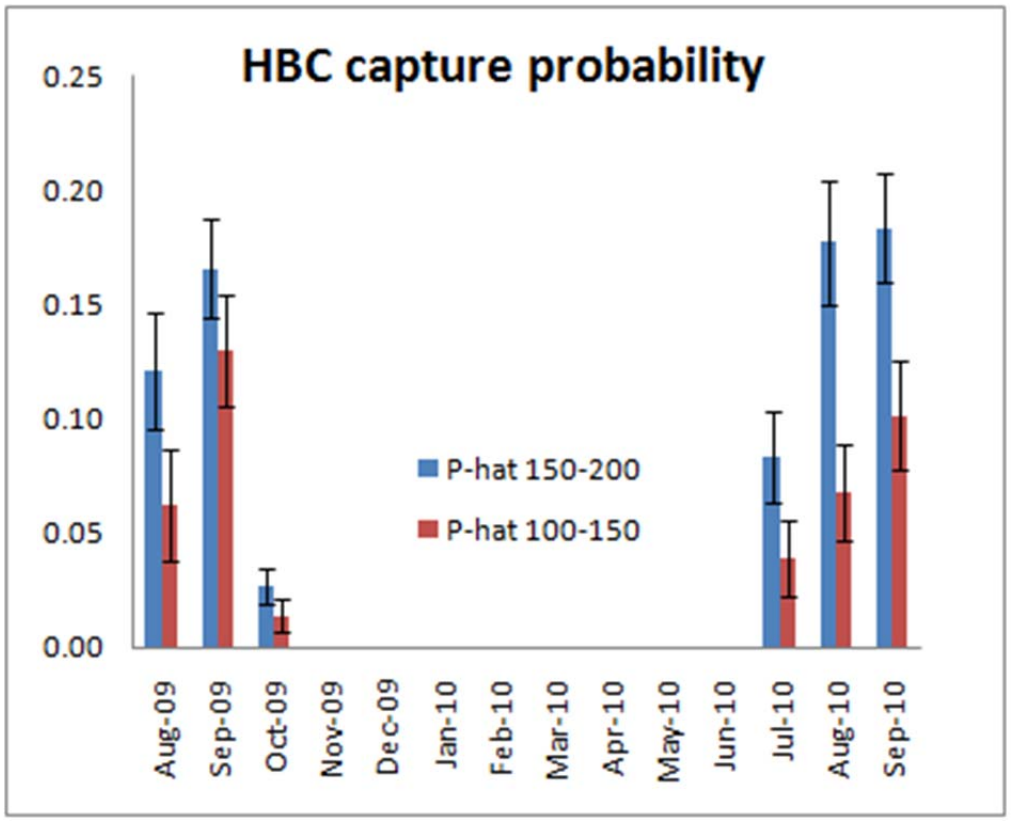

Figure 10. Representative capture probabilities (p-hat) of humpback chub from two size categories collected during the NSE project across a range of trips in 2009 and 2010 with both hoopnets and electrofishing. Error bars represent approximate 95% confidence intervals.

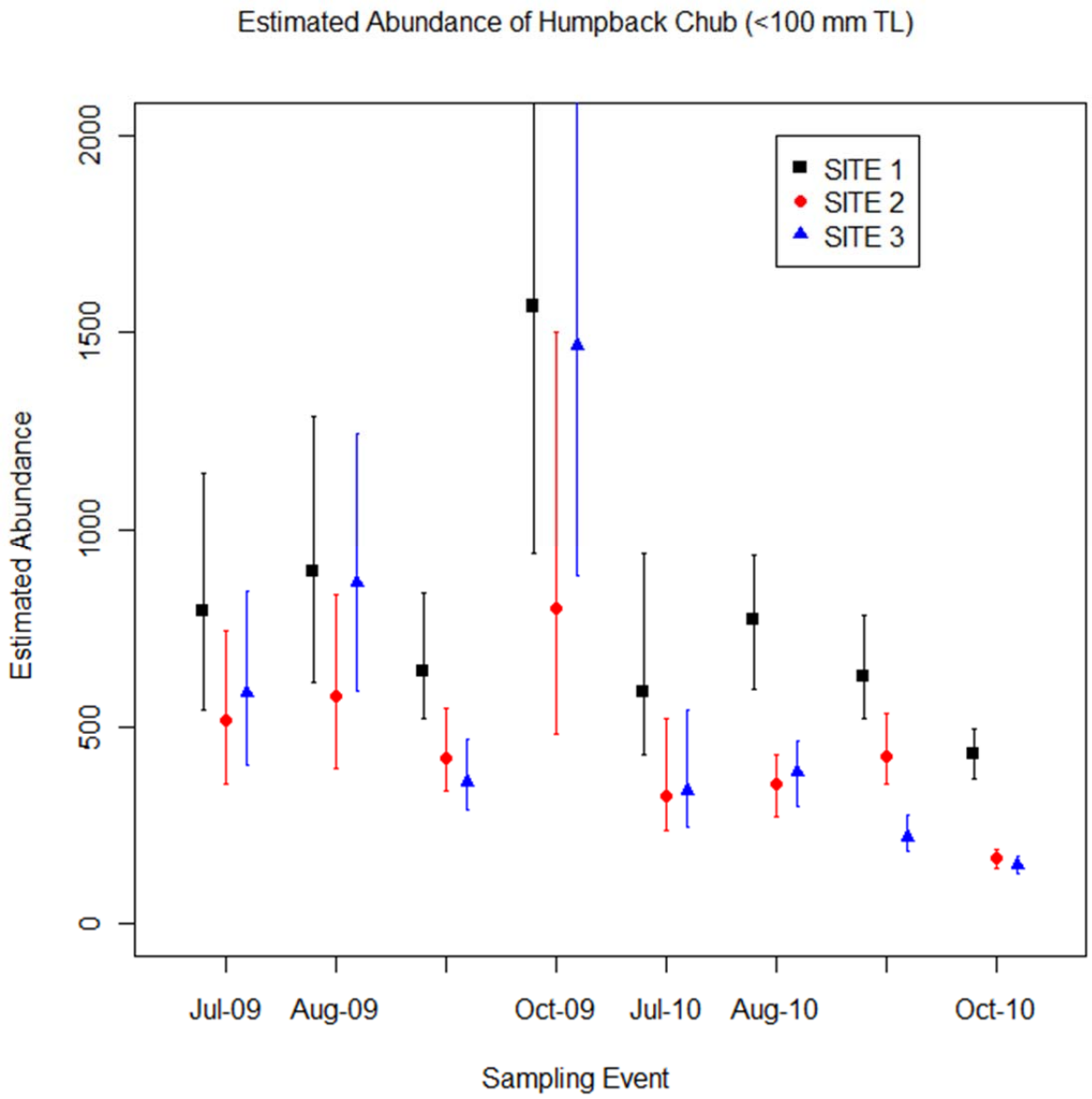

Figure 11. Estimated abundance of humpback chub < 100-mm TL from each site during 2009 and 2010. Error bars represent approximate 95% confidence intervals. We are currently refining analytical approaches used to estimate abundance and will have revised estimates available in summer 2011.

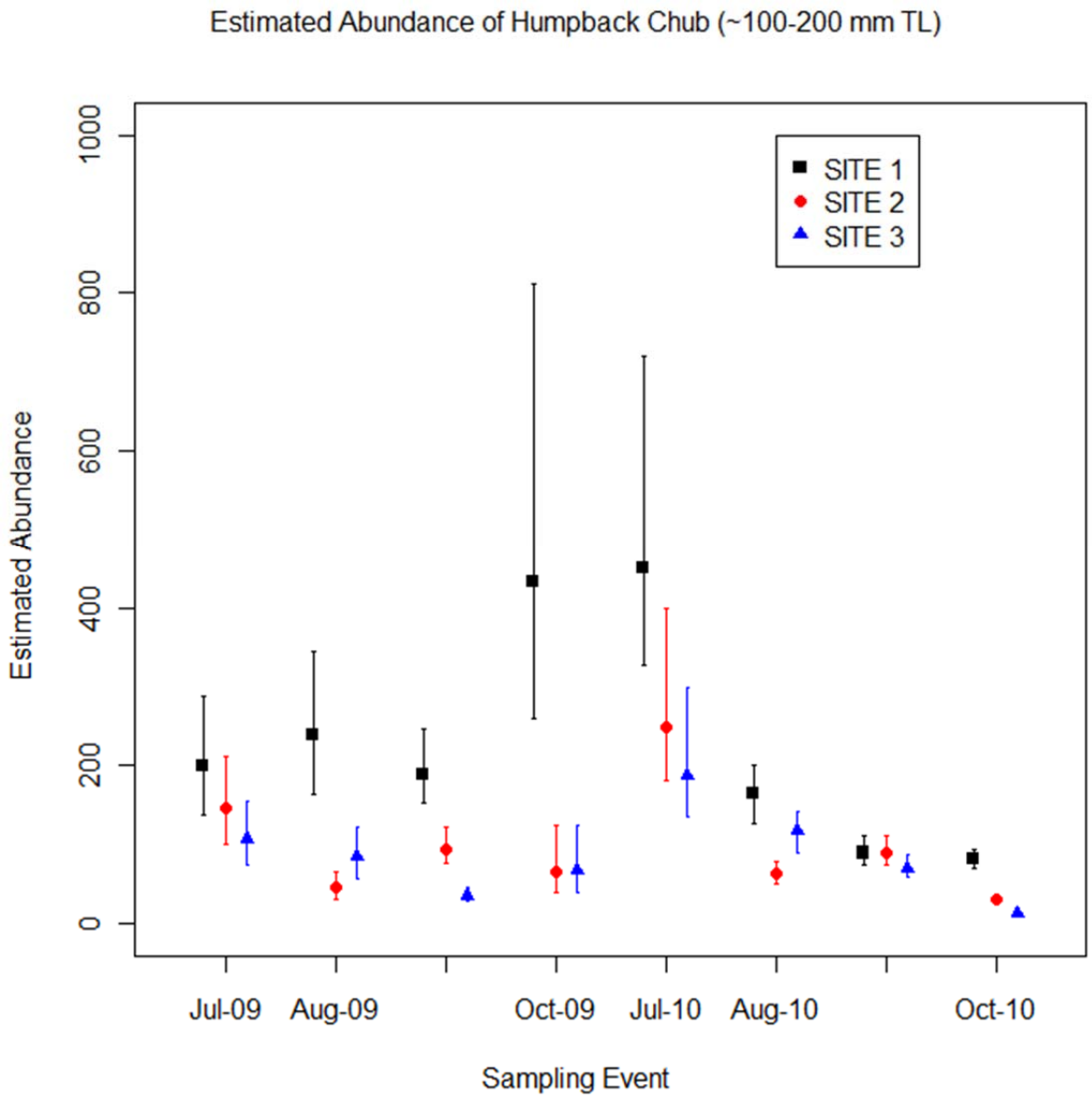

Figure 12. Estimated abundance of juvenile humpback chub from 100-200-mm TL from each NSE sampling site during 2009 and 2010. Error bars represent approximate 95% confidence intervals. We are currently refining analytical approaches used to estimate abundance and will have revised estimates available in summer 2011.

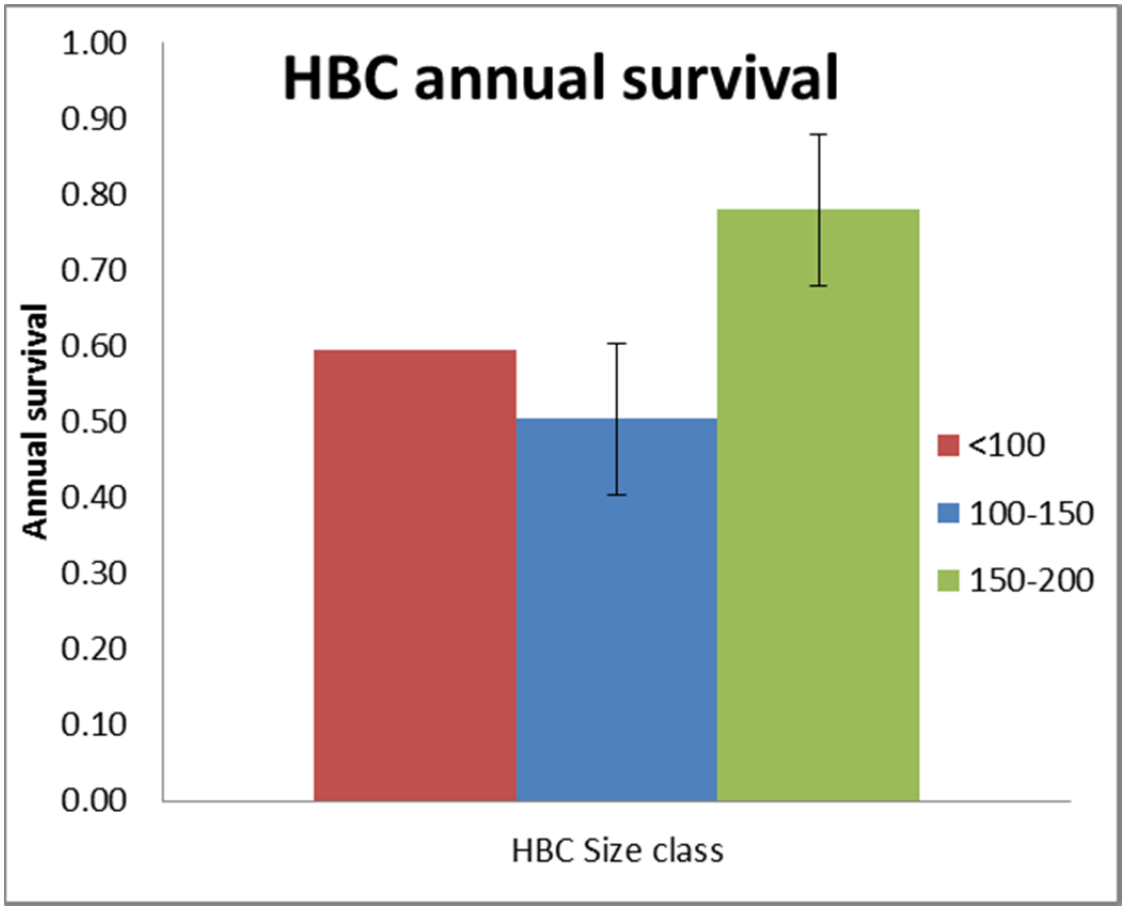

Figure 13. Estimated humpback chub annual survival rates from three different size classes estimated from mark-recapture. Error bars for fish greater than 100-mm TL represent approximate 95% confidence intervals. We are developing an approach to estimate uncertainty on fish <100-mm TL. We are currently refining analytical approaches used to estimate survival and will have revised estimates available in summer 2011.

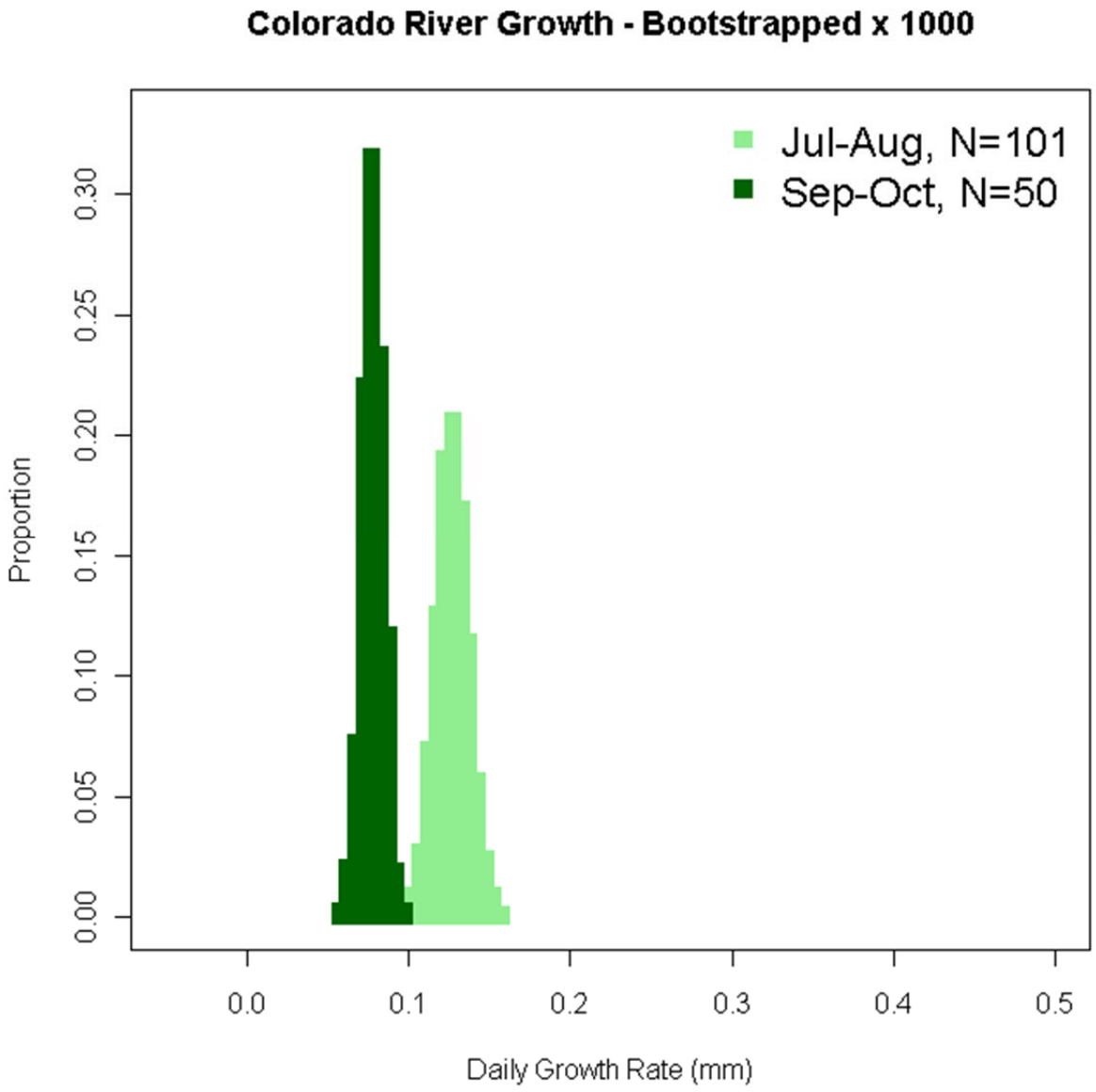

Figure 14. Daily growth rate (mm) of juvenile humpback chub in the mainstem Colorado River during fluctuating flows (July and August) and steady flows (September and October) from Glen Canyon Dam. Distributions represent approximate 95% bootstrap confidence intervals.

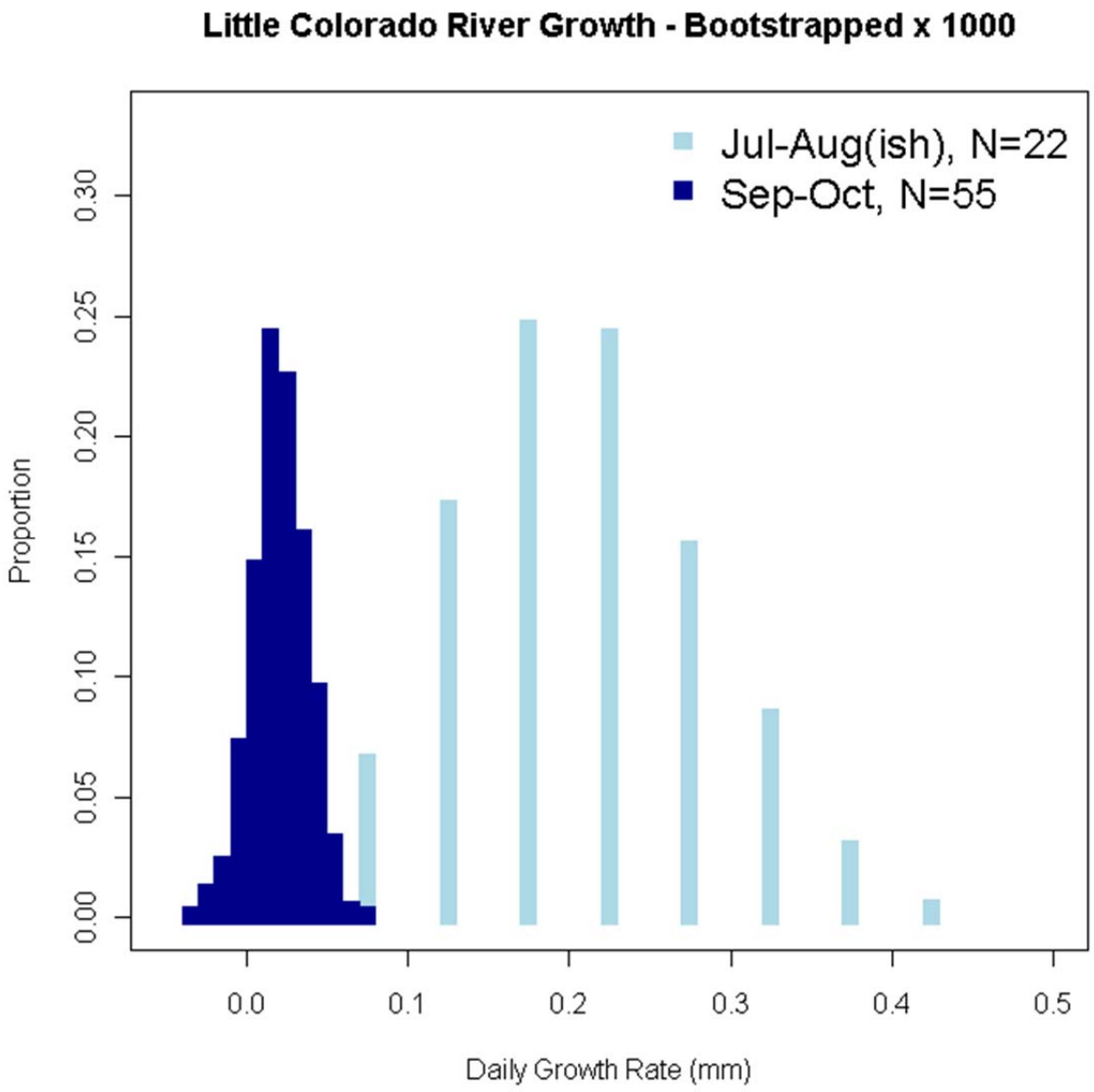

Figure 15. Daily growth rate (mm) of juvenile humpback chub in the Little Colorado River during fluctuating flows (July and August) and steady flows (September and October) from Glen Canyon Dam. Distributions represent approximate 95% bootstrap confidence intervals.

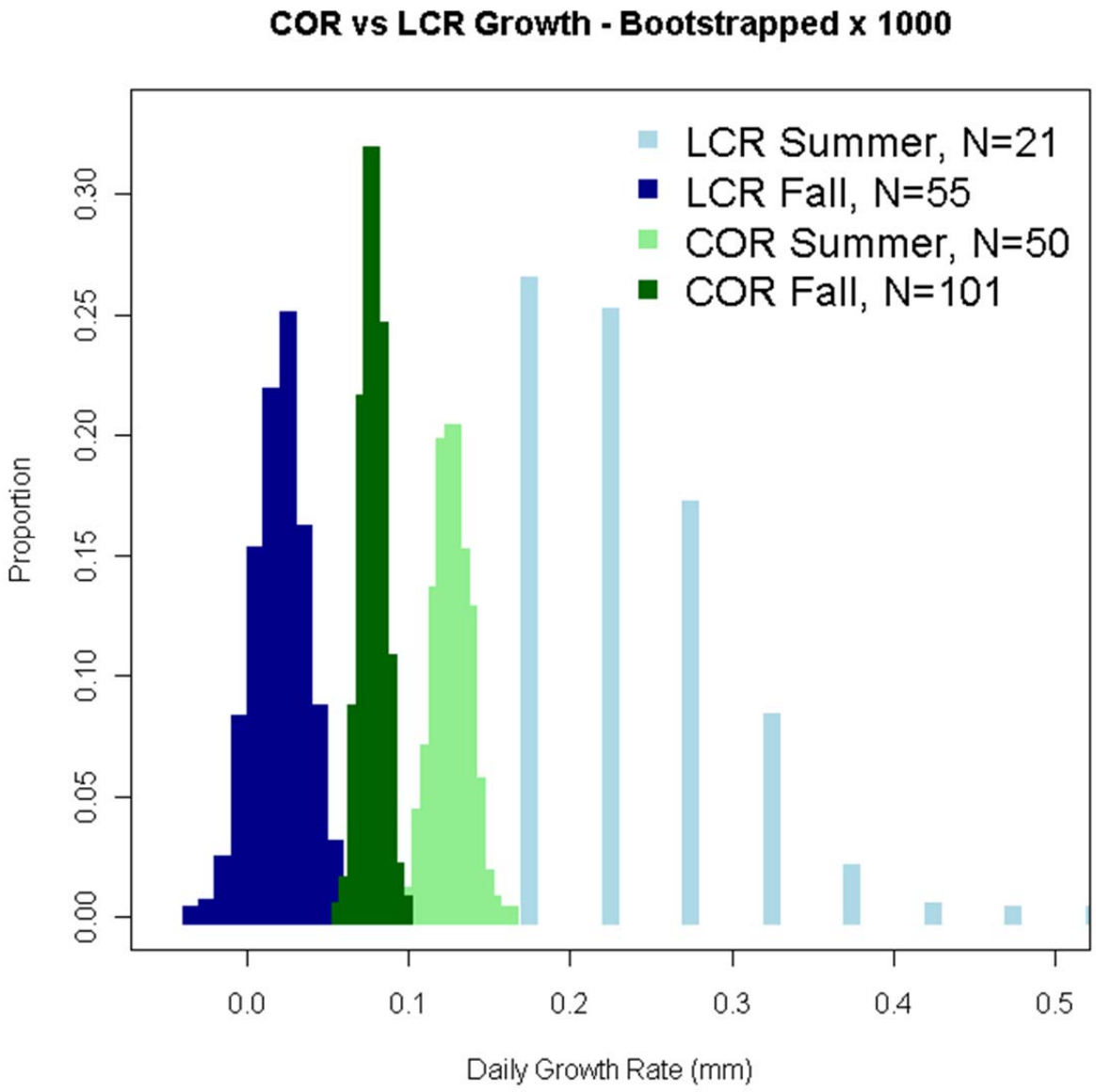

Figure 16. Daily growth rate (mm) of juvenile humpback chub in both the mainstem Colorado and Little Colorado rivers during fluctuating flows (July and August) and steady flows (September and October) from Glen Canyon Dam. Distributions represent approximate 95% bootstrap confidence intervals.