HYDROACOUSTIC FISHERIES SURVEY FOR LAKE ELSINORE: SPRING, 2008

Draft Final Report

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Project Description

A hydroacoustic fisheries survey was conducted on April 23-24, 2008 to determine the abundance and distribution of fish in Lake Elsinore. Acoustical target strength is related to the size of the target, and a number of regressions have been developed between target strength and fish length (e.g., Love, 1970). Length-weight relationships (e.g., Carlander, 1977) further allow one to derive biomass estimates from hydroacoustic data. This hydroacoustic survey complements recent electrofishing and seine surveys and provides high-resolution information about the vertical and lateral distribution of fish and their size.

Approximately 8 - 10 parallel transects across the short (SW-NE) axis of the lake were made using a BioSonics DT-X 200 kHz split-beam echosounder at a sampling rate of 6 pings per second and 0.4 ms pulse duration during separate daytime and nighttime surveys. Hydroacoustic survey results were compared with results from an electrofishing survey by DFG conducted that same evening on April 23rd, and with beach seine results from carp harvesting efforts of the City of Lake Elsinore. These additional measurements ground-truth hydroacoustic survey results, corroborate fish size inferred from acoustical target-strength and determine species composition associated with different size classes of fish. The survey was conducted from approximately 9 p.m. – 2 a.m. and again from 6:30 a.m. – 2 p.m. The nighttime survey was conducted to eliminate potential acoustic “shadowing” that occurs when fish are tightly schooled up; this is often an issue for shad, that are typically found in dense schools during the daytime (Schael et al., 1995).

Measurements were made using vertical beaming at a nominal boat speed of 4 knots. BioSonics VisualAnalyzer software was used to deconvolve the echograms and quantify the number and strength of targets present in the transects. Differential GPS information was collected along the survey transects and used, in conjunction with geostatistical techniques, to develop a synoptic map of fish distribution across the lake.
Results

Daytime Survey

Ten transects across the lake totaling approximately 23 km in length were made during the daytime survey. Fish targets were identified using −70 dB thresholding, corresponding to targets >0.2 inches (5 mm) in length, and mapped across all the transects (Fig. 1). At the scale of this figure, fish were identified nearly continuously across the transects, with only the 3 shallowest transects yielding some apparent spacing between targets (Fig. 1).

Fig. 1. Transect locations for daytime survey. Individual targets along transect shown as small solid circles.

A typical echogram across the lake revealed details concerning the bathymetry of the basin, as well as sediment characteristics, volumetric backscatter (due principally to zooplankton) and distribution and abundance of fish (e.g., Fig. 2). The color within the echogram indicates the strength of the acoustic backscatter at any location on the transect (x-axis) and depth (y-axis), using the scale on the left side of the figure (Fig. 2). Thus, we see low backscatter near the surface of the lake, depicted by the dark blue color (approximately -90 to -100 dB) generally present in the upper 2-3 m of the water column (Fig. 2). Even within this region, however, the appearances of lighter blue streaks indicate the presence of slightly more reflective targets that represent zooplankton and very small fish. One does note larger targets, appearing as lime-green streaks at 2-3 m depth on the left and right sides of the echogram. Thus larger fish (target strengths of −40 to −60 dB) were found at drop-offs near the shoreline. A higher
number of targets were found below about 4 m depth (Fig. 2). Zooming in on the echogram shows more clearly the backscatter profiles of individual targets (Fig. 2, inset). Thus, what appear as streaks on the scale of Fig. 2 are really well defined targets showing the classic backscatter profiles of moderately sized fish. Analysis of those targets > -70 dB will be described shortly, although it is useful to also highlight additional information provided in these echograms.

The lake bottom is consistently the strongest reflector of sound within a lake and can be readily identified as reddish to yellow band in the echogram (Fig. 2). Since real-time differentially-corrected GPS provides very accurate transect and target locations across the lake, combining this information with cm-scale vertical precision provides detailed bathymetric information across these transects. It is particularly interesting to note the small and narrow depression near the center of the echogram (at about ping number 4500). This is thought to be the Lake Elsinore fault, here showing a dislocation of about 25 cm in the vertical dimension. With additional measurements, it would be possible to map out the details of this fault.

Importantly, the composition and properties of the bottom sediments (e.g., fine organic sediment, coarse textured sands or gravels) can also be inferred from the backscatter strength of the lake bottom. Thus we notice the strongest backscatter from
sediments found at depths greater than approximately 6.5 m depth and located in deepest sub-basin of the lake. A previous sediment survey found fine-textured sediments with high organic matter contents and high dissolved phosphorus concentrations covering about 50% of the lake (Anderson, 2001). Lower backscatter strength was measured from the more coarsely textured sediments present in shallower water (Anderson, 2001) (Fig. 2). The higher backscatter from the deeper, finer sediments relative to the shallower, coarser sediments is due principally to the entrained gas within the fine organic sediments. Although gas content was not specifically evaluated in this survey, previous field and lab work has confirmed the presence and strong production of gas within the sediments of Lake Elsinore. Gas bubbles are very effective reflectors of sound and thus are responsible for the strong backscatter in the sediments there. Gas production and ebullition is also thought to help drive nutrient release from sediments.

Finally, volumetric backscatter (i.e., backscatter not due to a specific fish target) is a convenient index of zooplankton and other suspended particles in the water column. Backscatter decreases with size and with density contrasts with water, so proportionally very little sound is reflected by algae and other very small organisms. Thus, most acoustic backscatter can be attributed to zooplankton within the water column. Some recent work on Lake Skinner shows a strong correlation between zooplankton biovolume and volumetric backscatter (Anderson, unpubl. data). Although not considered here, acoustic backscatter can thus be used to estimate zooplankton abundance and distribution within the lake.

Analysis of the echograms was conducted in several ways. First of all, since the GPS location of each fish target on all the transects is known, it is possible to spatially represent the distribution of any particular size class of fish. With that in mind, the distribution of the largest 1% of the fish surveyed is shown in Fig. 3a. We thus see that the largest fish were found distributed across the lake, although higher densities were found in the northwestern and southeastern-most transects (Fig. 3a). There also tended to be greater numbers of large fish near the shoreline and comparatively few in the center of the lake.
The opposite trends were found for smallest 1% of the fish (Fig. 3b). For example, very few small fish (<0.4 inches or 10 mm or so) were found in the northwestern-most transect, with fewer near the shoreline, and generally highest numbers were found near the center of the lake. Similar overall distributions were found for median sized fish with an average estimated length of 1.6 inches (40 mm) (Fig. 3c).

A total of 21,448 fish targets were found across the 22 km of transects, yielding about 1,000 fish per km. The echosounder measures the fish in a cone with a 6° beam width, and thus actually measures fish per unit area projection (fish/acre) as well as fish per unit volume (fish/m$^3$). Since target strength (proportional to size) is also recorded, one is able to calculate the fish per acre as a function of target strength (Fig. 4). The population density of fish as a function of target strength exhibited an approximately normal distribution, with very few fish (<200 per acre) with large (e.g., < -30 dB) or small target strengths (e.g., -70 dB) (Fig. 4). The average target strength (TS) across all fish identified in the daytime survey was –51.15 dB. The average sized fish (within a 3 dB bin size) was present at a density of about 2,700 fish per acre; averaged over all target strengths, one estimates a total fish density of 18,090 fish per acre in Lake Elsinore. Most of these fish will be very small (less than a couple inches).
A number of regressions as well as theoretical calculations have been developed to relate fish size to target strength (e.g., Love, 1970). One of the most commonly used relationship is that developed by Love (1970), which for a fish in dorsal aspect, relates target strength (TS) and length (L) and can be written as:

\[ TS = 19.1 \log L + 0.9 \log F - 62.0 \]  

(1)

where TS is the target strength (dB), L is length (cm) and F is echosounder acoustic frequency (kHz).

Using this equation, one can estimate the size of fish from measured target strengths. Applying this equation to the measured target strengths (Fig. 4, upper x-axis), we see that most of the fish are between 1 – 20 cm in length (0.5 – 6 inches) (note log scale). A much smaller fraction of the fish (<7%) exceed this length range.

Fig. 4. Probability distribution of target strength and length expressed on fish/acre basis.

Since hydroacoustics only quantifies the acoustic backscatter from targets in the water column, with regression equations providing an estimate of fish length, it is not possible to directly determine species composition. Because of this, traditional fish survey techniques are generally needed to make species assignments. The California
DFG recently completed the fish survey report from their electrofishing survey conducted concurrently with this hydroacoustic survey (Ewing, 2008). Electrofishing was conducted at 6 short transects on the lake and restricted to shallow, generally brushy areas on the southeast and northwest ends of the lake (Ewing, 2008).

Ewing (2008) found carp, bluegill, largemouth bass, black crappie and channel catfish during their survey. Results from their electrofishing survey are summarized in Table 1.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number</th>
<th>Percent (%)</th>
<th>Mean Length (mm)</th>
<th>Length Range (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Carp</td>
<td>51</td>
<td>43.2</td>
<td>506</td>
<td>418 - 650</td>
</tr>
<tr>
<td>Bluegill</td>
<td>44</td>
<td>37.3</td>
<td>116</td>
<td>50 - 170</td>
</tr>
<tr>
<td>Largemouth Bass</td>
<td>13</td>
<td>11.0</td>
<td>363</td>
<td>271 - 424</td>
</tr>
<tr>
<td>Black Crappie</td>
<td>8</td>
<td>6.8</td>
<td>312</td>
<td>279 - 335</td>
</tr>
<tr>
<td>Channel Catfish</td>
<td>2</td>
<td>1.7</td>
<td>442</td>
<td>419 - 465</td>
</tr>
</tbody>
</table>

Common carp were the most abundant species found in the survey, accounting for 43.2% of the fish collected, followed by bluegill (37.3%), largemouth bass (11%) and black crappie (6.8%). Two channel catfish were also collected, although they accounted for only 1.7% of the total catch. Carp and channel catfish were the largest species collected (mean total lengths of 506 and 442 mm) (or 19.9 and 17.4 inches, respectively). The carp (and the 2 catfish) were significantly larger than all the remaining fish except for three largemouth bass, making 400 mm (or 15.7 inches) a convenient cutoff to separate carp and other large fish from smaller species. This size cutoff also accounts for 92% of all carp measured from fall net seining by City of Lake Elsinore staff (Santa Cruz, 2008).

Using this size as the length cutoff for carp (plus channel catfish and the largest bass) and solving eq 1 for TS, one estimates a corresponding target strength of -33.5 dB or larger for carp. Of the 21,448 targets found in the daytime survey, only 186 (or 0.867%) exceeded this target strength. Averaging over all transects, the daytime hydroacoustic survey yielded a total fish population density (all sizes) of 17,443 fish/acre. If 0.867% are carp (plus channel catfish and the largest bass), one estimates a density of 151 carp plus channel catfish and largest bass per acre. We can correct for the channel catfish and largest bass using the fraction recovered in the DFG electrofishing survey; since a total of 5 fish (2 channel catfish and 3 largemouth bass) falls within this size length, the above estimate should be reduced by 5/56 or 8.9%. One thus estimates a carp density of 138 carp/acre. This can be compared with fishery
results from the mark-recapture survey conducted by EIP in April 2003 (EIP, 2004). In that study, they estimated 250-500 carp/acre. Based upon 2003 results then, one estimates that fish removal efforts by the City of Lake Elsinore have reduced the net carp population by 45-72%. These values are below densities and percent reductions estimated from seining data over the past several years (Kilroy, 2008), but nevertheless confirm successful efforts to control carp populations in the lake.

Since there is a growing body of information on the size and fitness of carp in the lake, it is useful to consider some of the available data (Table 2). Fishery data was collected from seining (EIP, 2004; Anderson, unpubl.; Santa Cruz, 2008) and from electrofishing (Ewing, 2008). The differences in collection techniques and locations have some influence on findings, although it seems clear that the size (length and weight) of the carp in the lake has increased from that in April 2003 (Table 2). The larger length and lower condition factor found by Ewing (2008) relative to beach seining efforts the prior fall or this past September results from use of total length, rather than fork length as used in the other measurements. The condition factor for carp sampled over the past year also appears to be lower than that found in 2003, suggesting that despite the general improvement in the salinity, habitat and other conditions at the lake, the overall fitness of the carp has degraded somewhat. The reduction in fitness could be due to greater competition with other fish in the lake, although more work would be needed to be done before this could be clearly established.

<table>
<thead>
<tr>
<th>Property</th>
<th>April, 2003</th>
<th>September, 2007</th>
<th>April, 2008</th>
<th>September, 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (cm)</td>
<td>37.0</td>
<td>44.0 ± 2.3</td>
<td>50.6</td>
<td>42.8 ± 4.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.90</td>
<td>1.246 ± 0.261</td>
<td>1.714</td>
<td>1.167 ± 0.424</td>
</tr>
<tr>
<td>Condition Factor</td>
<td>1.78</td>
<td>1.44 ± 0.15</td>
<td>1.33</td>
<td>1.49 ± 0.11</td>
</tr>
<tr>
<td>N</td>
<td>3,333</td>
<td>22</td>
<td>51</td>
<td>150</td>
</tr>
</tbody>
</table>

*aEIP, 2004; *bAnderson, unpubl.; *cEwing, 2008; *dSanta Cruz, 2008; *etotal length; *fpresumably low since using total length rather than fork length for estimation of K.

While the hydroacoustic survey sheds little light on species and condition of fish, it does provide a potentially complete accounting of all size classes of acoustic (fish) targets within the water column. Hydroacoustics thus overcomes the limitations of electrofishing that is restricted to shallow water, and of the limitations to using a large mesh beach seine that allows small but ecologically important ichthyoplankton, and juvenile and mature small fish (e.g., threadfin shad) to avoid quantitation.
Threadfin shad have remained the largest uncertainty in understanding the fishery of the lake. The survey from 2003 documented the presence of shad with fork lengths of 80-175 mm, although most were <150 mm in length (EIP, 2004). No population estimate was possible, however. Taking 80-150 mm as the size range for adult shad, one estimates that about 20% of the total fish in Lake Elsinore may be adult shad; this translates to approximately 3,550 adult shad/acre. This number appears broadly reasonable, since it is known that about $8 \times 10^6$ shad perished in the fish die-off in 1998; assuming a lake surface area at that time somewhere near 3400 acres, this would correspond to at least 2350 – 3530 shad/acre in 1998. In addition to the adult shad, larval and juvenile shad no doubt comprise a substantial part of the fish targets < 3 inches in length that comprise two-thirds of the total number of fish in Lake Elsinore (Fig. 3).

Black crappie comprised a substantial part of recent beach seine measurements. For example, crappie comprised the majority of fish (61.6%) collected in a beach seine survey in September, 2007 (Anderson, unpubl. data) and 21.4% of the fish collected on September 17, 2008 (Santa Cruz, 2008). This suggests that the black crappie population is comparable to or probably even exceeds that of carp in the lake. Assuming that adult crappie in the size range of 20-33 cm, as found in 2007 beach seine counts, adequately conforms to the general equation of Love (eq 1), one estimates that adult black crappie comprise 5.1% of the total fish in Lake Elsinore and have a population density of 899 black crappie/acre. This suggests that black crappie are the 2nd most abundant fish in the lake behind threadfin shad.

The vertical distribution of fish within the water column is also available from the hydroacoustic data. We note that the greatest proportion of fish targets were found between approximately 5-7 m depth, with comparatively few present in the uppermost 3 m of the water column during the survey (Fig. 5a). (Note that the uppermost 1 m of the water column was not acoustically sampled.) One also notices that a greater proportion of the larger fish were found between 1-2 m depth (note log scale on upper x-axis) (Fig. 5b).

The size of targets attributed to carp (plus channel catfish, stripers and largest bass) is shown in the dashed region. Thus a proportionally greater number of the largest fish were in relatively shallow water at the time of the survey (6:30 a.m. – 2:00 p.m.). Black crappie (20-33 cm) also appear to be more abundant in the upper 3 m of the water column, while adult shad (8-15 cm) appear to be located deeper in the water column.
The majority of the targets were found below 4 m depth and generally bore moderate target strength values (-45 to -60 dB), corresponding to an average nominal length near 5 cm or approximately 2 inches based upon eq 1 (Fig. 5b). These targets are likely larval and juvenile threadfin shad and other fish species.

![Graph showing vertical distribution of fish targets: a) percent of total targets, and b) target strength and approximate length of fish.](image)

**Fig. 5. Vertical distribution of fish targets: a) percent of total targets, and b) target strength and approximate length of fish.**

The number density (Fig. 4) overstates the importance of the small fish targets on a biomass basis, however. Using an empirical relationship developed from carp collected this September (Santa Cruz, 2008) between fish length (L) and body weight (W) of the form:

\[ W (lbs) = 7.90 \times 10^{-4} L (inches)^{2.852} \]  \hspace{1cm} (2)

one can estimate approximate biomass per acre attributable to each target strength or size class (Fig. 6). We thus see that although smaller fish targets (< -50 dB) comprised the dominant size class based upon sheer number (Fig. 4), they constitute a minimal portion of total biomass in the lake (Fig. 6). Conversely, the lower number of large fish dominate the biomass in the lake. This figure should be interpreted with some care,
however, since a general dorsal-view scattering equation (eq 1) was used to infer fish length from target strength, and the length-weight relationship for carp (eq 2) was applied to all fish in the lake. More details concerning uncertainties in findings will be discussed shortly.

![Biomass distribution by target strength and fish length.](image)

**Fig. 6. Biomass distribution by target strength and fish length.**

**Night-time Survey**

Results to this point have focused on the 10 daytime transects. While it was initially thought that the nighttime survey would reduce acoustic shadowing due to schooling of shad that was expected during the day, evidence for dense schooling was not found (e.g., Fig. 2). Targets were generally readily resolvable (Fig. 2, inset), allowable reasonable estimation of populations through echo integration and target counting.

The night-time survey, in fact, yielded echograms that suggested denser aggregations of generally small scatterers; a particularly dramatic example is shown in Fig. 7, where much higher densities were present than found during the day (Fig. 3). In fact, total population estimates based the nighttime survey results were over 2x higher
than found during the day. This initially curious observation can be reconciled however due to the nighttime emergence of larval aquatic insects from the sediments into the water column. Larval Chaoborus spp., chironomids and other insects can scatter sound and complicate interpretation of echograms, especially for enumeration of larval and small juvenile fish (Knudsen et al., 2006).

Evidence for the nighttime emergence of larval aquatic insects was found in uplooking deployments of an RDI 600-kHz acoustic Doppler current profiler made in the summer of 2001 (Fig. 8). The ADCP was deployed to evaluate water current velocities, but also records acoustic backscatter and echo intensity (related to backscatter). The blue color in that figure corresponds to lower echo intensity and backscatter and the lime green color represents greater backscatter, with the dashed lines denoting midnight (Fig. 8). One notices a high amount of echo intensity/backscatter in the upper 1 m of the water column, with lower intensities below this depth during the daytime, although echo intensity increased throughout the water column each night, remained high through the night, and then decreased quite dramatically during the day (Fig. 8). Zooplankton tows made at the lake periodically over the past 5 or 6 yrs have not recorded any significant

*Fig. 7. Echogram collected near midnight showing swarm of larval insects above sediments.*
number of larval aquatic insects at any time during the daytime, although adult midges and other insects are found near the lake. One can thus reasonably conclude that the increased number of small scatterers found during the nighttime survey can be attributed to larval aquatic insects, underscoring their importance to the food web of the lake, although their contribution to the fishery population estimate derived from daytime hydroacoustic measurements is expected to be minimal and, moreover, restricted to the small (undetermined) targets found in the surveys.

![Contour plot showing echo intensity as function of time and depth from uplooking ADCP deployment in 2001.](image)

**Fig. 8.** Contour plot showing echo intensity as function of time and depth from uplooking ADCP deployment in 2001.

**Limitations to Data Interpretation**

While the distribution, abundance and acoustic backscatter strength of targets within the water column are well-resolved in the survey, correlating target strength to fish size requires a number of assumptions that bear some discussion. First of all, the measured target strength is a function of the acoustic scattering cross-section of targets within the water column. The scattering cross-section is a complex function of orientation of fish to the acoustic beam, morphology of the fish, presence of swim bladder, and other factors. As a result, a number of empirical equations have been developed for different fish species and for different orientations relative to the acoustic beam. Love’s
equation for fish in dorsal view (eq 1) is often used for vertical beaming (as done in this survey), although individual equations for different species do vary. For example, Kubecka (2006) reported an equation for a 200-kHz echosounder (as used here) for common carp where:

\[ TS = 22.581 \log L - 93.617 \]  

(3)

where TS is target strength in dB and L is the fork length in mm. This equation differs somewhat from that of Love (eq 1), in part since the echosounder frequency is assumed to be 200-kHz and not an explicit variable in the equation. The two equations do yield differences in predicted fish length for the target strengths expected for carp and other large fish in the lake (Table 3)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>-20</td>
<td>79.9</td>
<td>71.7</td>
<td>-10.3</td>
</tr>
<tr>
<td>-25</td>
<td>43.7</td>
<td>43.0</td>
<td>-1.6</td>
</tr>
<tr>
<td>-30</td>
<td>23.9</td>
<td>25.8</td>
<td>8.0</td>
</tr>
<tr>
<td>-35</td>
<td>13.1</td>
<td>15.5</td>
<td>18.5</td>
</tr>
</tbody>
</table>

The implications of all this is that some uncertainty inherently exists in the lengths predicted from hydroacoustic data (i.e., the orientation of the fish targets, species distribution and backscattering cross-section are not known a priori). Rigorously assigning uncertainty to survey results is not practical, but the above example suggests that uncertainties of at least 10-20% are likely. It is suggested that population estimates provided in this analysis should be viewed with at least a 20% uncertainty; this would put the estimated carp population at 138±28 per acre, black crappie at 899±180 per acre, and adult threadfin shad at 3,550±710 per acre. Actual uncertainties could be substantially larger. Comparison of results from periodic hydroacoustic surveys provides an internally self-consistent way to quantify interannual changes in standing fish stock that may result from lake management efforts and natural hydrological and geochemical changes at Lake Elsinore.

References


