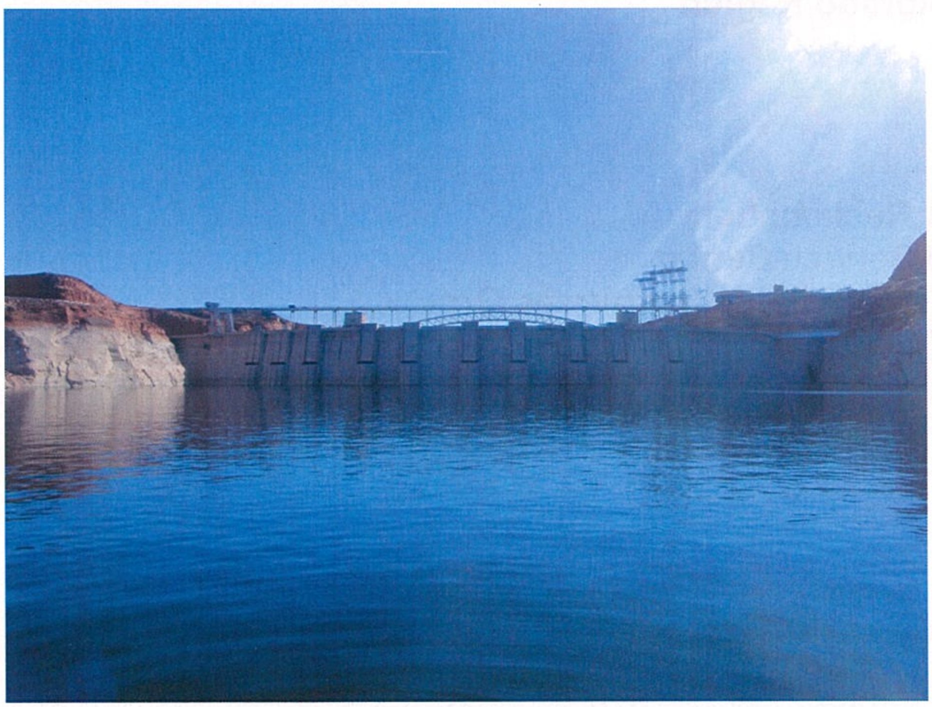
RECLAMATION
Managing Water in the West

HYDROACOUSTIC SURVEYS OF PELAGIC FISHES IN THE GLEN CANYON DAM FOREBAY: 2007- 2009



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

February 2012

HYDROACOUSTIC SURVEYS OF PELAGIC FISHES IN THE GLEN CANYON DAM FOREBAY: 2007- 2009

prepared for

Bureau of Reclamation
Upper Colorado Area Office
Upper Colorado Region

prepared by

Bureau of Reclamation
Technical Service Center
Fisheries and Wildlife Resources Group
Denver, Colorado

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acknowledgements

We would like to thank Dennis Kubly, David Speas, and Mark McKinstry and the Upper Colorado Area Office for its funding and input during this project. We are grateful to Reclamation's Research and Development Program for its funding contributions to this study. The staff at Glen Canyon Dam was particularly helpful in allowing access and assisting with logistics, and we wish to thank them. Special thanks are offered to George Blommer with the Utah Division of Wildlife Resources for help with species composition verification. We thank various contractors who have provided assistance during sampling trips, and / or data analysis including: Seth Kennedy, Charles Hueth, Katherine Zehfuss and Vicky Johansen. Finally, we would like to thank Tracy Vermeyen for assistance with the ADCP data collection and analysis.

Executive Summary

As an element of the reasonable and prudent alternative set forth in the 1995 Biological Opinion on the operation of Glen Canyon Dam to prevent jeopardy for the endangered humpback chub and razorback sucker, the Bureau of Reclamation agreed to implement a selective withdrawal program for Lake Powell to determine the feasibility of releasing warm, epilimnetic water below Glen Canyon Dam. As part of this program, the Bureau of Reclamation conducted a two-year field investigation from June of 2007 through June 2009 to establish base-line data for monthly density and distribution of pelagic fishes within the Glen Canyon Dam forebay. The study sought to refine Reclamation's understanding of the potential for entrainment of warm-water non-native piscivorous fish into the Colorado River below the dam, because these fish (if entrained into the river) could potentially affect the survival of the endangered fish through predation or competition. Other study objectives included: monitoring water quality parameters and far-field velocity profiles within the forebay, documenting species composition within the forebay, and to determine the Glen Canyon forebay water surface elevation where entrainment of pelagic fish could become problematic if epilimnion withdrawal occurs.

The study findings indicate that the density and distribution of fish within the forebay varies with light vs. dark periods, month of the year, and depth, with more fish present during dark periods from June through September in each year of the study. Regardless of reservoir elevation, fish in the Glen Canyon Dam forebay were most abundant in the top 14 m of water during the study period, which overlapped largely with the epilimnion during periods of thermal stratification. Fish entrainment through Glen Canyon Dam penstocks during the course of the overall study was likely low based on densities of fish at water elevations where they would be entrained. Entrainment is likely via a selective withdrawal system operating at 40' below the surface or during periods of low reservoir elevations ca. ≤ 3,516 mean sea level) even without a selective withdrawal.

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INTRODUCTION

The endangered humpback chub (*Gila cypha*) population inhabiting the Colorado River in Grand Canyon National Park is the largest population of this species in the Colorado River Basin (U.S. Fish and Wildlife Service [USFWS] 2002a). In contrast, the endangered razorback sucker (*Xyrauchen texanus*) is very rare in this reach of the Colorado River (USFWS 2002b). Numerous management actions designed to benefit these species have been implemented over the past two decades, perhaps most notably the 1996 Record of Decision implementing the Operation of Glen Canyon Dam Environmental Impact Statement (1995 EIS; U.S. Department of Interior 1995). The 1995 EIS contains guidelines for operation of Glen Canyon Dam in a manner that minimizes adverse impacts to downstream environmental and cultural resources, which specifically include humpback chub, razorback sucker and other native fish. More recently, the Bureau of Reclamation and cooperators implemented a series of management actions designed in part to alleviate negative impacts of nonnative fish on humpback chub (U.S. Bureau of Reclamation [Reclamation] 2002, 2008, 2011).

As an element of the reasonable and prudent alternative set forth in the 1995 Biological Opinion, Reclamation was directed to implement a selective withdrawal program for Lake Powell to determine feasibility of releasing warm, epilimnetic water below Glen Canyon Dam and determine its impacts on native and non-native fish species. Water withdrawal from the epilimnion (ca. upper 40' of the water column; Reclamation 1999) of Lake Powell through a selective withdrawal structure (SWS) has the potential to complicate recovery of the humpback chub by potential entrainment of predatory or competitive non-native fish species into the Colorado River below the dam (Baron et al. 2003). The majority of the reservoir's piscivorous pelagic species are generally located within the epilimnion for a majority of the year (Table 1). Mueller and Horn (1999) speculated (based on limited 1996 hydroacoustic survey near Glen Canyon Dam) that water withdrawals from the epilimnion could entrain up to 250,000 fish per week, including large-bodied species such as striped bass. In recent years, Arizona Game and Fish Department has documented presence of walleye and green sunfish (*Lepomis cyanellus*) in the tailwater below Glen Canyon Dam (Makinster et al. 2009). However the mechanism of their introductions has not been determined.

Table 1. Common pelagic fishes found in Lake Powell.

COMMON PELAGIC FISHES OF LAKE POWELL	SCIENTIFIC NAME
Channel Catfish*	*Ictalurus punctatus*
Common Carp*	*Cyprinus carpio*
Gizzard Shad**	*Dorosoma cepedianum*
Smallmouth Bass*	*Micropterus dolomieu*
Striped Bass*	*Morone saxatilis*
Threadfin Shad*	*Dorosoma petenense*
Walleye	*Sander vitreus*
*Observed in forebay	
**Recently observed in Lake Powell	

It is also possible that entrainment could occur during periods of low reservoir elevations resulting from prolonged drought. During the past decade, the water elevation of Lake Powell fluctuated considerably in relation to basin-wide drought conditions that began in 1999 and may persist through the present day. During that period, for example, lake elevations fell to below 3,560 feet msl, which is less than 90 feet above the dam penstocks, and analyses conducted since that time indicate that the reservoir could reach such levels (or lower) again in the future under current operating guidelines (Reclamation 2007).

In order to refine our understanding of the potential for entrainment of warm-water non-native fish into the Colorado River below Glen Canyon Dam, Reclamation conducted a two-year field investigation from June of 2007 through June 2009 to establish base-line data for monthly density and distribution of pelagic fishes within the dam forebay. The objectives of this study were:

1) Determine monthly light and dark density and distribution of pelagic fish within the forebay of Glen Canyon Dam.

2) Monitor water quality parameters and far-field velocity profiles within the forebay. These data were collected in an attempt to understand if there were interactions between fish densities and operational / abiotic conditions within the forebay.

3) Attempt to document species composition within the forebay. These data would be useful in order to understand what species of fish were present during surveys, and by extension, possibly subject to entrainment if epilimnion withdrawals occur.

4) Determine the Glen Canyon forebay water surface elevation where entrainment of pelagic fish could become problematic if epilimnion withdrawal occurs.

This report summarizes the findings of two years of hydroacoustic, water quality and forebay velocity data collection within the Glen Canyon Dam's forebay.

METHODOLOGY

The Glen Canyon Dam forebay is over 365 m (1200 ft) from the east wall to the west wall, and is subject to wind, waves, and currents affected partly by hydroelectric power generation. To negate the effect of these forces, and allow for repetitive sampling at marked locations, a Kevlar sampling line and associated anchoring system were installed in the forebay prior to study implementation in June 2007. The system was robust to reservoir water level changes during the study. The anchoring system utilized galvanized all-thread bar and eye-nuts anchored to the forebay wall with commercial concrete anchor epoxy. When the anchors were cured, the Kevlar line could be strung across the forebay and tightened using hand winches.

HYDROACOUSTIC SURVEYS

Surveys were conducted monthly from July 2007 to June 2009. Volumetric hydroacoustic surveys involved data collection at predetermined stations on the Kevlar line (Fig. 1). The stations were located so that the transducers were oriented downstream (toward the dam) and in-line with the turbine being sampled. Turbines 2 - 7 were selected for volumetric density estimation. Turbines 1 & 8 could not be sampled effectively from the survey line because of the curvature of the dam and the interference caused by the forebay canyon walls. Volumetric data were collected to document fish density and distribution by depth. During the first year of the study (July 2007 to May 2008) the surveys involved 15 minute light and dark samples, while in the second year (June 2008 to June 2009) volumetric surveys involved a repetitive, systematic sampling approach (multiple 5 minute light and dark samples). The volumetric fish density (presented as fish per 1000 m^3) of each repetition (A-D) was calculated by depth-bin for both down and side-looking transducers. Volumetric data are presented both by month and by turbine.

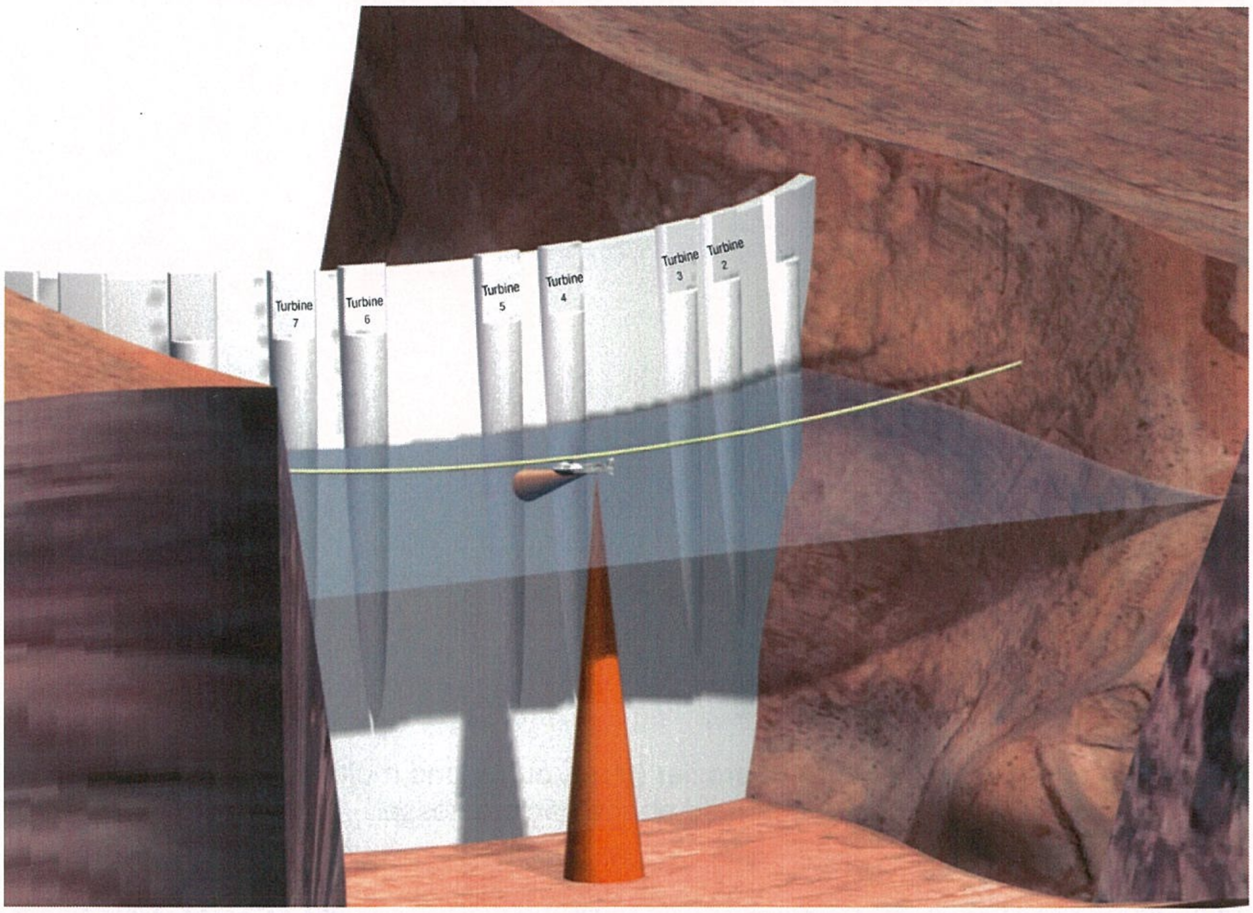

Figure 1. Schematic of the sample vessel attached to the Kevlar line (yellow) within the Glen Canyon Dam forebay. The figure shows the ensonified volumes of water as cones for both down and side-looking transducers.

Survey equipment included a Biosonics DTX split-beam hydroacoustic system consisting of down and side-looking transducers coupled with a scientific echosounder and portable laptop. We used a multiplexed down and side-looking transducer array (Figs. 1 & 2) in an effort to account for problems associated with hydroacoustic sampling, e.g. sound propagates as a spherical pressure wave along an acoustic axis. This means that for deeper sample depths, a larger volume of water is ensonified. Thus, fish in epilimnion layers are potentially undersampled. We anticipated both individual fish and aggregations (schools) within the forebay. Because of these distributional differences, fish density was computed using echo integration. Echo integration measures the total reflected energy in a sample volume and scales it by the energy per averaged-sized fish. A two-pass technique was used for each data file collected: 1) the first pass was a target strength analysis to measure the acoustic reflectivity of individual fish, and 2) the second pass was an echo integration pass that used the determined target strengths to scale integration values and calculate fish densities. In this manner, fish density, fish size, (converted using Love's Equation, Love 1977), and vertical distribution of fish within the water column were calculated. Vertical distribution was quantified by using depth bins (e.g. 0-4 m, 5-6 m, 7-10 m, 11-14 m, etc).

Figure 2. Acoustic Doppler current profiler (foreground) and multiplexed hydroacoustic transducer array (background) mounted on the sample vessel.

Water Quality

The suspected biologically relevant water quality parameters of dissolved oxygen (mg/l) and water temperature (°C) were collected using a multi-probe once monthly at a location approximately centered in the forebay. Probes were deployed to obtain vertical profiles of these parameters during each sampling occasion.

Forebay Velocities

Two velocity measurement instruments were used for this study. An acoustic Doppler velocimeter (ADV) was used to measure point velocities at the centerline elevation of the penstock intakes (El. 3470 ft) and an occasional vertical temperature profile. An acoustic Doppler current profiler (ADCP) was used to measure velocity profiles in front of penstock intakes (turbines) 2 - 7. Attempts to measure velocity profiles at units 1 and 8 were corrupted by acoustic reflections off the steep canyon walls, so they were excluded from the data collection plan. Due to budget constraints, ADCP measurements were not made for every field visit. To estimate velocity profiles when ADCP data were not available, a one-dimensional selective withdrawal spreadsheet model (SELECT) was used. The SELECT model was developed by the US Army Corps of Engineers to assist reservoir operators with the day-to-day operations of a dam equipped with a selective withdrawal structure. For this project, SELECT was used to estimate the far-field velocity profiles for Glen Canyon Dam operations for 20 sets of field data. SELECT Version 1.0 Beta (Schneider, et al. 2004) was used for all selective withdrawal modeling. Six sets of ADCP data were used to calibrate the SELECT model for Glen Canyon Dam's penstock intakes.

Statistical Analysis

For statistical and graphical analysis, the down and side looking data were combined to facilitate their inclusion into an index that could be compared, tested, and graphed.

Because there were repetitive, systematic sampling events (multiple 5 minute daylight and dark samples) associated with each turbine during sampling trips for the second year, we ran non-parametric statistical analysis on these data in an effort to identify the significance of various interactions between fish densities and operational abiotic conditions within the forebay. All statistical tests were completed using a significance level of alpha (α) = 0.05. From June 2008 – July 2009 we tested the following:

1) Is there a difference between light vs. dark volumetric density averaged over month & turbine? Test: Wilcoxon Signed Rank Test.

2) Is there a difference in volumetric density among the turbines during light and dark sampling? Test: Kruskal-Wallis One Way Analysis of Variance on Ranks.

3) Is there a difference in volumetric density among months during light and dark sampling? Test: Kruskal-Wallis One Way Analysis of Variance on Ranks.

4) Is there a difference in volumetric density during light and dark sampling? Test: Kruskal-Wallis One Way Analysis of Variance on Ranks.

Species Composition Sampling

Attempts to identify species composition in the forebay included midwater icthio-trawls, vertical gill-netting, electrofishing, and direct observation.

Results

LAKE ELEVATIONS

The Glen Canyon forebay elevations fluctuated in both years of the study (Fig. 3). During the first year (July 2007 – May 2008), forebay elevations were highest in July and May (both at approximate elevation 1100 m or 3608 ft) and lowest in March (approximate elevation 1094 m or 3589 ft). During the second year (June 2008 – June 2009) forebay elevations were highest in June 2008 (approximate elevation 1109 m or 3638 ft) and lowest in March (approximate elevation 1100 m or 3610 ft).

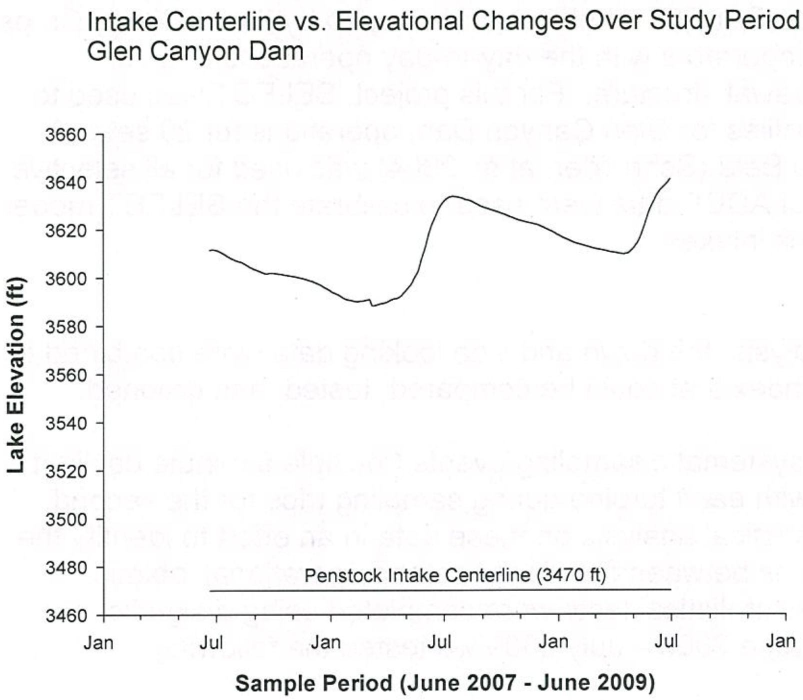

Figure 3. Water surface elevation fluctuations for the Glen Canyon Dam forebay over the course of the study. The penstock intake centerline (elevation 1058 m or 3470 ft) is shown for reference at the bottom of the figure.

FISH DENSITY IN THE FOREBAY: JULY 2007 – MAY 2008

Forebay fish densities were highest in July. Fish densities were at their lowest during the winter months of December and January. There was a small increase in fish density during February and early March followed by another drop into April. Densities were increasing again by May 2008 (Fig. 4).

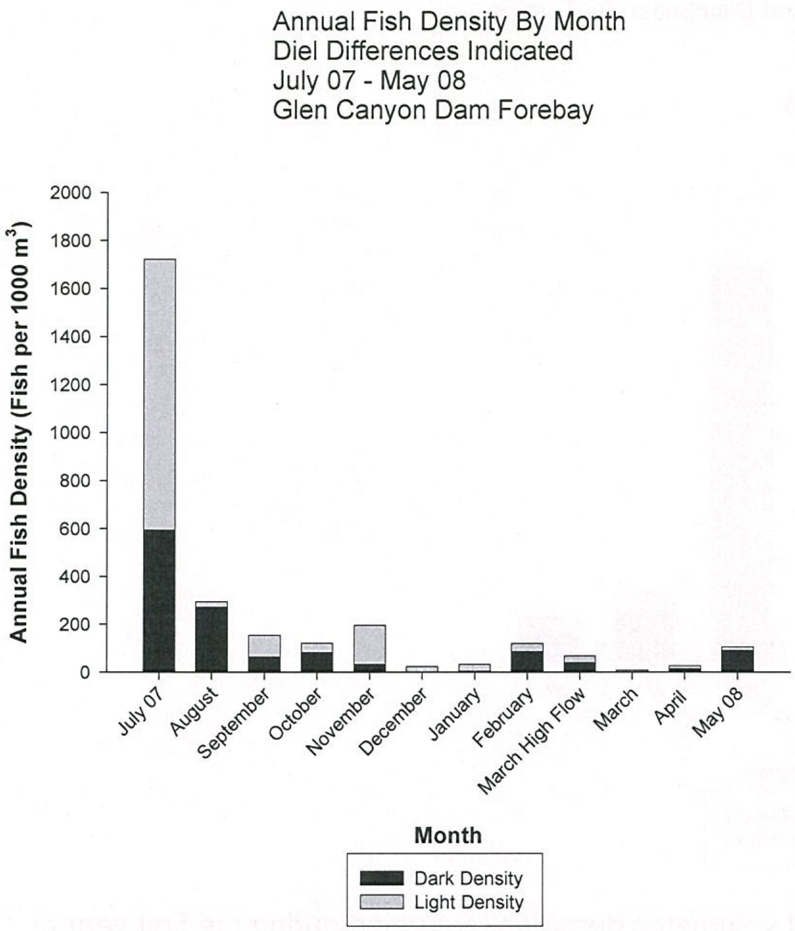

Figure 4. Histogram of summed volumetric fish density, by month during the first year of the study. Night and day density differences are indicated by shading.

Of the six turbines where densities were estimated, volumetric fish densities were highest at turbine 4 (Fig. 5) largely as a result of the high densities associated with this turbine for the month of July 2007. Differences among turbines were much less in the remaining survey months.

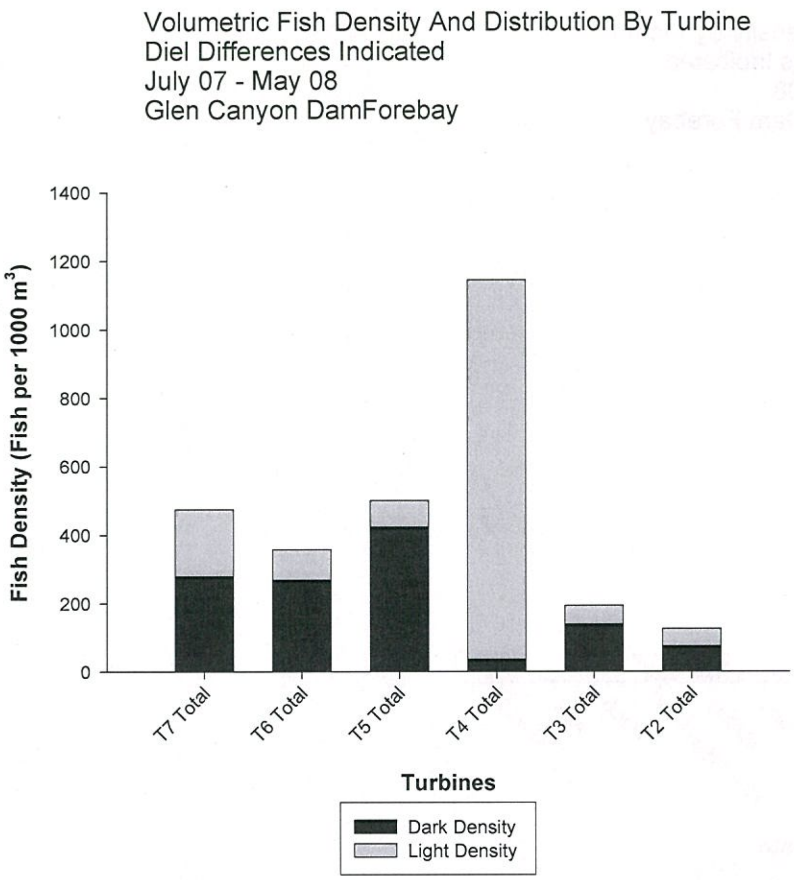

Figure 5. Histogram of summed volumetric densities by turbine during the first year of the study during light and dark sampling periods.

The majority of the fish sampled during the first year were found in the top 10 m of water for both light and dark periods (Fig. 6) with the first four meters of water (surface to four meters deep) having higher densities than any other depths.

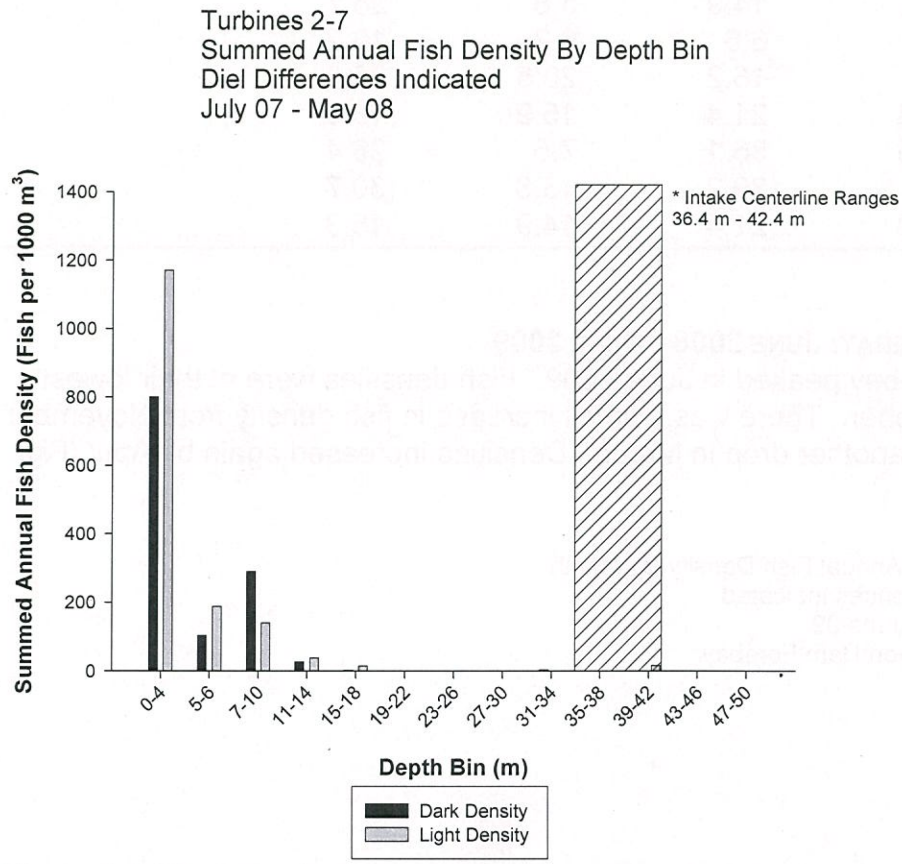

Figure 6. Volumetric fish densities, summed for all turbines sampled and referenced to turbine intake centerline fluctuations over the first study year during light and dark sampling periods.

Fish sizes as determined by Love's equation (1977) varied by month (Table 2). We considered small fish to be predominantly threadfin shad (*Dorosoma petenense*) while acknowledging the possibility of mixed schools of smaller size or age classes of other pelagic Lake Powell fishes. Large fish were mixtures of piscivores and common carp (*Cyprinus carpio*). The largest fish in the forebay were present in the early spring. This is consistent with documented striped bass behavior in the lower portion of Lake Powell (Wayne Gustaveson, Utah Division of Wildlife Resources [UDWR] - *pers. com.*) for this time of year.

Table 2. Fish Size as Determined by Love's Equation, First Year.

Month	Smallest Dark Size (cm)	Largest Dark Size (cm)	Smallest Light Size (cm)	Largest Light Size (cm)
July 2007	6.8	10.6	8.5	24.9
August	8.3	9.2	8.3	27.7
September	9.8	16.4	4.2	18.2
October	15.5	24.6	9.8	17.6
November	13.4	14.2	17.2	17.4

December	5.6	14.9	5.8	26.7
January 2008	5.3	6.6	6.2	16.2
February	5.8	15.2	20.5	25.2
March (High Flow)	17.3	21.4	15.9	19.9
March	15.5	36.1	7.5	28.4
April	9.7	39.2	13.8	30.7
May 2008	15.0	21.4	14.9	16.8

Fish Density in the Forebay: June 2008 – June 2009

Fish densities in the forebay peaked in June 2009. Fish densities were at their lowest during the month of October. There was a small increase in fish density from November to February followed by another drop in March. Densities increased again by April (Fig. 7).

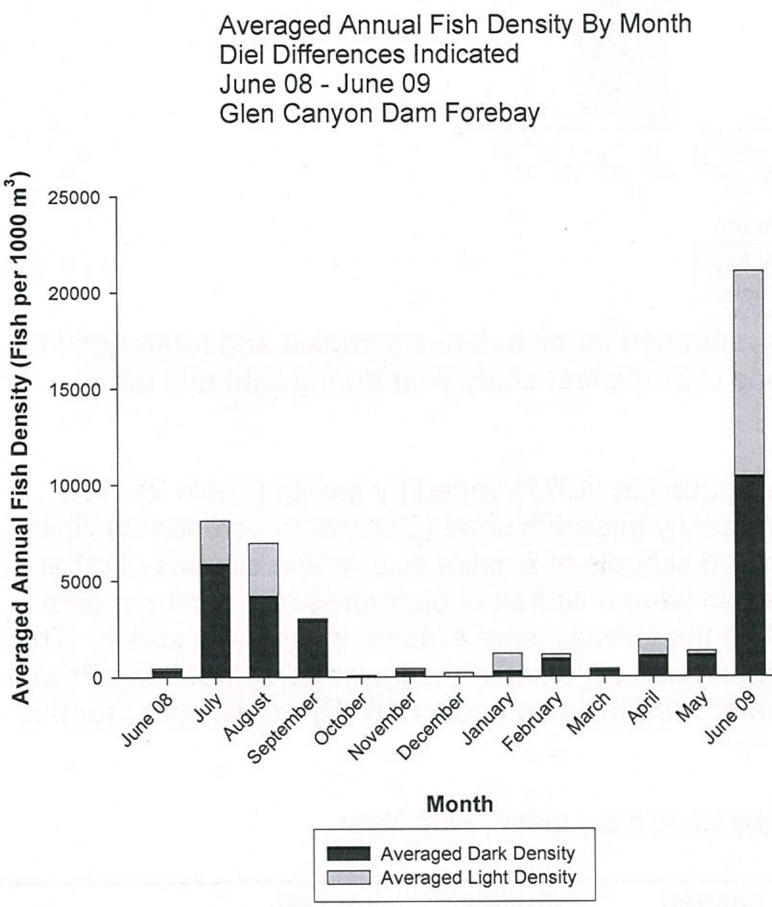

Figure 7. Histogram of averaged volumetric fish density by month during the second year of the study during light and dark sampling periods.

On a per-turbine basis during the second year, volumetric fish densities were highest at turbine 2 (Fig. 8).

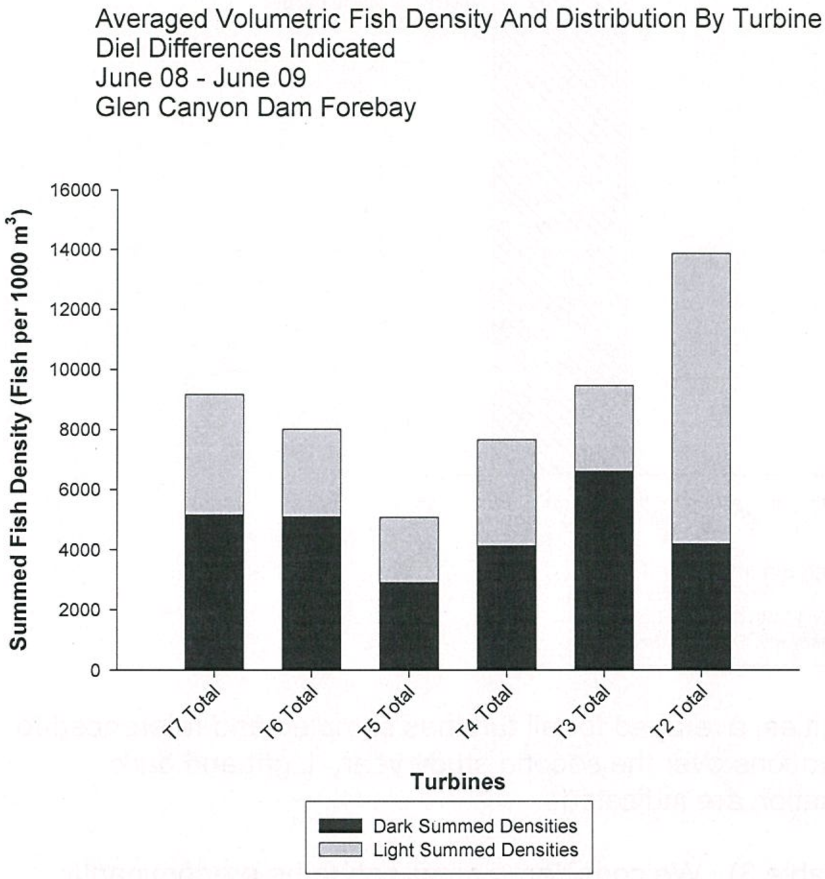

Figure 8. Histogram of averaged volumetric densities by turbine during the second year of the study during light and dark sampling periods.

The majority of the fish sampled during the second year were found in the top 14 m of water for both light and dark periods (Fig. 9) with the first four meters of water (surface to four meters deep) having higher densities than any other depths.

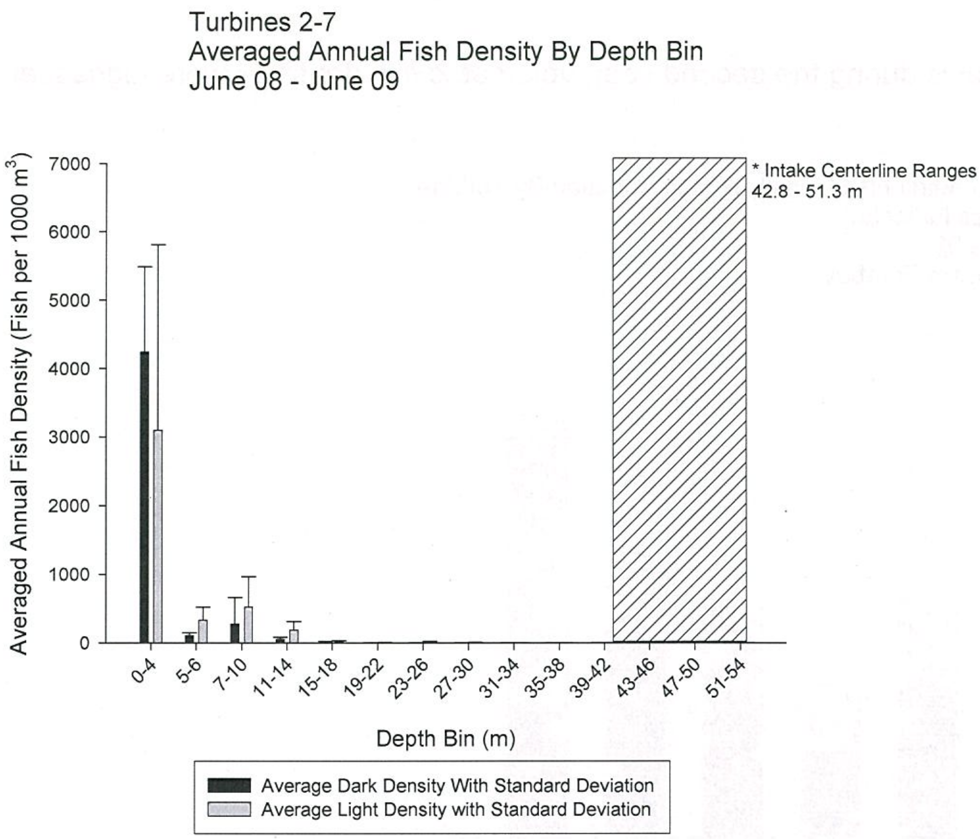

Figure 9. Volumetric fish densities, averaged for all turbines sampled and referenced to turbine intake centerline fluctuations over the second study year. Light and dark differences with standard deviation are indicated.

Fish sizes varied by month (Table 3). We considered small fish to be predominantly threadfin shad while acknowledging the possibility of mixed schools of smaller size or age classes of other pelagic Lake Powell fishes. Large fish were likely mixtures of piscivores and common carp. The largest fish in the forebay were present in summer and winter through early spring. Smaller fish were present late spring and early summer.

Table 3. Fish Size as Determined by Love's Equation, Second Year.

Month	Smallest Dark Size (cm)	Largest Dark Size (cm)	Smallest Light Size (cm)	Largest Light Size (cm)
June 2008	5.5	11.7	16.6	26.7
July	6.8	13.9	6.8	25.8
August	13.6	24.1	19.8	22.6
September	8.5	8.6	9.8	12.4
October	10.6	13.8	10.6	13.8

November	19.1	26	19.1	27.3
December	6	6.6	8.6	22.7
January 2009	5.6	7.7	5.9	26.1
February	6.9	10.1	7.9	22.2
March	7.6	15.3	6.3	16.8
April	12.7	19.8	8.5	22.8
May Low Flow	7.3	14.9	6.2	15.4
June 2009	8.4	15.4	9.3	9.8

STATISTICAL ANALYSIS: JUNE 2008 – JUNE 2009

1) Is there a significant difference between light vs. dark volumetric density averaged over month & turbine?

We used the Wilcoxon Signed Rank Test to test whether the difference between the median of light and dark density is greater than would be expected by chance (Table 4, also, Fig. 7). There was a statistically significant difference between densities of fish in light and dark conditions (W= -63, Z= -2.20, P-Value = 0.027).

Table 4. Median and quartile values of light and dark fish density averaged over month and turbine during the second year of the study.

GROUP	N (JUNE '08 - JUNE '09)	MEDIAN	25%	75%
DARK	13	970.26	305.72	3279.41
LIGHT	13	188.18	70.13	1230.18

2) Is there a difference in volumetric density among the turbines during light and dark sampling?

We used the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for significant differences in the median values among turbines. Data were summed over depth, yielding a sample size of 13 months**.** There was not a statistically significant difference between densities under light and dark turbine conditions (Table 5, Figs. 8 & 10).

TABLE 5. Statistical results of the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences in turbine fish density between light and dark periods during the second year of the study.

GROUP	N (JUNE '08 - JUNE '09)	DF	H	P-VALUE
DARK BY TURBINE	13	5	2.67	0.75
LIGHT BY TURBINE	13	5	1.24	0.94

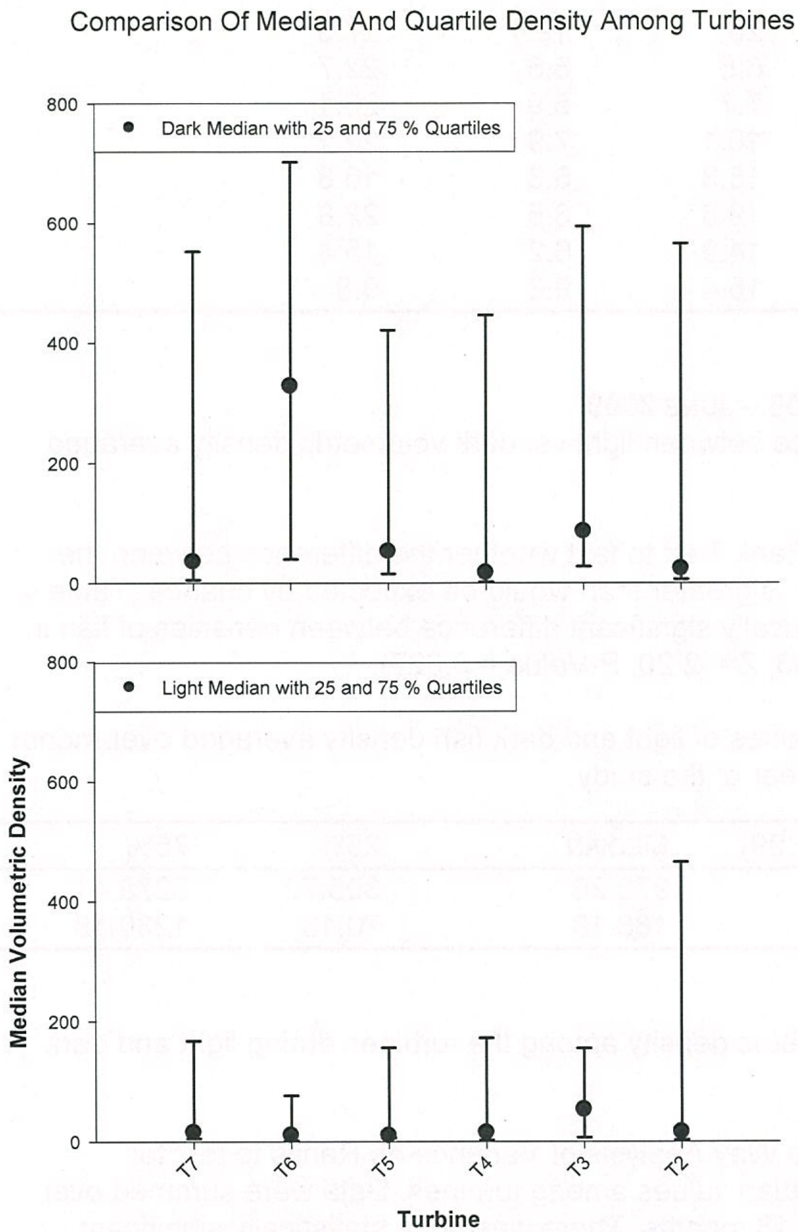

Figure 10. Comparison of median and quartile fish density among turbines during the second year of the study.

3) Is there a difference in volumetric density among months during light and dark sampling?

We used the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences in the median fish density values among months. Data were summed over depth for each turbine, yielding a sample size of 6 (i.e. turbines 2 – 7). There was a statistically significant difference between light and dark monthly densities (Table 6).

TABLE 6. Statistical results for the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences in light and dark density among turbines.

GROUP	N (TURBINES 2-7)	DF	H	P-VALUE
DARK	6	12	56.4	<0.001
LIGHT	6	12	50.86	<0.001

To isolate the months that differed from the others, we used a multiple comparison Tukey's Test. Most summer months had statistically higher densities than the winter months; more so during dark sampling than the day sampling (see Fig. 11, July – September '08 and June '09).

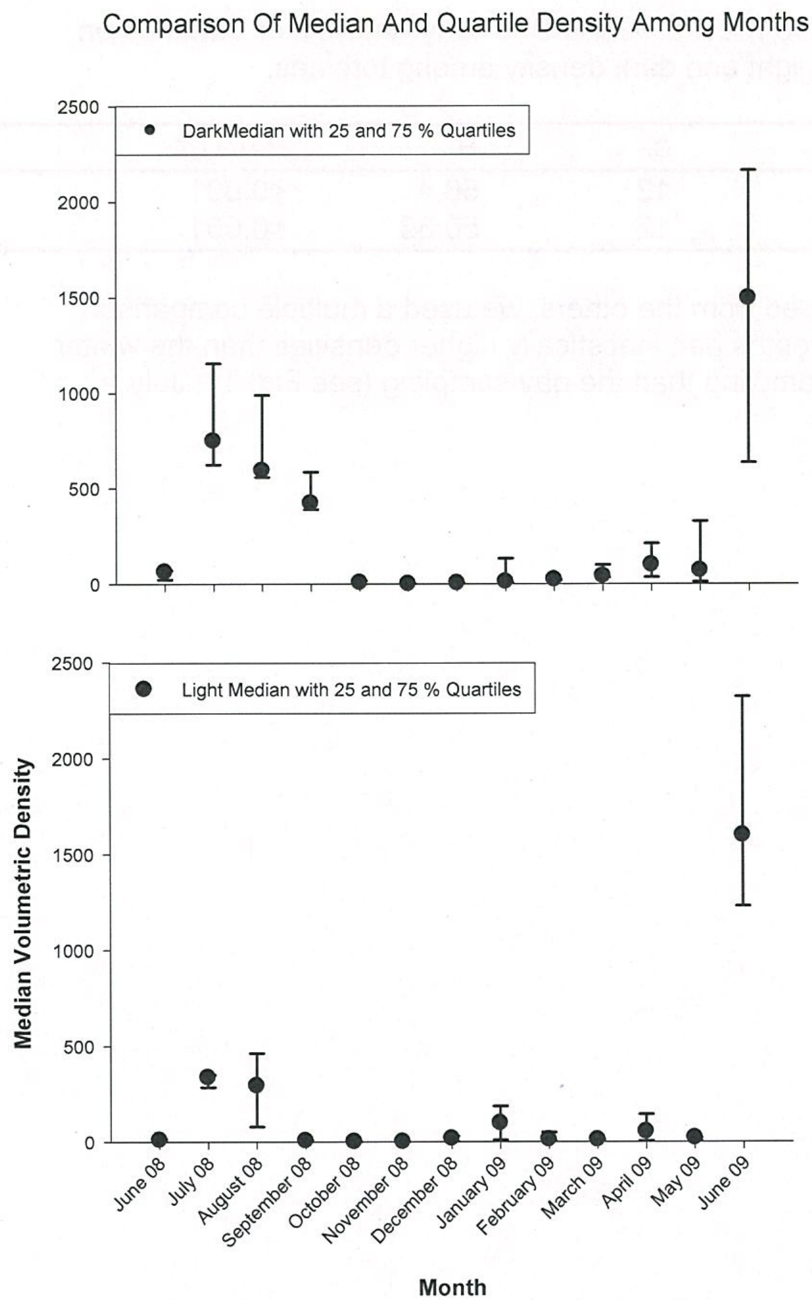

Figure 11. Comparison of median and quartile fish density among months during the second year of the study.

4) Is there a difference in volumetric density during light and dark sampling?

We used the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences in the median fish-density values among depths. Data were summed over depth for each turbine, yielding a sample size of 6 (i.e. Turbines 2 – 7); and depths were partitioned as follows: 0-4, 5-6, 7-10, 11-14, 15-18, and 19 + meters). There was a statistically significant difference between light and dark depth density (Table 7, see also Fig. 9).

TABLE 7. Statistical results for the Kruskal-Wallis One Way Analysis of Variance on Ranks to test for differences in light and dark density by depth among turbines.

GROUP	N (TURBINES 2-7)	DF	H	P-VALUE
DARK	6	5	30.84	<0.001
LIGHT	6	5	30.25	<0.001

WATER QUALITY AND VELOCITY PROFILES: JUNE 2007 – MAY 2008

Water quality parameters in the forebay are subject to the influence of peaking power generation occurring at the Glen Canyon Dam Powerplant. Biologically relevant water quality parameters (temperature and dissolved oxygen) are presented in Figures 12 and 13. Forebay surface temperatures peaked in July at 27 °C, and fell to a low of 9.1 °C in January (Fig. 12). Thermocline formation was apparent June – October. Dissolved oxygen levels in the top 25 m of water peaked in late winter and spring of 2008, and were at their lowest levels in October (Fig. 13); however levels did not drop below 4 mg/l.

Comparison of Temperature Fluctuations At Three Depths, By Month
Glen canyon Dam Forebay

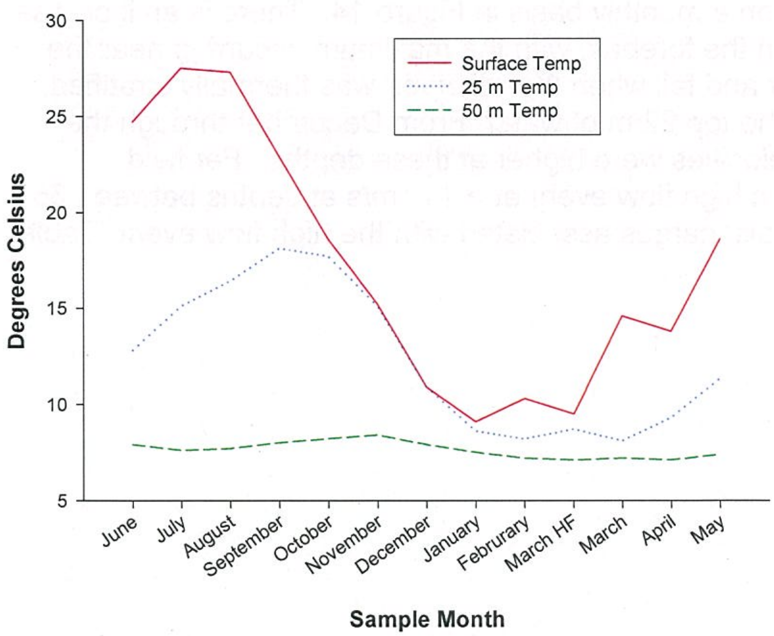

Figure 12 . Comparison of temperature fluctuations in the Glen Canyon Dam forebay, June 2007 to May 2008.

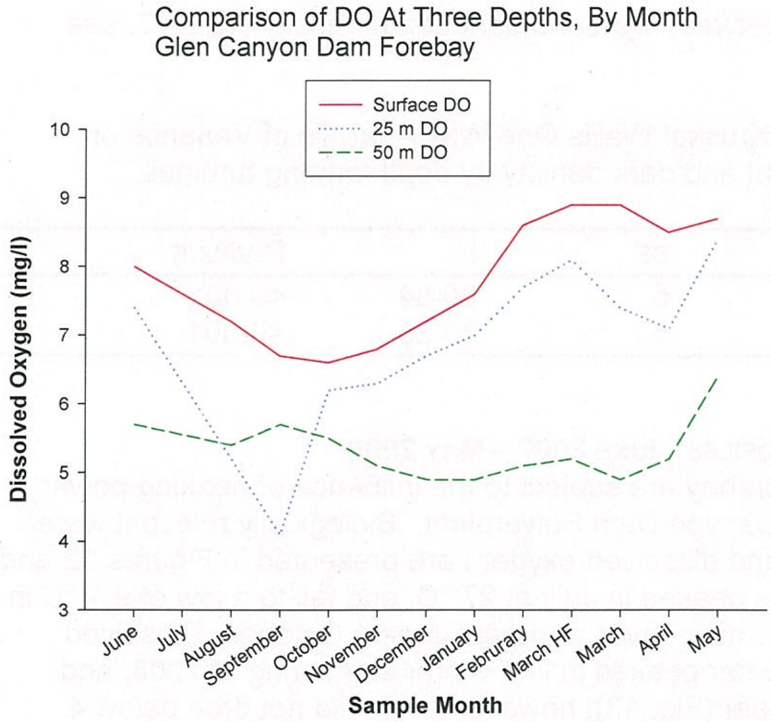

Figure 13. Comparison of dissolved oxygen by depth, Glen Canyon Dam forebay, June 2007 to May 2008.

Far field velocities are presented on a monthly basis in Figure 14. There is an increase in velocity as a function of depth in the forebay, with the maximum occurring near the intake centerline. During summer and fall when the reservoir was thermally stratified, velocities were low (< 3 cm/s) in the top 22 m of water. From December through the March high flow event, far field velocities were higher at these depths. Far field velocities peaked during the March high flow event at > 11 cm/s at depths between 35-38 m. This is a result of the high discharges associated with the high flow event (Table 8).

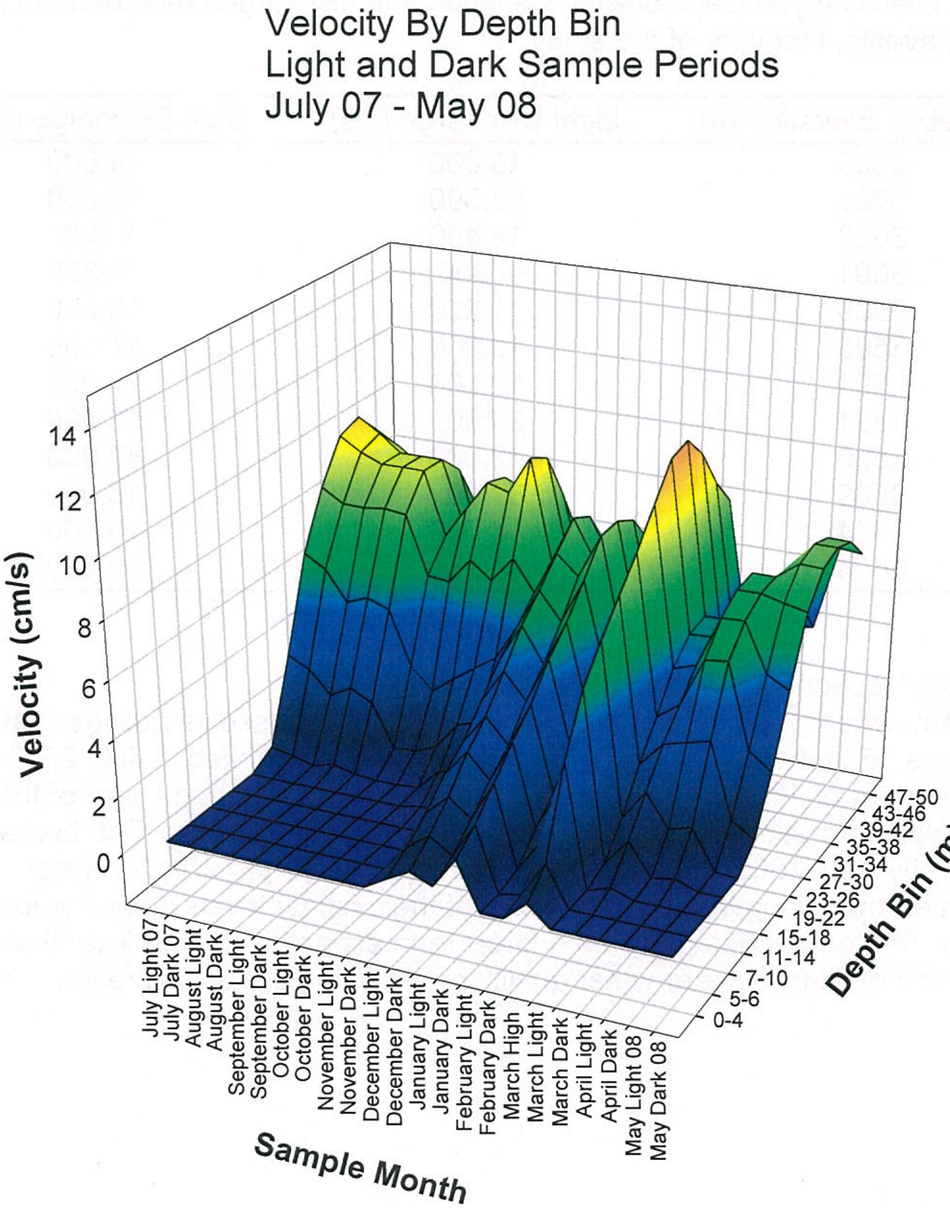

Figure 14. Far field velocities in the Glen Canyon Dam forebay, by depth bin. Velocities were measured with ADCP /ADV or computed with SELECT model during the first year of the study.

Table 8. Specific Glen Canyon Dam forebay elevation and discharges recorded during monthly sampling events, first year of the study.

Month	Forebay Elevation (ft)	Light Discharge (cfs)	Dark Discharge (cfs)
July 2007	3608	15,800	14,800
August	3605	13,000	15,000
September	3602	12,400	9,000
October	3601	9,800	11,300
November	3599	11,250	13,000
December	3595	13,000	17,000
January 2008	3591	12,500	17,000
February	3591	9,000	13,500
March High Flow	3590	42,800	42,800
March	3589	8,100	13,000
April	3594	14,000	15,500
May 2008	3608	15,250	12,250

WATER QUALITY AND VELOCITY PROFILES: JUNE 2008 – JUNE 2009

Biologically relevant water quality parameters (temperature and dissolved oxygen) are presented in Figures 15 and 16. Forebay surface temperatures peaked in July 2008 at 28.7 °C, and fell to a low of 10 °C in January (Fig. 15). During the second year of the study, the thermocline formation was apparent in June and had abated by October; and was re-established by April 2009. Dissolved oxygen levels in the top 25 m of water peaked in late winter and spring of 2009, and were at their lowest levels in September (Fig. 16); however, September data indicate a lower than expected oxygen level that is likely the result of the multi-parameter water quality probe being out of calibration.

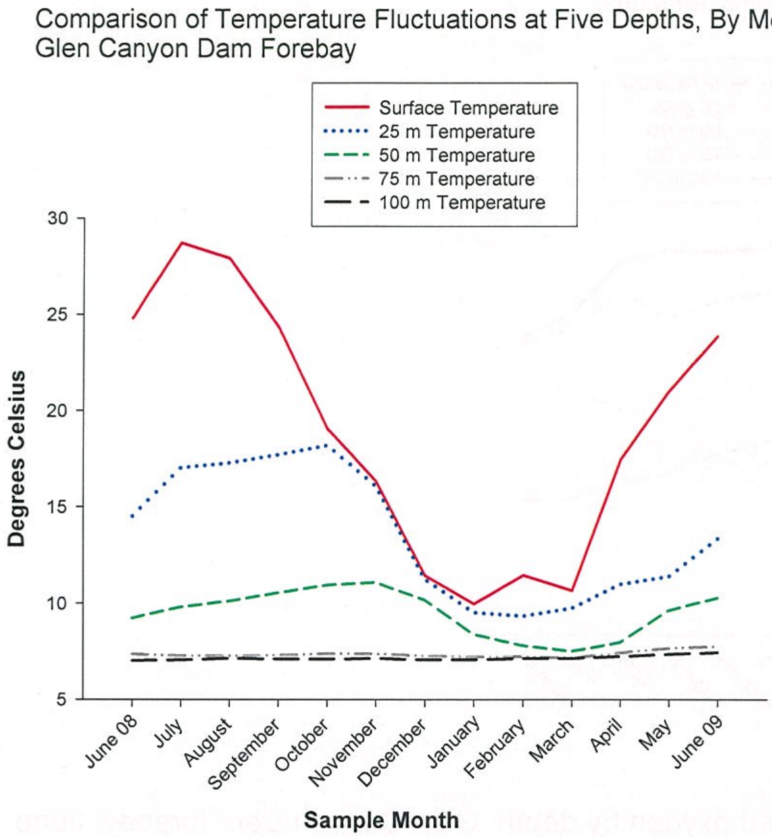

Figure 15. Comparison of water temperature fluctuations in the Glen Canyon Dam forebay, June 2008 to June 2009.

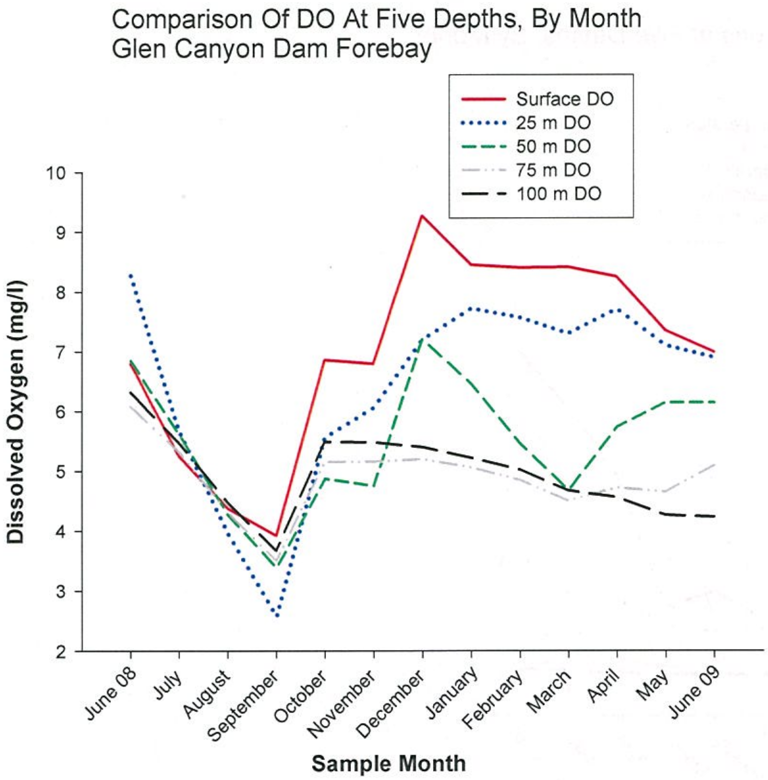

Figure 16. Comparison of dissolved oxygen by depth, Glen Canyon Dam forebay, June 2008 to June 2009.

Far field velocities (cm/s) are presented on a monthly basis in Figure 14. There is an increase in velocity as a function of depth in the forebay, with the maximum occurring near the intake centerline. During summer and fall 2008, and again in late spring / summer 2009 velocities were low (< 3 cm/s) in the top 22 m of water. From December through April, far field velocities were higher at these depths. Far field velocities peaked during the July sampling event at > 11 cm/s at depths between 47-50 m. This is a result of the high discharges associated with the sampling event (Table 9).

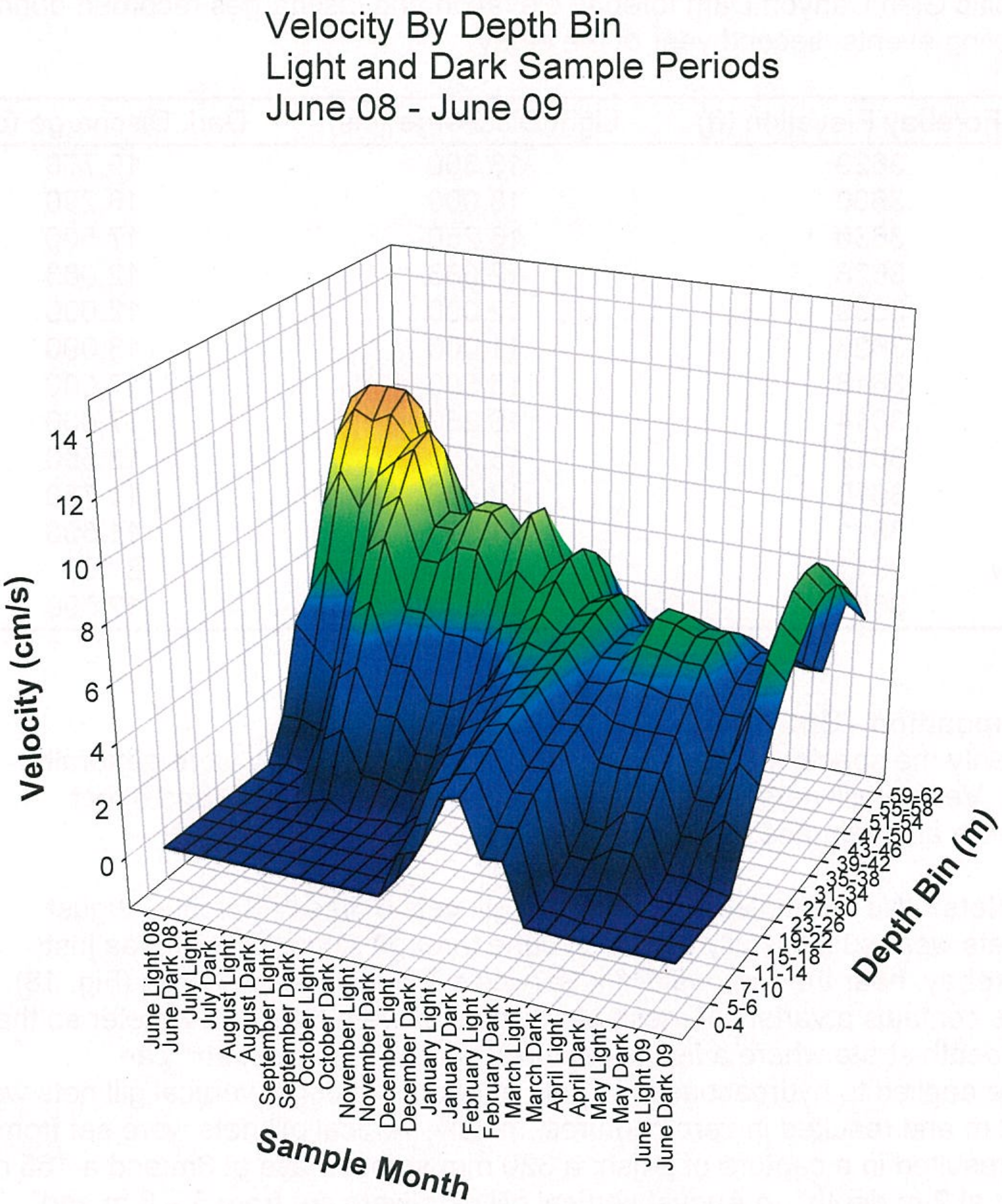

Figure 17. Far field velocities in the Glen Canyon Dam Forebay, by depth bin. Velocities were estimated with SELECT modeling during the second year of the study.

Table 9. Specific Glen Canyon Dam forebay elevation and discharges recorded during monthly sampling events, second year of the study.

Month	Forebay Elevation (ft)	Light Discharge (cfs)	Dark Discharge (cfs)
June 2008	3629	13,300	15,750
July	3630	18,000	16,250
August	3630	16,250	17,500
September	3628	12,083	12,083
October	3630	12,000	12,000
November	3623	11,000	13,000
December	3618	15,500	17,000
January	3614	16,250	17,000
February	3612	13,300	13,500
March	3610	12,000	11,750
April	3611	11,500	11,500
May Low Flow	3611	8,100	8,100
June 2009	3638	14,000	12,500

Species Composition - Both Years
Attempts to verify the species composition of fish within the forebay were generally unsuccessful. Vertical gill nets, electrofishing, mid-water icthio-trawls and direct observation were all attempted.

Vertical Gill Nets: We attempted to set vertical gill nets 6 times (March – August 2008). The nets were successfully deployed June through August, in an area just outside the forebay, near the National Park Service's 'Chains' Access Area (Fig. 18). The net arrays contains a variety of mesh bar sizes and were labeled by meter so that the particular depth strata where a fish is captured can be recorded, and can presumably be applied to hydroacoustic targets at depth. In June, vertical gill nets were set from 7 -12 m and resulted in zero captures. In July, vertical gill nets were set from 11-13 m and resulted in a capture of 2 fish: a 320 mm striped bass at 3m and a 155 mm threadfin shad at 2 m depth. In August vertical gill nets were set from 5 – 8 m and resulted in a capture of 2 smallmouth bass: 242 and 255 mm at 8 m depth.

Figure 18. Deployed vertical gill nets, near Glen Canyon Dam.

Electrofishing (First Year 07-08): We attempted to electrofish the canyon walls of the forebay during the June 2008 hydroacoustic survey. The survey was done at night with UDWR personnel. There were 42 common carp observed during the sample, of which 7 were captured. Their mean size was 390 mm, with a size range of 255 – 430 mm. Two channel catfish were observed but not captured, and were estimated to be 270 and 330 mm. There was one large unidentified species observed (briefly) and was believed to be a large striped bass between 500 – 600 mm.

Electrofishing (Second Year 08-09): We attempted to electrofish the canyon walls of the forebay as well as the dam face itself during the June 2008 hydroacoustic survey, and again in June 2009 (Fig. 19). The surveys were done at night with UDWR personnel. During the 2009 survey, there were several dozen observed of which 8 were captured (mean size: 425 mm, range: 391 – 432 mm). Three smallmouth bass were captured (mean size: 114 mm, range: 84 – 135), 2 green sunfish (mean size: 55 mm, range: 45 – 64 mm) and one threadfin shad was also captured (33 mm).

Figure 19. Electrofishing effort near the Glen Canyon Dam Face.

Mid-Water Icthyo-trawl (First Year 07-08): We attempted a mid-water icthio-trawl during the August 2007 survey. The survey was done with UDWR personnel at night, just outside of the forebay log-boom. No fish were captured during 2 trawls.

Mid-Water Icthyo-trawl (Second Year 08-09): We attempted a mid-water icthio-trawl during the July 2009 survey. The survey was done with UDWR personnel at night, just outside of the forebay log-boom. The first trawl captured 12 shad. The second trawl captured six fish (five shad and 1 small unknown).

Direct observation (Both Years): Fish activity was periodically observed at different times during monthly surveys. Notably, striper 'boils' were observed in the forebay in June, July, and August (Fig. 20), as well as large schools of shad (Fig. 21). Infrequently observed species such as channel catfish were noted during dark surveys in August, September, and October. Common carp were observed nearly every sampling trip both years.

Figure 20. Summer 2008 striper 'boil' within the Glen Canyon Dam forebay.

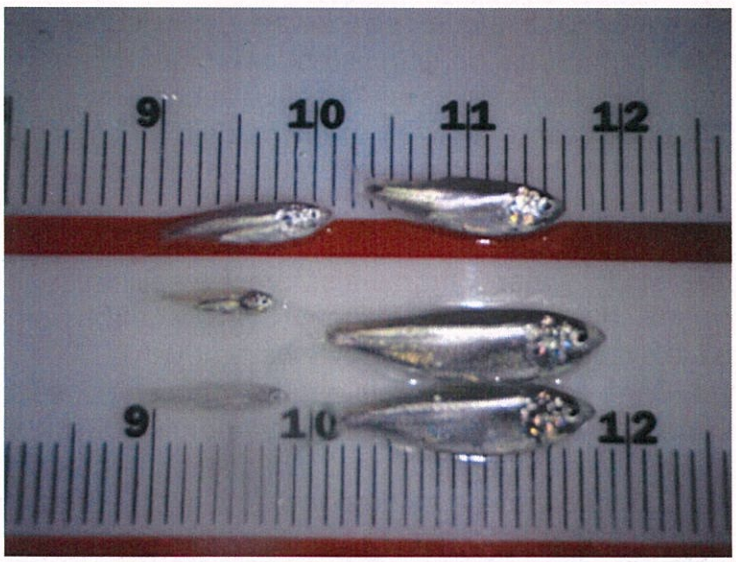

Figure 21. Representative sample of a large shad school sampled with a dip-net in September 2008, Glen Canyon Dam forebay.

Discussion

The density and distribution of fish within the forebay varies with light vs. dark periods, month of the year, and depth. It appears that fish in the forebay are predominantly found in the top 14 m of water, even as the intake centerline elevations changed as Lake Powell's surface elevation rose and fell in both years (Figs. 3, 6, & 9)

On a per-turbine basis volumetric fish densities were highest at turbine 4 in the first year and turbine 2 during the second year (Figs. 5 & 8). This is likely indicative of a 'patchy' or variable distribution in the general vicinity of the dam, or possibly a result of operational activity during the surveys.

Fish entrainment through Glen Canyon Dam penstocks during the course of the overall study was likely low. This is based upon several factors. For example, far field velocities associated with power production were lowest (2-3 cm/s) in the top 22 m of water for the majority of this study, and especially during the seasonal periods when fish densities were higher (Figs. 14 & 17). Another important factor that should be mentioned was that the reservoir's thermocline formation was well above the penstock intake centerline. Fish density in the forebay was generally higher during the spring and summer months when stratification occurs, and fish distribution appears to be higher in the epilimnion of the forebay during stratification.

Attempts at linking species composition with density were ultimately unsuccessful during this study. We could not say with any reasonable certainty what species of fish were present, only: 1) how many by depth or location and 2) what sizes were present. We attribute this difficulty in gathering species composition data to be with problems inherent to sampling fish in the forebay, notably depth and velocity associated with peaking power. Vertical gill nets are designed for this purpose; however, they could only be set outside the forebay and outside of normal boating lanes / swimming areas in the water leading to the forebay log-boom. Electrofishing was effective at capturing surface oriented common carp, but cannot be used effectively in the pelagic areas of the forebay. Mid-water icthyo-trawls can only occur outside the forebay log-boom, and ultimately only recruit to smaller fish such as shad.

Based on observations made during this study, water withdrawals from the epilimnion, whether in a low reservoir or through a selective withdrawal system (SWS) would have potential to entrain fish inhabiting these elevations. Even if a SWS were never constructed on the face of Glen Canyon Dam, long term, persistent drought conditions and resulting lowered lake elevations could also compress the density and distribution of fish in the forebay. For example, and based on our data from 2008, fish entrainment could increase significantly if the forebay surface elevations drop to within 14 m of the penstock centerline (Figs. 22 & 23) and if the near-field intake velocities are high enough to entrain the fish species present. Entrainment potential will vary with swimming performance of fish species and also with fish size, with the earliest life stages (i.e., eggs and larvae) being highly vulnerable to entrainment.

The Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead Environmental Impact Statement (Shortage EIS; Reclamation 2007) analyzed probabilities of Lake Powell reaching discrete reservoir levels under current operational guidelines. According to those analyses, percentages of simulations whereby lake levels fell to 3,550 and 3,490 feet mean sea level (msl) during 2016 through 2060 were 2-7% and 0-3%, respectively. Fish occur within 14 m (46') or less of the reservoir surface so, at 3,516 msl or 46' above the penstock centerline, the potential for fish entrainment will likely increase. Since 3,516 msl falls between the two values analyzed in the shortage EIS, it appears that fish entrainment could occur under low reservoir elevations. While these probabilities are admittedly low, biological ramifications of large numbers of warm water predatory fish (such as those known to inhabit the forebay) becoming entrained into the Colorado River below Glen Canyon Dam (including humpback chub and razorback sucker critical habitat) during such low reservoir periods are significant (Baron et al. 2003).

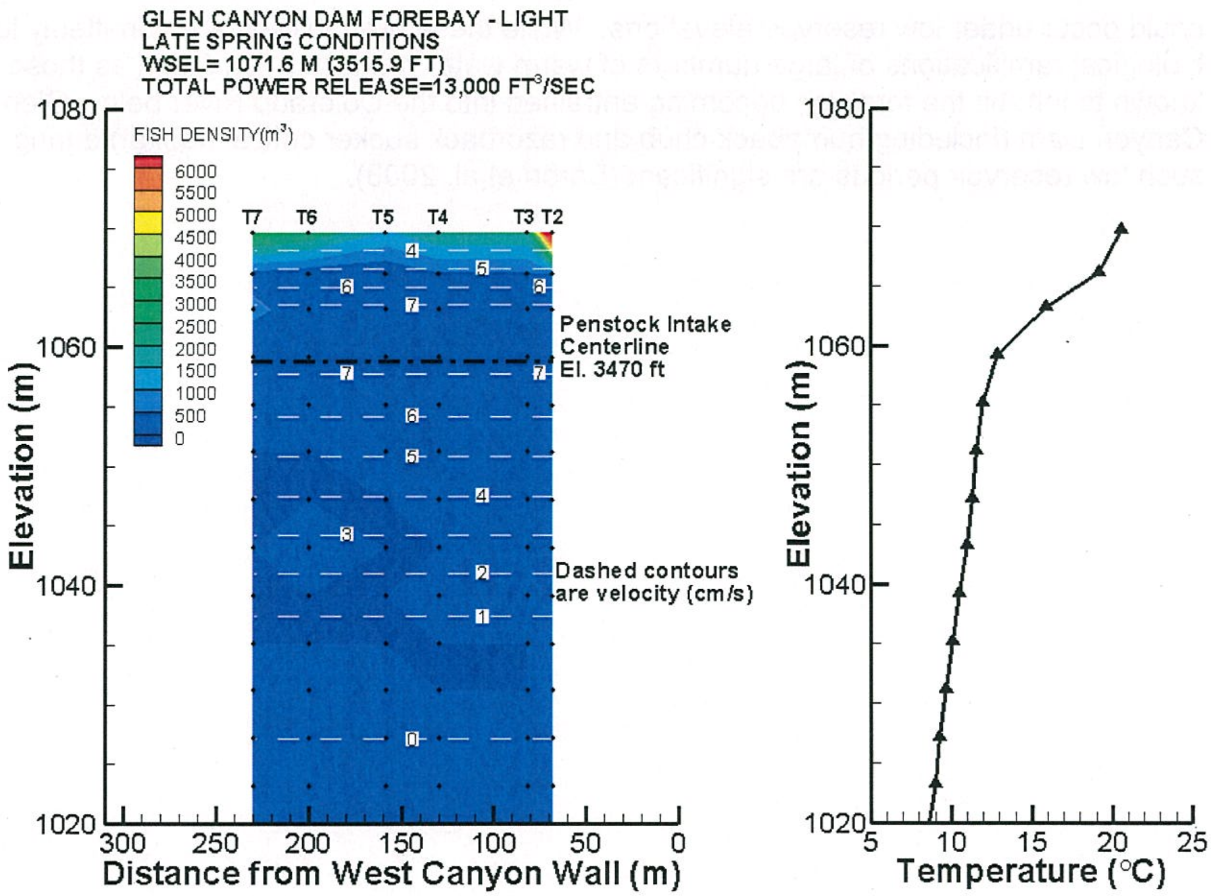

Figure 22. Summed 2008 light volumetric density plot overlaid with velocity and temperature data for typical late spring conditions (flow and thermal stratification). The hypothetical velocity profile was based on a powerplant release of 13,000 cfs.

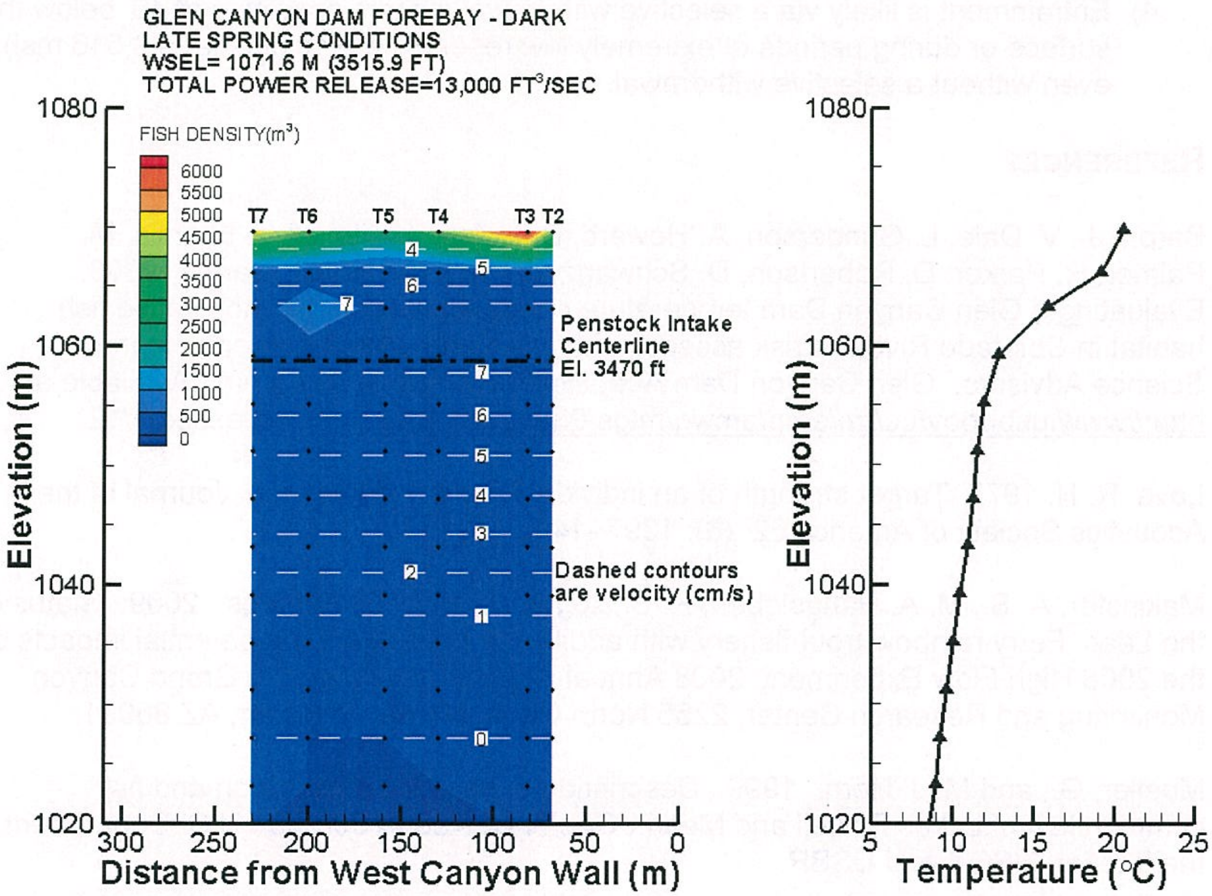

Figure 23. Summed 2008 dark volumetric density plot overlaid with velocity and temperature data for typical late spring conditions (flow and thermal stratification). The hypothetical velocity profile was based on a powerplant release of 13,000 cfs.

Conclusions

1) The density and distribution of fish within the forebay varies with light vs. dark periods, month of the year, and depth, with more fish present during dark periods from June through September.

2) Regardless of reservoir elevation, fish in the Glen Canyon Dam forebay were most abundant in the top 14 m of water during the study period, which overlapped largely with the epilimnion during periods of thermal stratification. Fish were especially abundant in the top 4 m the water column.

3) Fish entrainment through Glen Canyon Dam penstocks during the course of the overall study was likely low based on densities of fish at water elevations where they would be entrained.

4) Entrainment is likely via a selective withdrawal system operating at 40' below the surface or during periods of extremely low reservoir elevations ca. ≤ 3,516 msl) even without a selective withdrawal.

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