2007-2008 ANNUAL PROGRESS REPORT

Responses of Lahontan cutthroat trout prey items to changing hydrological regimes and salinity in Walker Lake

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Executive Summary

The objective of this study is to assess responses of Lahontan cutthroat trout (LCT) prey items to changing hydrological regimes and salinity in Walker Lake, Nevada. LCT prey items include tui chub, benthic macroinvertebrates, and zooplankton. Because other lakewide responses to changing salinity may also affect food web and LCT productivity, additional limnological monitoring are also included. Specific tasks for the 1st year of this study were 1) to expand limnological monitoring, 2) to conduct a quantitative assessment of benthic macroinvertebrates, 3) to conduct hydroacoustic fish surveys to estimate the total population size and inter-annual variability in recruitment of tui chub; and 4) to map the current distribution of macrophytes at peak seasonal development.

Expanded limnological monitoring was conducted in cooperation with NDOW personnel. The expansion of the monitoring program to 10 stations will allow more accurate assessments of long-term change than the previous monitoring. Also, the additional nutrient and phytoplankton measurements will allow comparison to previous studies and the ability to detect significant changes in ecosystem functioning. During 2007, the physical, nutrient, and plankton seasonal regimes were within the range observed during previous years.

The first quantitative assessment of benthic macroinvertebrates was conducted as planned and an optimized sampling design for long-term monitoring initiated this year. From the 96 littoral and 31 sub-littoral samples collected in 2007, ten different invertebrate taxa were found, of which only 4 could be considered abundant (thousands per square meter) – the midges *Cricotopus* (*sylvestris* group) *ornatus* and *Tanypus grodhausi*, the damselfly *Enallagma clausum*, and an unidentified oligochaete worm.

Hydroacoustic fish surveys were conducted during October & November 2007 and in April 2008. The widespread occurrence of gas bubbles, other non-fish targets, extensive macrophyte beds, and low fish densities complicated the analysis. Individual target tracking coupled with reduced survey speeds in April 2008 allowed differentiation between gas bubbles and small tui chub age classes. A reduction in macrophytes, other non-fish targets, and gas bubbles during late winter and early spring recommends this time period for hydroacoustic fish surveys. A rough population estimate of 3.2 million tui chub was derived from the results of a single nighttime survey in April, but given the low target density approximately 4 nights should be surveyed to establish reasonable confidence intervals for this estimate. The new survey design will be fully implemented in spring 2009.

A hydroacoustic survey of macrophytes was conducted 27-28 August 2007 at the time of peak macrophyte development. Twenty-eight transects were conducted perpendicular to the shore from offshore (> 8 m) to nearshore waters (<1 m) at ~2-km intervals around the entire shoreline. Reliable measures of %cover and height have not yet been achieved using the automated processing by EcoSAV software. Further testing is being conducted this year and if satisfactory results are not forthcoming, we will derive simpler measures of macrophyte distribution from the raw echograms. Several activities

to assess the replicability of hydroacoustic macrophyte surveys are planned for August and September 2008.

Acknowledgments

The expanded limnological monitoring component of this project was conducted cooperatively with the Nevada Department of Wildlife (NDOW) and we thank Patrick Sollberger and Karie Wright (NDOW) for providing logistical support and assistance in the field. Sandra Roll, Scott Roberts, Matt Wilson, Eric Huber, Bruce Medhurst, Brian Cashore, and Kimberly Rose all assisted both in the field and with sample processing in the laboratory. Samples were processed and analyzed at the Sierra Nevada Aquatic Research Laboratory, University of California. We also thank Stephanie Byers for her review and comment.

Chapter 1
Introduction

Background

Lahontan cutthroat trout (LCT), *Oncorhynchus clarki henshawi*, occupy remnant streams and lakes throughout the Lahontan Basin and were abundant in Walker Lake during the 19th century (McQuivey 1998). The lake's self-sustaining native population was eliminated by the construction of several dams. Currently, a hatchery-based recreational LCT fishery is maintained in Walker Lake at salinities near the upper tolerance limit for this species. LCT is listed as a threatened species under the Endangered Species Act of 1973 and the Walker River Basin and Walker Lake are integral to the proposed U. S. Fish and Wildlife Service's species recovery plans. The immediate threat of high and increasing salinity to the hatchery-based recreational fishery is well-established. Less well-known are indirect effects of salinity on Walker Lake LCT mediated through changes in the abundance of their prey items.

Adult LCT are piscivorous and the previously abundant tui chub (*Siphateles bicolor pectinifer*) were considered important to LCT's high productivity in Walker Lake. LCT are opportunistic feeders and their diet includes tui chub, zooplankton, and benthic macroinvertebrates. All of these prey types are directly affected by changing salinity and hydrological regimes in Walker Lake.

Other lakewide responses to changing salinity may also impact food web and LCT productivity. Extensive macrophyte beds occur in the littoral region of Walker Lake providing refuge for larval and young tui chub and habitat for benthic macroinvertebrates. Changing salinity is likely to alter the macrophyte composition, density, and distribution. Thus, understanding the responses of macrophytes and the seasonal pattern of thermal stratification to changing salinity and hydrological regimes may also important to interpreting LCT prey abundance and productivity.

As part of the activities of the Walker Lake Fishery Improvement Program (WLFIP) task agreement 84240-7-J007 between U. S. Fish and Wildlife Service (USFWS) and Drs. Robert Jellison & David B. Herbst (UCSB) issued under Californian CESU and USFWS Agreement 81332-5-G004 to assess responses of Lahontan cutthroat trout prey items to changing hydrological regimes and salinity in Walker Lake, Nevada.

Goal & objectives of first year, 2007-2008

The goal of this study is to assess responses of tui chub, benthic macroinvertebrates, and zooplankton to changing salinity and hydrological regimes over a 5-yr period. Specific objectives of the 1st year were:

A) to implement an expanded limnological monitoring program with a primary focus on zooplankton dynamics in cooperation with members of the Walker Lake Fishery

Improvement Team (Service, Nevada Department of Wildlife, Walker River Paiute Tribe),

B) to conduct the first quantitative assessment of benthic macroinvertebrates in Walker Lake and implement an appropriate and efficient long-term monitoring program,

C) to conduct an extensive hydroacoustic survey of the tui chub population allowing estimates of both population size and inter-annual variability in recruitment, and

D) to map the current distribution of macrophytes.

This report describes the progress, results, and proposed modifications to specific tasks conducted during the first year of this study under each of these four objectives; expanded limnological monitoring (Chapter 2), benthic macroinvertebrate assessment (Chapter 3), tui chub hydroacoustic assessment (Chapter 4), and macrophyte mapping and monitoring (Chapter 5).

References

McQuivey, Robert. 1998. "Nevada Habitat and Fisheries Historical Media File," a compilation of historic reference for fish from the Walker River basin as extracted from old newspapers. Carson City, NV: Nevada Division of Wildlife.

Beutel, M. W., A. J. Horne, J. C. Roth, and N. J. Barratt. 2001. Limnological effects of anthropogenic desiccation of a large, saline lake, Walker Lake, Nevada. Hydrobiologia 466:91-105.

Chapter 2
Expanded zooplankton and limnological monitoring

Introduction

The Walker Lake zooplankton community was sampled seasonally during 1975-1977 (Cooper and Koch 1984) and during 1992-1996 (Horne et al. 1994, Beutel and Horne 1997, Beutel et al. 2001). In the mid-1970s, the macrozooplankton consisted of three species, *Leptodiaptomus sicilis*, *Moina hutchinsoni*, and *Acanthocyclops vernalis*. The copepod, *L. sicilis* (formerly called *Diaptomus sicilis*) dominated throughout most of the year, ranging in abundance from 30 to 120/liter and the cladoceran, *M. hutchinsoni*, was co-dominant in the late summer, reaching abundances of 65-85/liter in September of 1975 and 1976. Another copepod, *A. vernalis* (formerly *Cyclops vernalis*) was also present in very low numbers (<3 liter^{-1}) through much of the year. In the mid-1990s study, *L. sicilis* and *M. hutchinsoni* were still numerically abundant but *A. vernalis* was absent. Also, the rotifer *Hexarthra fennica* was seasonally abundant with peaks of 200-500/ liter in late summer in 1995 and 1996 and a second rotifer, *Branchionus plicatilis* was present in low numbers.

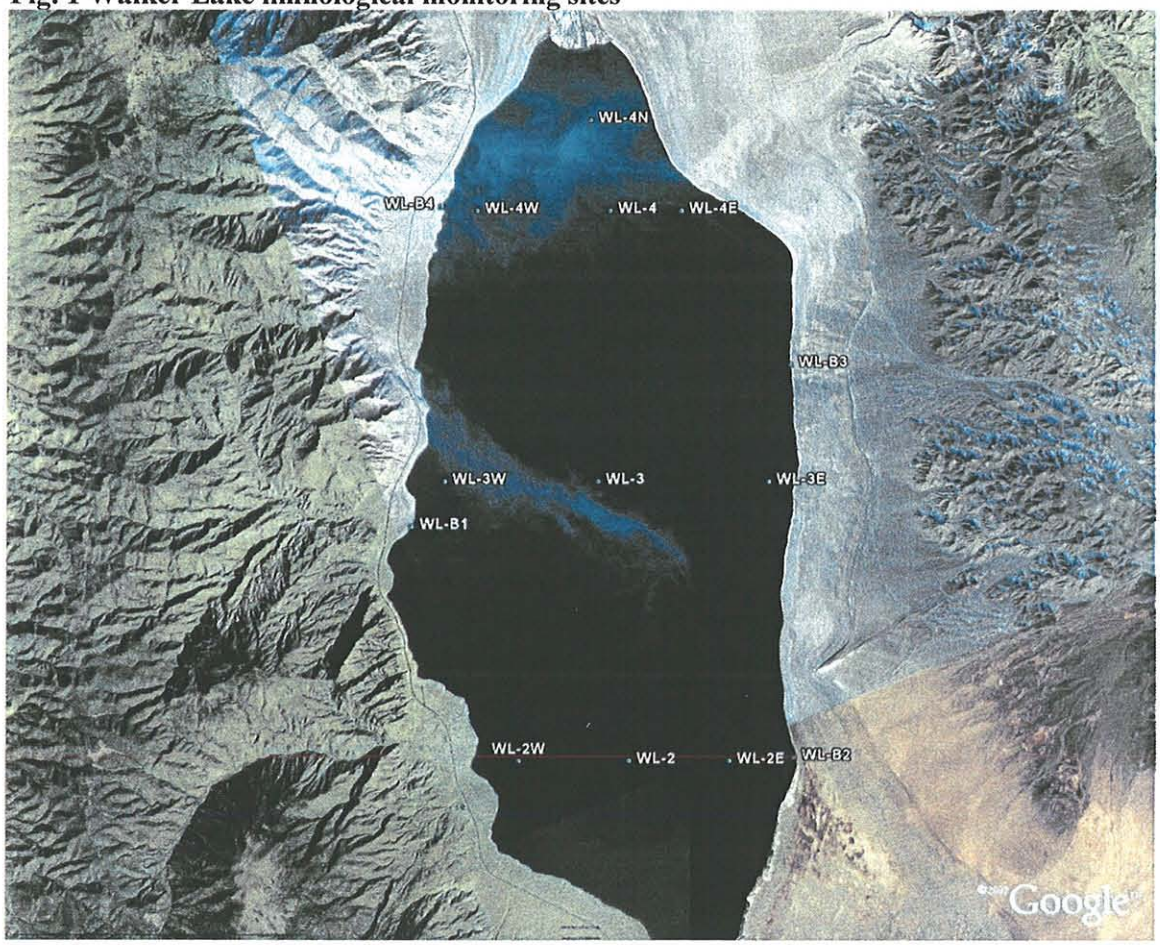
Beginning in 2002, NDOW has regularly monitored general limnological conditions and zooplankton abundance. NDOW routinely collects 1-m resolution vertical profiles of temperature, conductivity, dissolved oxygen and pH at 3 stations (WL2-4) oriented along the north-south axis of the lake. Transparency (Secchi depth), which is largely a function of phytoplankton biomass, and zooplankton abundance are also determined at these stations. While during past years, surveys were conducted 3-4 times per year, beginning in 2006 monthly surveys were conducted during most of the year. Also, water samples are collected from three depths at 2-3 stations for determination of salinity based on measurements of major ions on a quarterly basis.

The NDOW zooplankton monitoring was sufficient for documenting large changes in species abundance but not intensive enough to document modest trends. The relative standard errors associated with lakewide abundance of the three dominant zooplankton species (*M. hutchinsonia, L. sicilis, H. jenkinae*) based on three stations ranges from 3-72 % (mean, 24 %) based on 12 surveys conducted between 8 July 2004 and 31 August 2006. As part of this study, the number of stations was increased from three to ten (Fig. 1). This provides a better coverage of the entire lake and is expected to result in relative standard errors of 10-15 %. It will likely enable detection of a 25 % change in mean abundance of any of the three dominant species with 90 % certainty.

We also initiated the collection of temperature-conductivity profiles with a high-precision conductivity-temperature-depth (CTD) profiling instrument (Seabird Seacat 19) at all 10 stations to accurately characterize seasonal and spatial patterns of thermal and salinity stratification. In addition, water samples for nutrient, chlorophyll, and particulate analysis were collected from a variety of depths and stations (see Methods) to monitor seasonal, inter-year, and long-term variation in the nutrient and phytoplankton regimes. In temperate lakes, these regimes can vary substantially over a wide range of scales from

days to years and meters to kilometers. Knowledge of the variation in the physical, nutrient, and phytoplankton regimes is instrumental to interpreting changes in higher trophic levels (i.e. zooplankton and fish) and are a critical part of any long term monitoring program.

Fig. 1 Walker Lake limnological monitoring sites



Methods

Sampling Regime

The expanded limnological monitoring program at Walker Lake includes data collection at 10 stations during ten monthly surveys (February – October, December). The three NDEP/NDOW stations (Stations 2, 3, and 4) oriented along the N-S central axis of the lake were retained for consistency with past monitoring. Station 4N was added intermediate between Station 4 and the mouth of the Walker River to better quantify gradients arising from freshwater riverine inflows. Three additional pelagic stations were added along both the western and eastern shores at the same latitudes as Stations 2, 3, and 4 to provide a measure of east-west differences and patchiness; and to provide a better estimate of lakewide zooplankton abundance.

Water temperature and conductivity were measured at all ten stations with a high-precision, conductivity-temperature-depth profiler (CTD) (Seabird Electronics model Seacat 19). The CTD was deployed by lowering it at a rate of ~0.25 m s-1. The variation of conductivity with temperature in carbonate waters like Walker Lake differs slightly from those derived for fresh or marine waters. Specific conductivity (25°C) was calculated with a more precise temperature correction for Walker Lake water:

$$Cnd_{25} = \frac{Cnd_t}{(1 + 0.020647 \times (t - 25) + 0.000079297 \times (t - 25)^2}$$

where t is the in situ temperature. The relationship between total dissolved solids and conductivity for Walker Lake water derived from NDOW determinations is

$$TDS = 0.8466 \times Cnd_{25} - 1{,}470.4, \qquad \text{(from Tracy 2004)}$$

Samples for the determination of ammonia, nitrate, and chlorophyll concentrations are collected from 2 m depth at all 10 stations to provide lakewide epilimnetic estimates, from 2 and 14 m depth at Stations 2, 3, and 4 to assess any longitudinal metalimnetic variation due to inflows, and at 4-m depth intervals at the central deep Station 3 for examining the variation in the full vertical profile.

Chlorophyll samples were immediately filtered through a 120 μm net to remove zooplankton while nutrient samples were immediately filtered through Gelman GFF glass-fiber filters to remove both phytoplankton and zooplankton. All samples are kept cool and in the dark until later processing the same day at Sierra Nevada Aquatic Research Laboratory near Mammoth Lakes, CA.

Water samples

Upon return to the laboratory samples were immediately processed for ammonium and chlorophyll determinations. After ammonium concentrations were measured, soluble reactive phosphorus corrected for arsenic were measured the following day and the remaining sample was frozen for nitrate determination within 2 months of collection. Chlorophyll samples were filtered onto 47 mm Whatman GF/F filters and kept frozen until the pigments were analyzed within two weeks of collection. Particulate phosphorus (PP), particulate carbon (PC) and particulate nitrogen (PN) samples from station 3 - 2m were filtered, dried at 50°C for 48 h in a Fisher Scientific Isotemp oven and stored in a desiccator.

Chlorophyll a was extracted and homogenized in 90% acetone at room temperature in the dark. Following clarification by centrifugation, fluorescence of extracted pigments was measured on a fluorometer (Turner Designs, model TD-700) which was calibrated using a fluorometer solid standard and an acetone blank. The sample was then acidified in the cuvette, and fluorescence was again determined to correct for phaeopigments. Values were converted to phaeophytin-corrected chlorophyll a concentrations with the formulae of Golterman (1969).

Ammonium concentrations were measured using the indophenol-blue method (Strickland and Parsons 1972). Internal standards were prepared with Walker Lake water from 2 m depth at Station 3. Nitrate was measured using cadmium reduction followed by azo dye colorimetric (Strickland and Parsons, 1972; Wetzel and Likens, 1991; Joye, M. personal communication). A variation in which treated Cd is placed directly in the sample tubes and shaken for 4 hrs was employed in the reduction step. Particulate phosphorous was measured using the oxidation/phosphomolybdate method of Valderrama (1981). Particulate organic carbon (PC) and nitrogen (PN) filters were sent to the University of California Santa Barbara, Marine Science Institute Analytical Laboratory and analyzed on the automated organic elemental analyzer (Model CEC440HA) using the Dumas combustion method. Soluble reactive phosphorus (SRP) was determined by the ammonium molybdate method ((Strickland and Parsons 1972) as modified by Johnson (1971) to correct for arsenic interference.

Results and Discussion

NDOW personnel are responsible for continuing the basic limnological monitoring at the three central stations (Stations 2, 3, 4) including temperature, conductivity, and oxygen profiles; and collection, identification, and enumeration of zooplankton samples at all 10 ten stations. These data are summarized in NDOW's annual report to the WLFIP under a separate cooperative agreement (No. 84240-6-J).

Surface elevation, temperature, and conductivity

Sierran snowfall was well below normal during winter 2006-07 and snow water equivalent of Walker Basin snow pack was only 41% of normal on 1 April 2007. Below normal runoff resulted in a 1.0 m drop in surface elevation during the course of the year to 3933.99 ft on 15 December 2007, very near the historic low of 3933.6 ft observed in December 2005 (Fig. 2). This large decrease in surface elevation is significantly larger than during most years and many aspects of the plankton dynamics may differ from more "normal" years. Low runoff will affect the seasonal pattern of temperature and salinity stratification and north-south spatial gradients are also expected to be reduced.

During the 1st survey of the year conducted on 7 March 2007 seasonal stratification was already present with near surface water temperatures of 6–7 °C at all stations (Fig. 3). Upper waters in the southern portion of the lake was slightly warmer and the northern slightly cooler. The upper thermocline was shallowest at the northern stations where minor salinity stratification was present due to Walker River inflows (Fig. 4). The hypolimnion was 4.4–4.6 °C. By 25 April 2007, the lake had warmed significantly with near surface temperatures 11–13 °C and hypolimnetic temperatures of 9–10 °C (Fig. 5). Slightly less saline waters were still present at the northern stations (Fig. 6). The 13 June profiles show complex patterns resulting from various episodes of wind-driven mixing (Fig. 7). Multiple weak thermoclines were present and water temperatures varied by as much as 2-3 °C for a given depth among the different stations. The conductivities were fairly uniform among stations with the exception of a marked region of higher conductivity of unknown origin at station 2W (Fig. 8). The late summer 21 August profiles show a well-mixed epilimnion, sharp thermocline extending from 13

to 8 m (Fig. 9). Evaporative concentration of the epilimnion is clearly evident with more saline warm water overlying less saline cooler water (Fig. 10). The early December survey clearly shows the lake "turned over" in November and average conductivity was 21.44 mS cm^{-1} for a calculated salinity of ~16.7 g l^{-1} (Fig. 11-12).

The overall pattern of seasonal thermal stratification in 2007 (Fig. 13) was typical for Walker Lake and within the ranges observed in previous studies. All of the surveys are not shown here. The profiles shown were chosen to illustrate basic and interesting features of the seasonal dynamics. For purposes of long-term monitoring and interpretation of year-to-year variation in plankton dynamics it is important to be able to inspect differences among years. We intend to use 3-5 years of data to establish typical conditions and then present data not only as in Fig. 13 but as the difference between a given year and a multiyear mean.

A wide variety of data collected at different spatial and temporal scales is being collected as part of this monitoring program. We are modifying a relational database developed for Mono Lake data for purposes of storing and providing all the data collected as part of this study. Not only will this database serve as an archive for all the data, it will also facilitate querying and assembling data for various types of analyses.

Fig. 2 Walker Lake surface elevation, 2005-2006

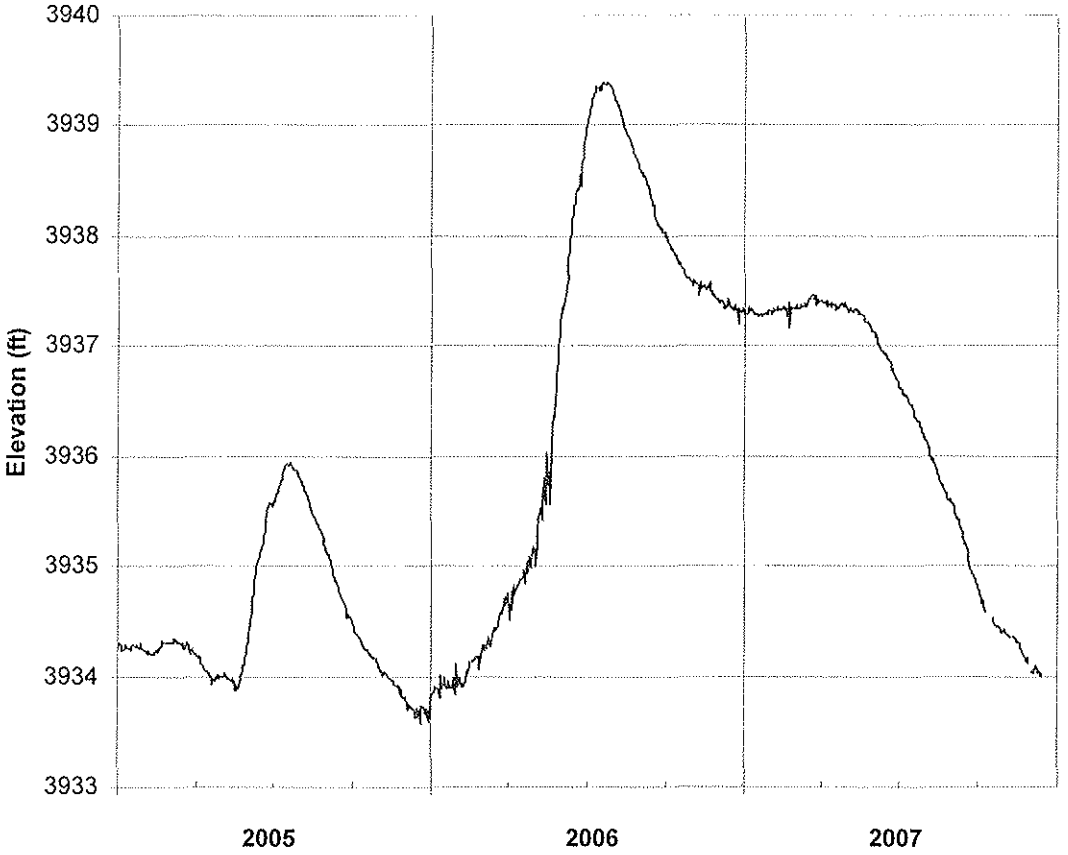


Fig. 3 Water temperatures during 7 March 2007 survey (During the March survey stations were taken intermediate to Stations 2, 3, and 4. These are labeled 2.5 and 3.5. They were dropped from subsequent surveys).

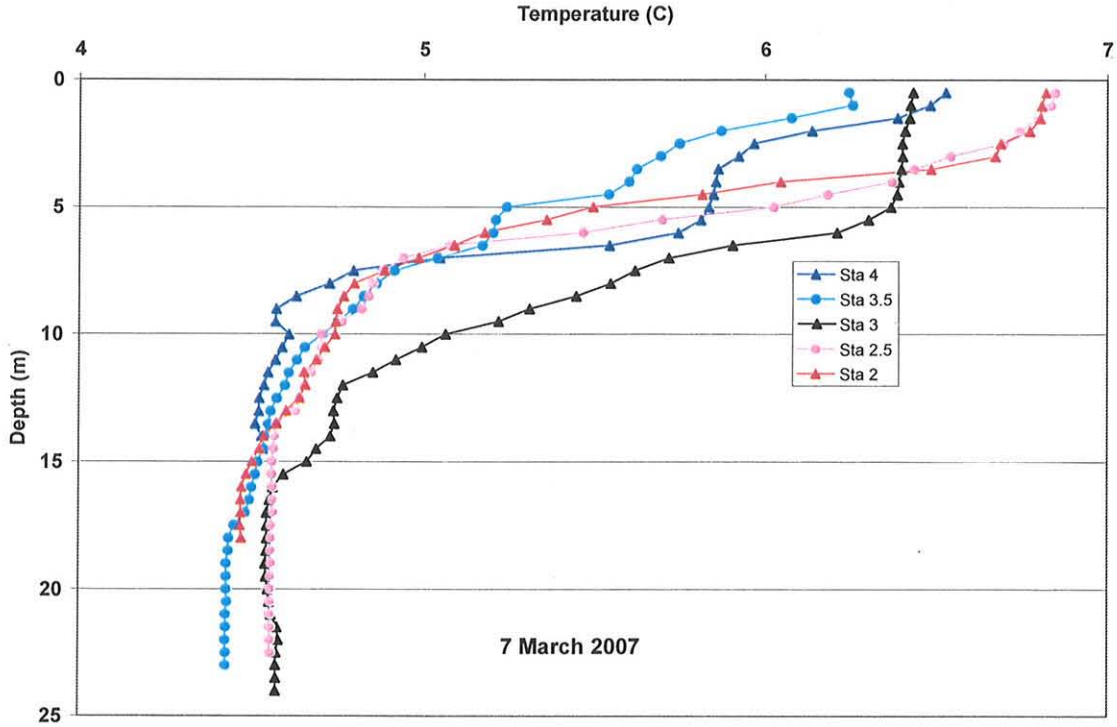


Fig. 4. Specific conductivity during 7 March 2007 survey

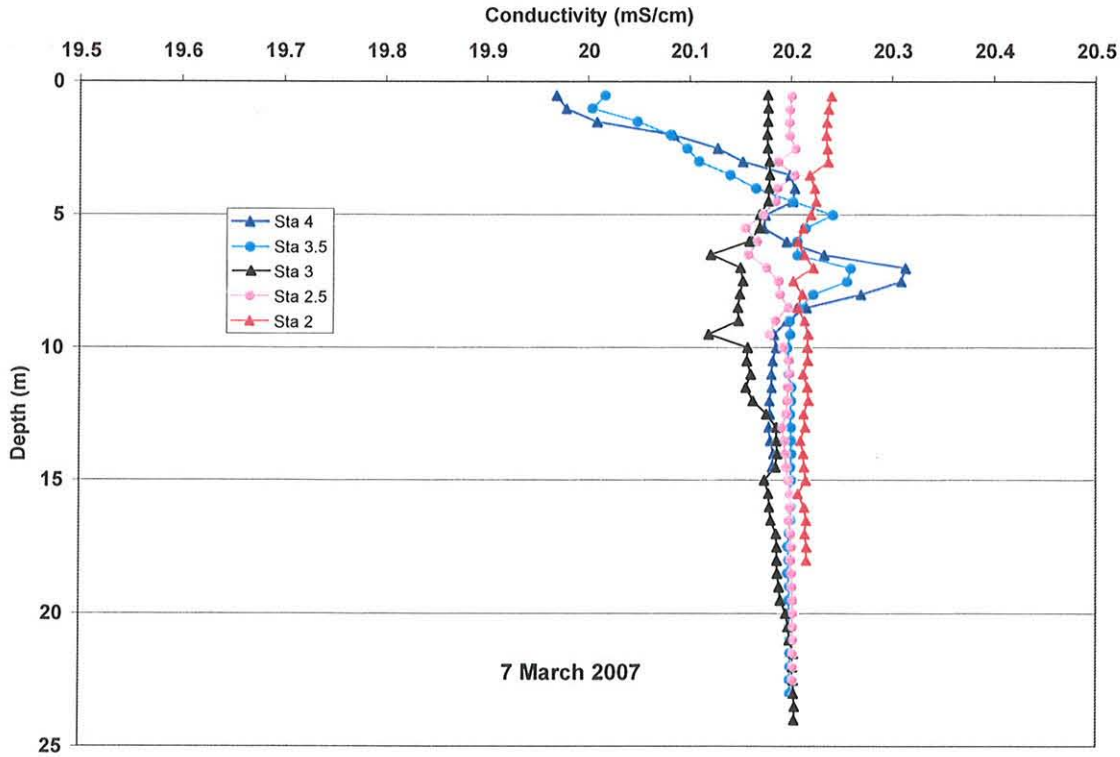


Fig. 5. Water temperatures during 25 April 2007 survey

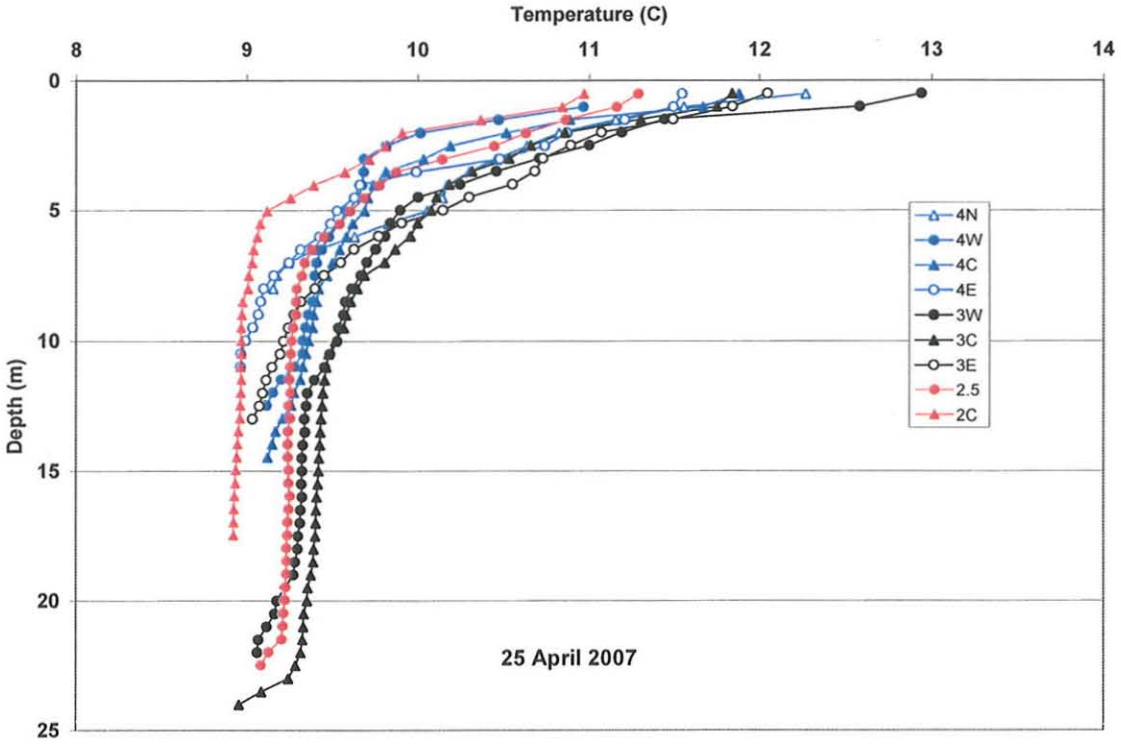


Fig. 6. Specific conductivity during 25 April 2007 survey

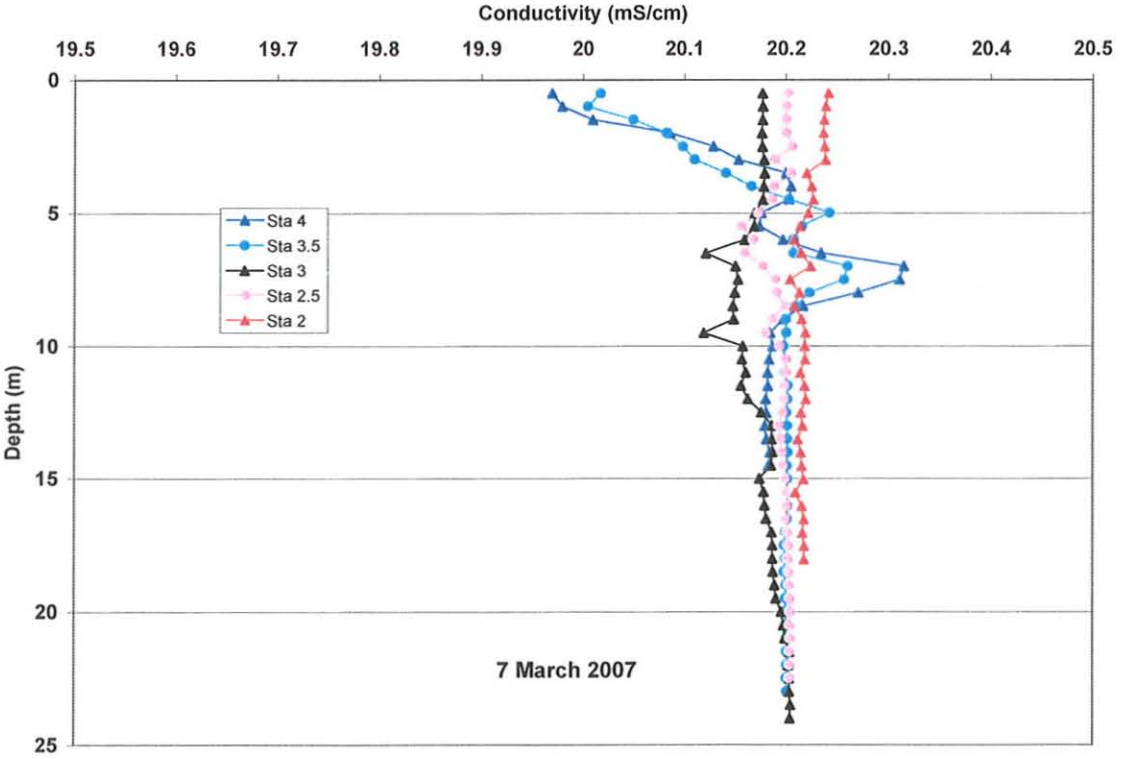


Fig. 7 Water temperatures during 13 June 2007 survey

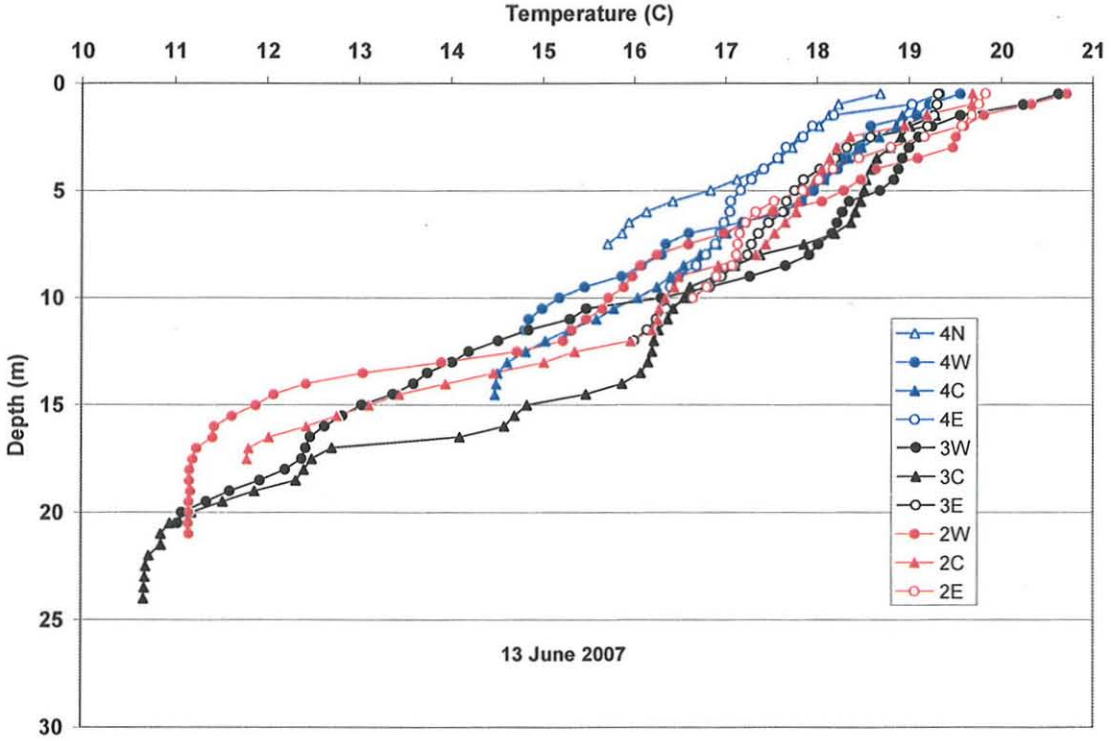


Fig. 8 Specific conductivity during 13 June 2007 survey

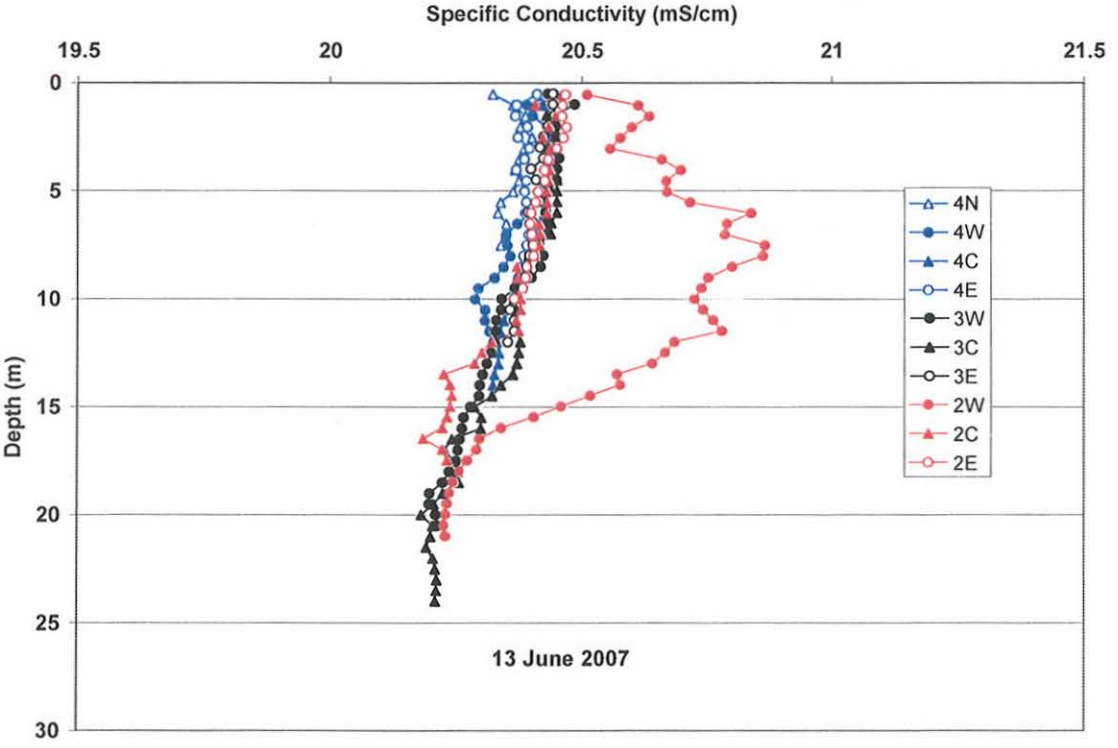


Fig. 9 Water temperatures during 21 August 2007 survey

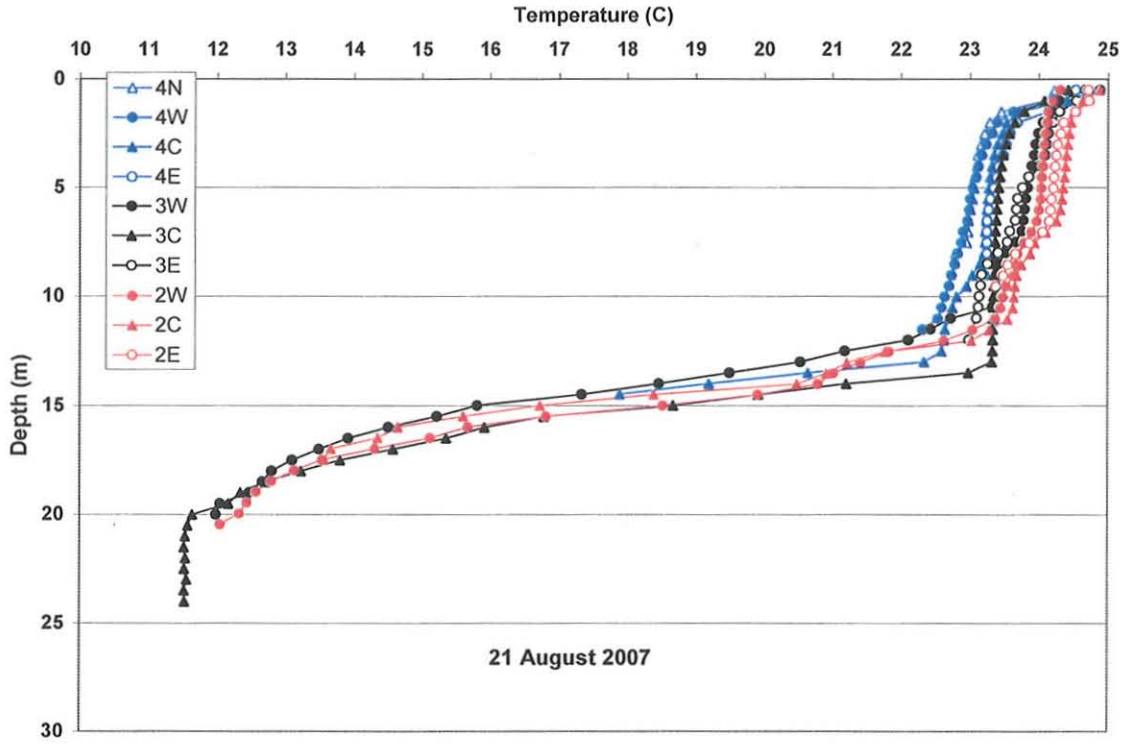


Fig. 10 Specific conductivity during 21 August 2007 survey

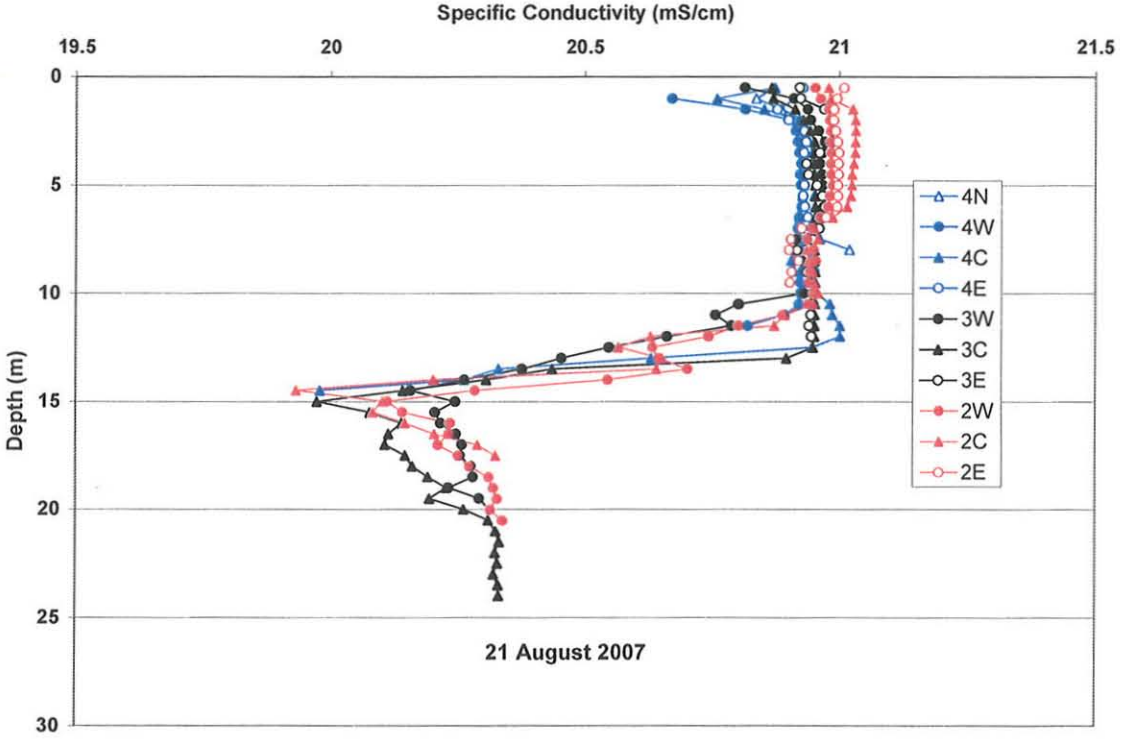


Fig. 11 Water temperatures during 4 December 2007 survey

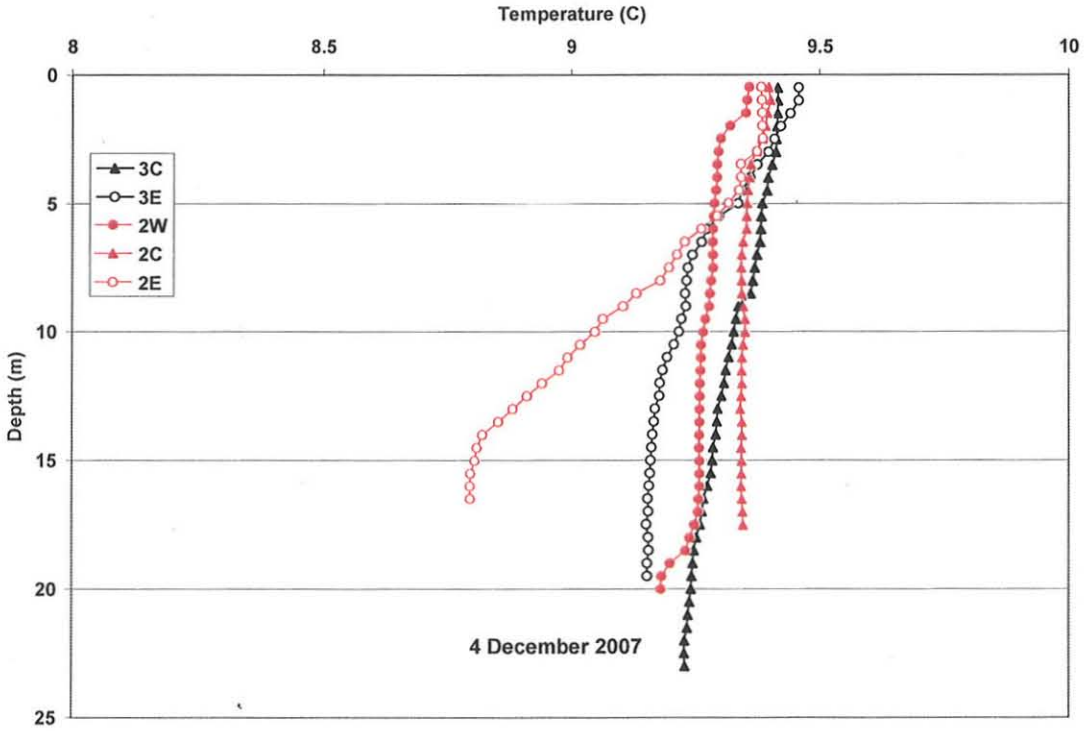


Fig. 12 Specific conductivity during 4 December 2007 survey

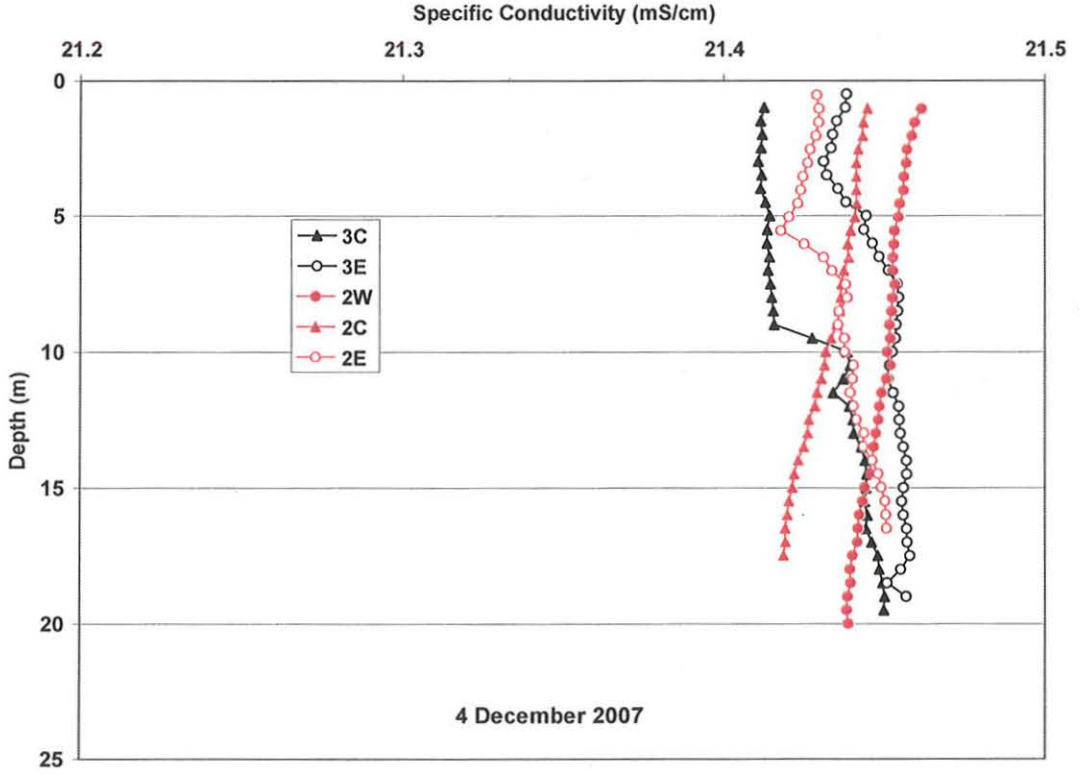
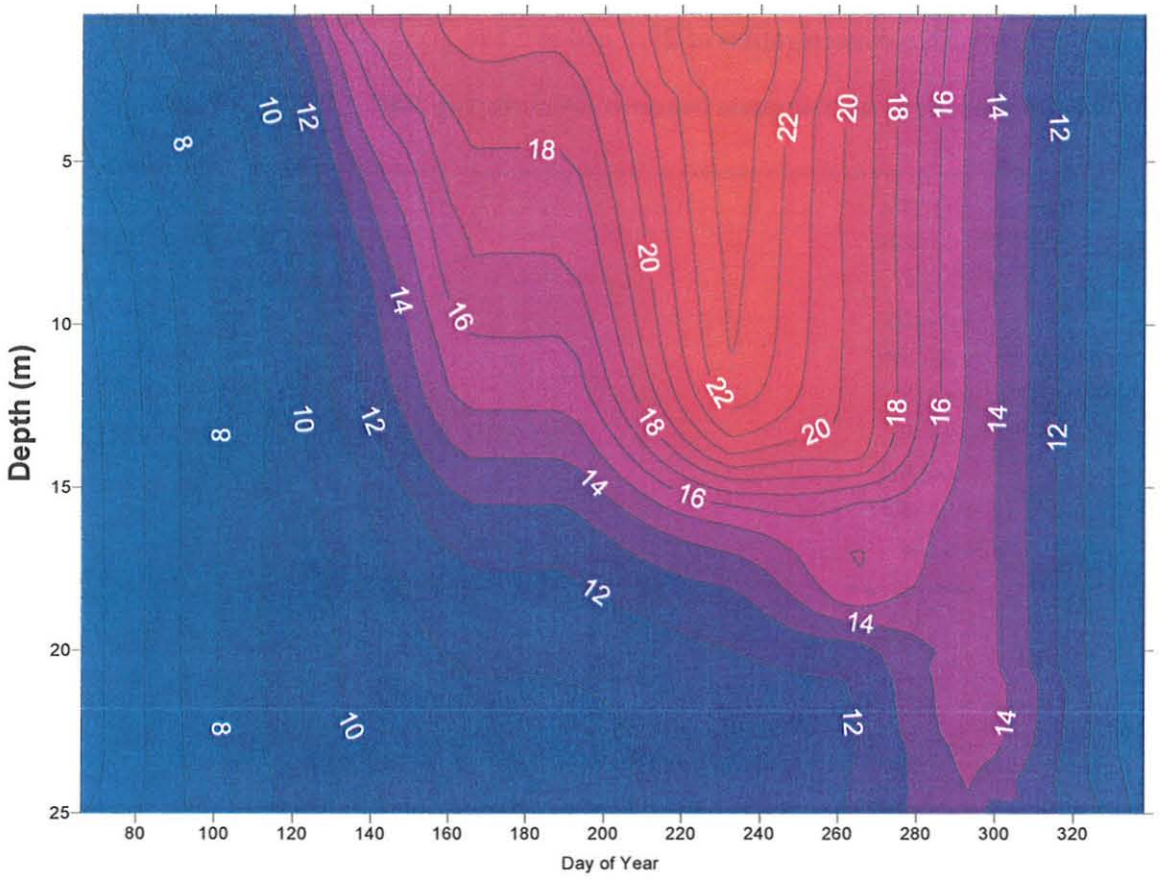


Fig. 13 Seasonal Walker Lake water temperatures during 2007



Nutrients, chlorophyll, and seston ratios

In contrast to most temperate freshwater lakes where phosphorus usually limits overall productivity, nitrogen is often the limiting nutrient in saline lakes. In Walker Lake, soluble reactive phosphorus is generally high and nitrogen is certainly the most limiting macronutrient for primary production. Nitrate and ammonium are almost in equal supply during much of the year in Walker Lake and both forms of inorganic nitrogen were measured.

Ammonia/ammonium

Both hydrated and unhydrated forms of ammonia are present at Walker Lake's high pH and we do not explicitly differentiate between the two in this analysis. The analytical method employed measures total analytical ammonia (ammonia+ammonium) and we use the term "ammonia" to designate the sum of both forms throughout this text.

Epilimnetic ammonium concentrations (2 m depth samples) remained low (≤1 μM) from March through August (Fig. 14) except for somewhat high values at Station 3 during May & June (1.27 and 2.07 μM, respectively). Mean values rose to 1.03±0.16 μM in September and further to 2.47±0.11 μM in October before declining to <1 μM in December. At 14 m depth, the mean concentration ranged from a low of 0.09 ± .11 μM in

December to a high of 3.06 ± .64 μM (Fig. 15). The depth profiles at the central Station 3 are nearly uniform during March, April and December due to vertical mixing (Fig. 16). A slight increase is seen below 20 m starting in May and further increase to a maximum in September with a concentration of 23.1 μM at 22 m.

Fig. 14 Epilimnetic (2 m) ammonia concentrations during 2007

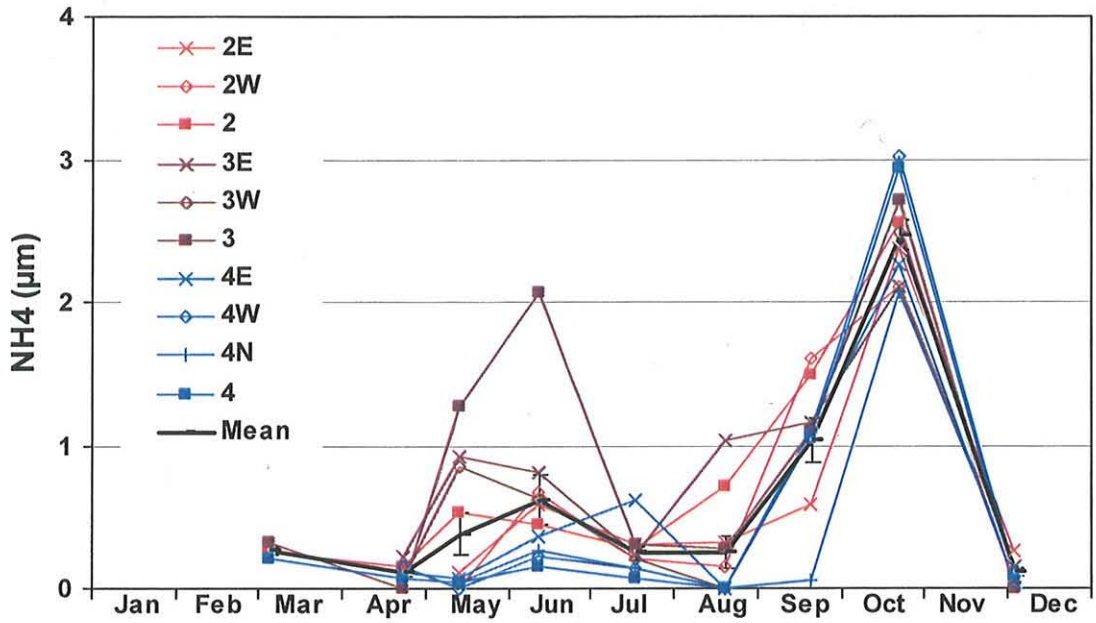


Fig. 15 Ammonia concentrations at 14 m depth during 2007

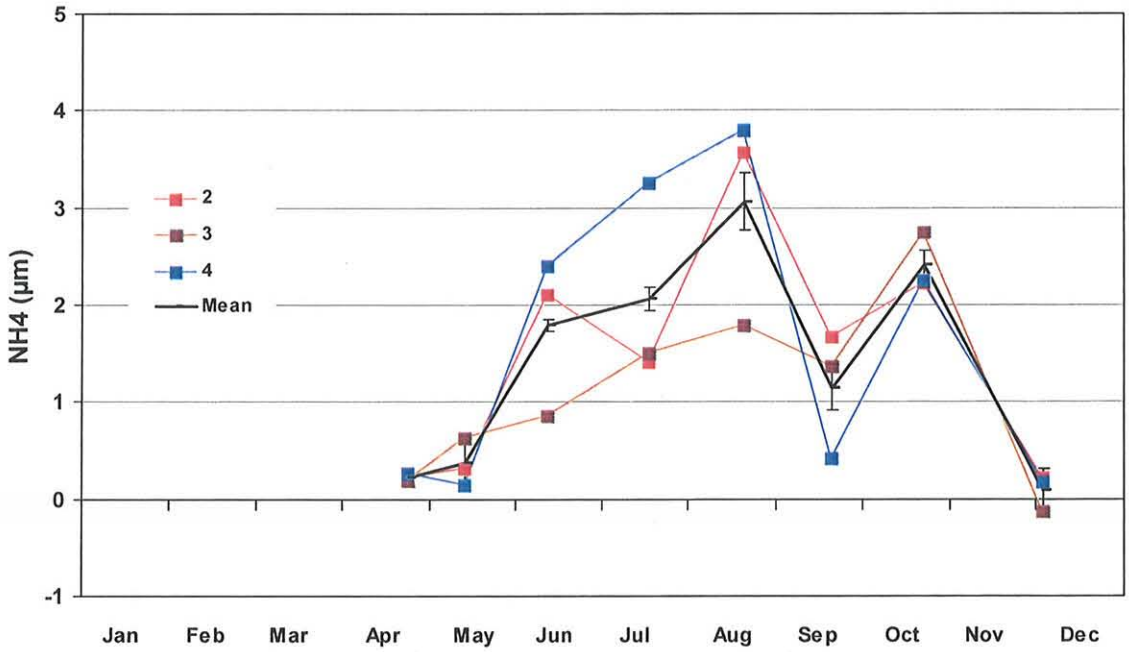
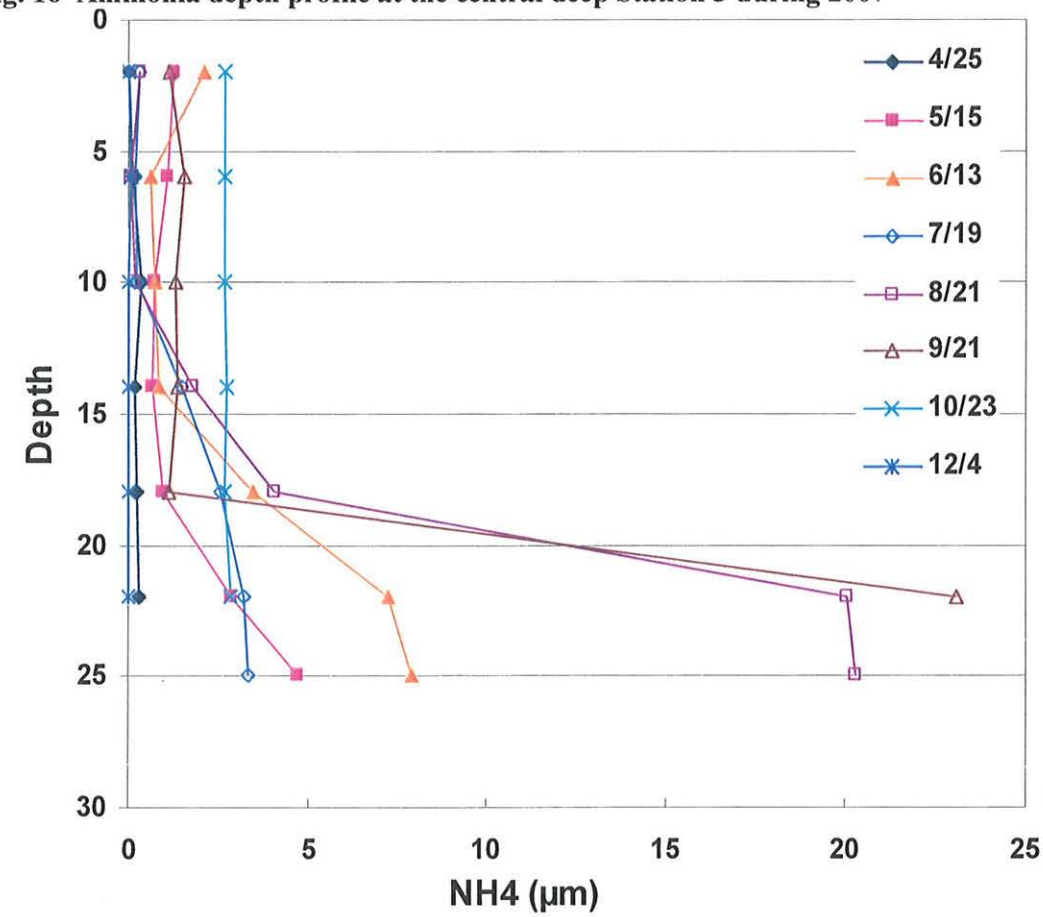


Fig. 16 Ammonia depth profile at the central deep Station 3 during 2007



Nitrate

Nitrate concentrations were already <1 µM in April when they were first measured and remained low through August (Fig. 17). Nitrate concentration increased to 1.01 ± .04 µM in September and reached a maximum mean value of 2.51 ± .02 µM in December. The concentrations at 14 m followed a similar pattern to ammonia with station 4 showing higher values than the other stations during June, July and August (Fig. 18). Nitrate concentrations were reduced to ~1.0 µM by September but then increased to 2.5 µM by December nutrient-rich waters from the hypolimnion were mixed throughout the water column. The profiles at station 3 once again indicate a mixed water column with slightly elevated values at 22 and 25 m in July (Fig. 19). The several higher values in July and August are unusually high but we have no reason to discard them. It is possible especially at the deeper sample at 22 and 25 m during July that samples were contaminated by being collected too close to the sediment.

Fig. 17 Epilimnetic (2 m) nitrate concentrations during 2007

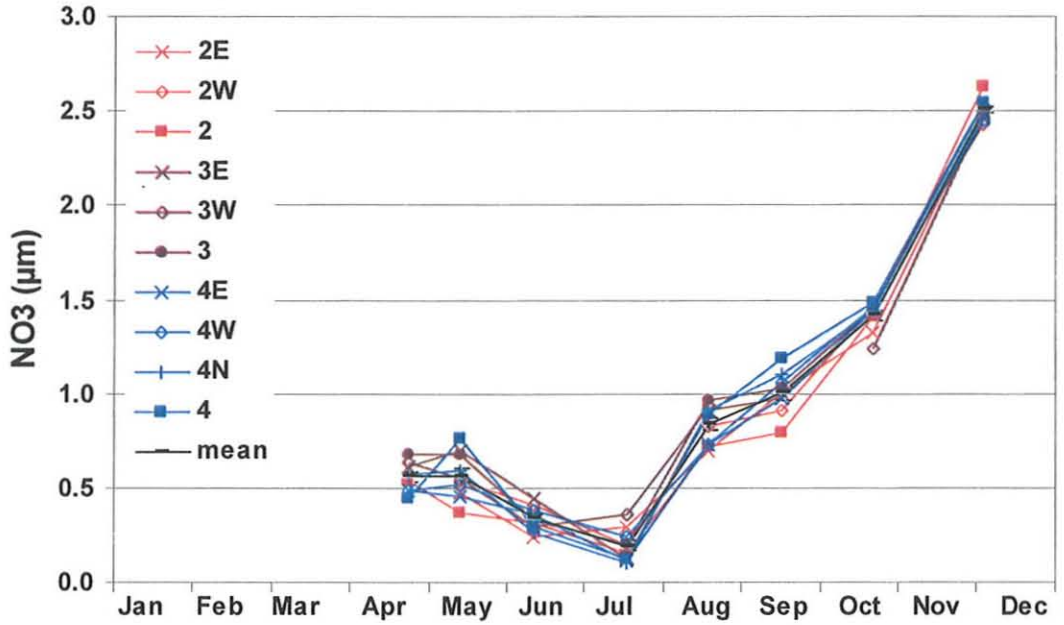


Fig. 18 Nitrate concentrations at 14 m depth during 2007

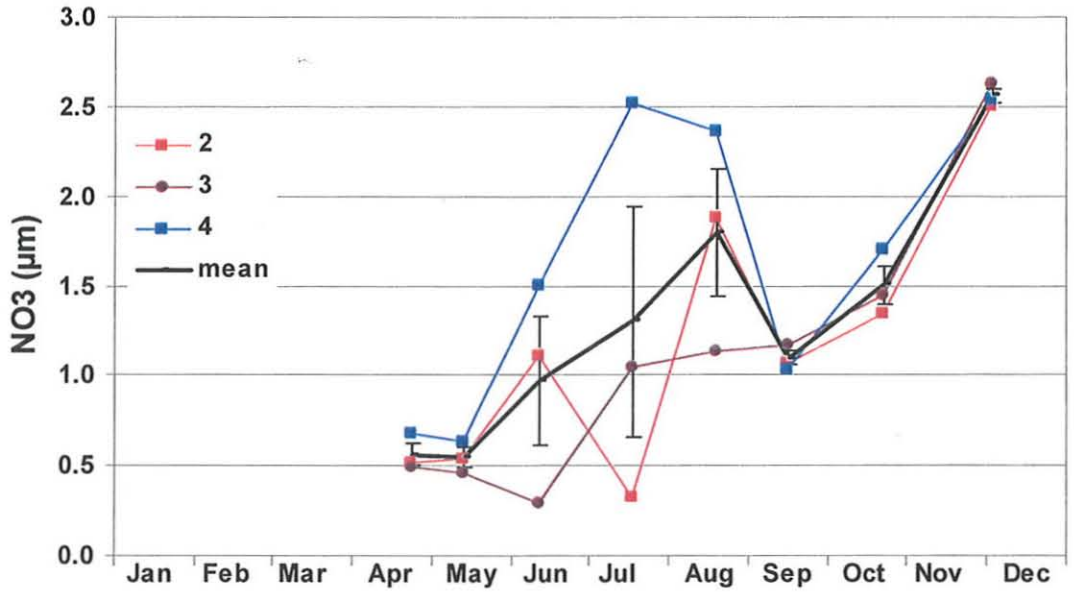
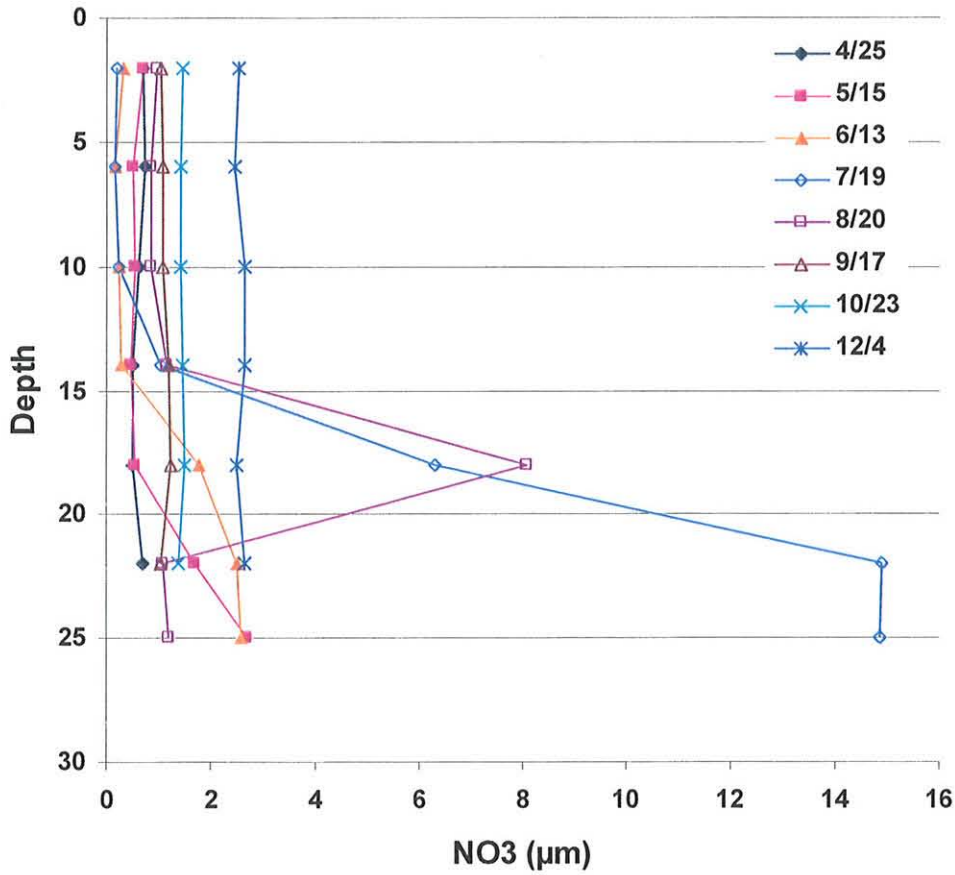


Fig. 19 Nitrate depth profile at the central deep Station 3 during 2007



Chlorophyll *a*

The phytoplankton community, as characterized by chlorophyll *a* concentration, is fairly low (~1 mg m^{-3}) during the summer when zooplankton grazing is high and shows only a modest bloom during spring and autumn. At 2 m depth the mean values ranged from a high in April of 2.85 ± .08 mg m^{-3} to a low value of 0.80 ± .04 mg m^{-3} in August (Fig. 20). At 14m the ranged increased to 3.45 ± .06 mg m^{-3} in April to 0.92 ± .29 mg m^{-3} in August (Fig. 21). Profiles indicate chlorophyll was fairly uniform throughout the water column except for deep mid-depth maxima at 18 m in May and 14 m in June (Fig. 22). These chlorophyll concentrations are within the range of those reported in past Walker Lake studies.

Fig. 20 Epilimnetic (2 m) chlorophyll *a* concentrations during 2007

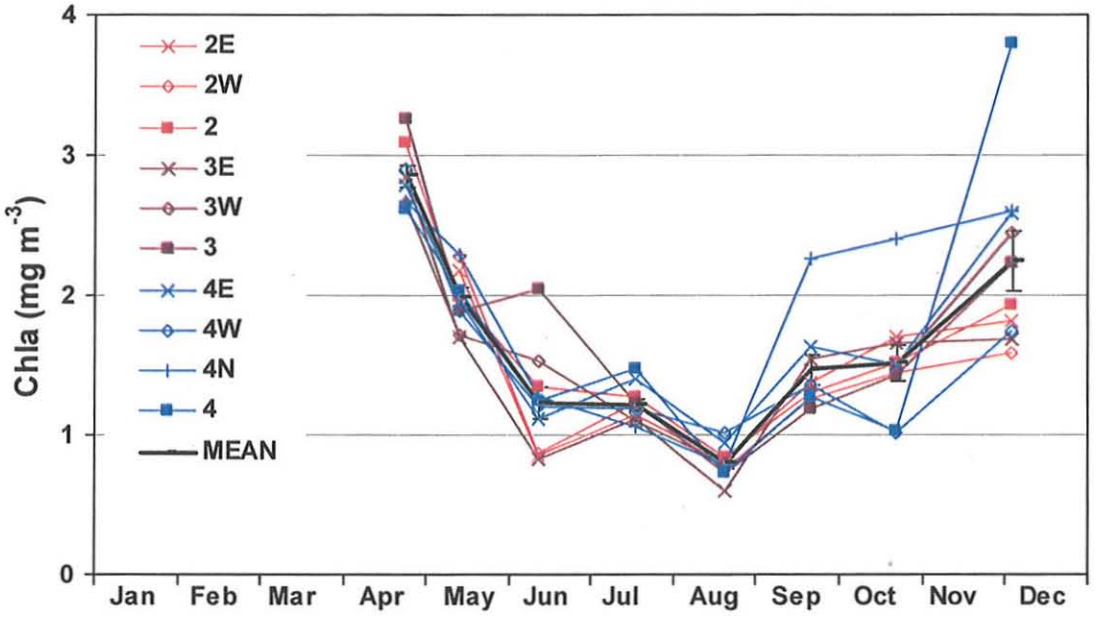


Fig. 21 Chlorophyll *a* concentrations at 14 m depth during 2007

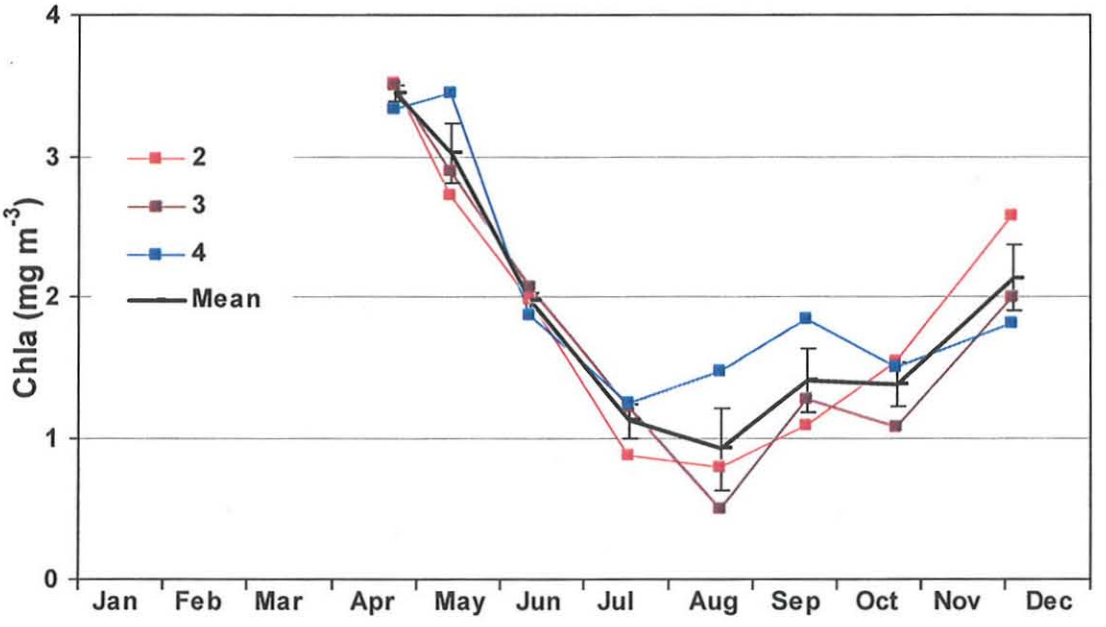
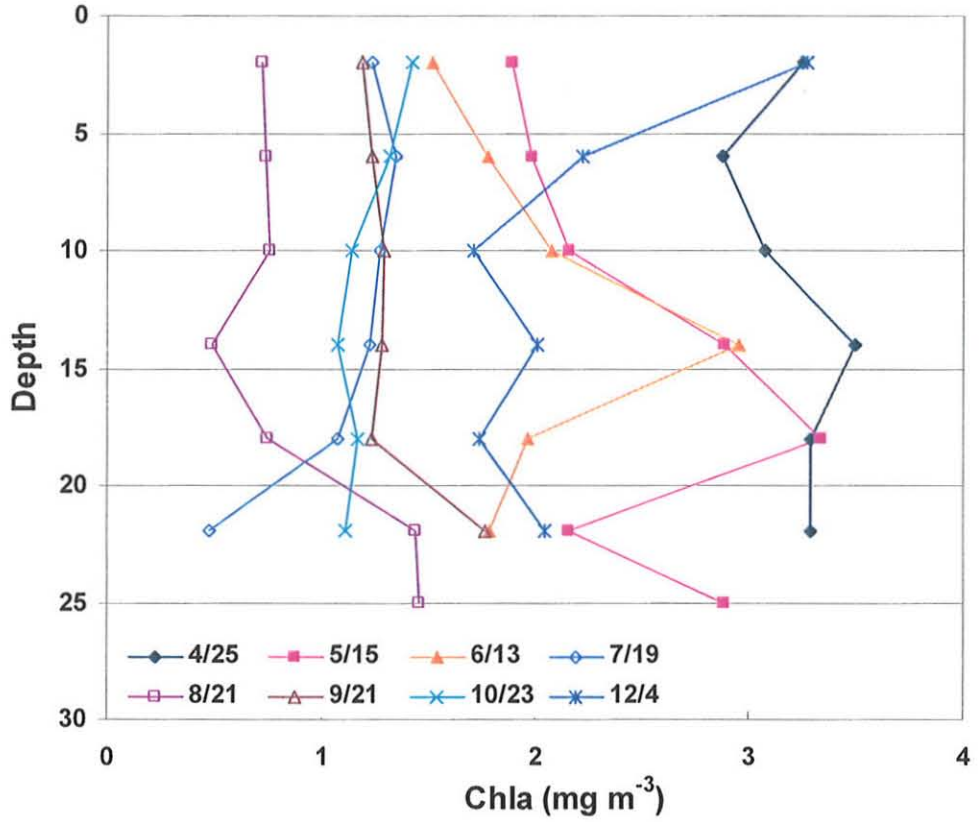


Fig. 22 Chlorophyll *a* depth profile at the central deep Station 3 during 2007



Sestonic ratios of organic carbon, nitrogen, and phosphorus

Sestonic ratios of particulate organic carbon, nitrogen, and phosphorus can provide an indication of seasonal and year-to-year changes in the degree of nutrient limitation by nitrogen or phosphorus. In Mono Lake they provided a useful index of changing nutrient stress associated with the onset and breakdown of meromixis over a 10 yr period (Jellison 2001). During growth under nutrient-replete conditions, sestonic ratios tend to be near the Redfield CNP ratio (106:16:1). N:P ratios well above 16 indicate phosphorus limitation while those well below 16 can indicate nitrogen limitation. However, interference from bacteria, detritus, and other sources can complicate the interpretation and ratios should be considered indices of change to be used in conjunction with other data.

The epilimnetic (2 m) C:N ratios in Walker Lake increased from 4.5 in March to 6.5 during the summer before decreasing to 5 on the December survey (Fig. 23). The epilimnetic (2 m) N:P ratios decreased from ~19 early in the year to 7-10 during summer/autumn and then to 35 on the December survey (Fig. 24). The low N:P ratios in summer are indicative of nitrogen limitation. While the C:N summer ratios are not strongly indicative of stress, their seasonal pattern in conjunction with the N:P ratios mutually support each other in suggesting nitrogen limitation in summer.

Fig. 23 C:N molar ratios of seston (particulate organic material) in the euphotic zone (2 m depth) at Station 3 during 2007

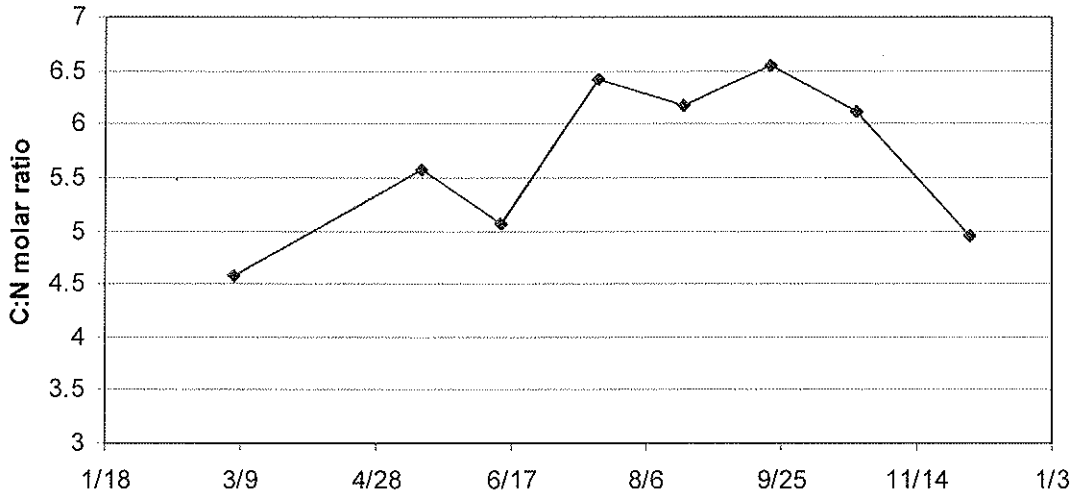
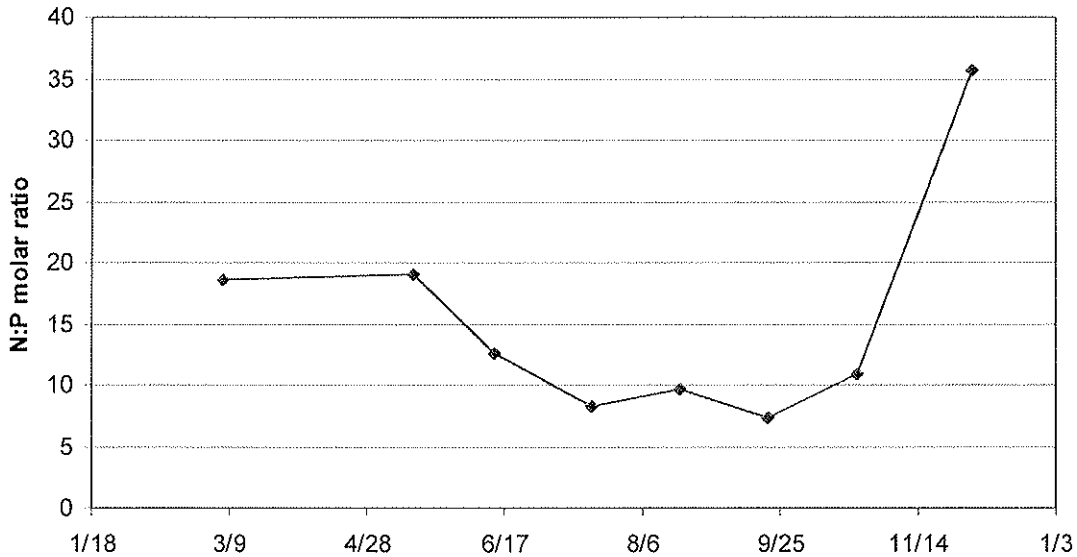


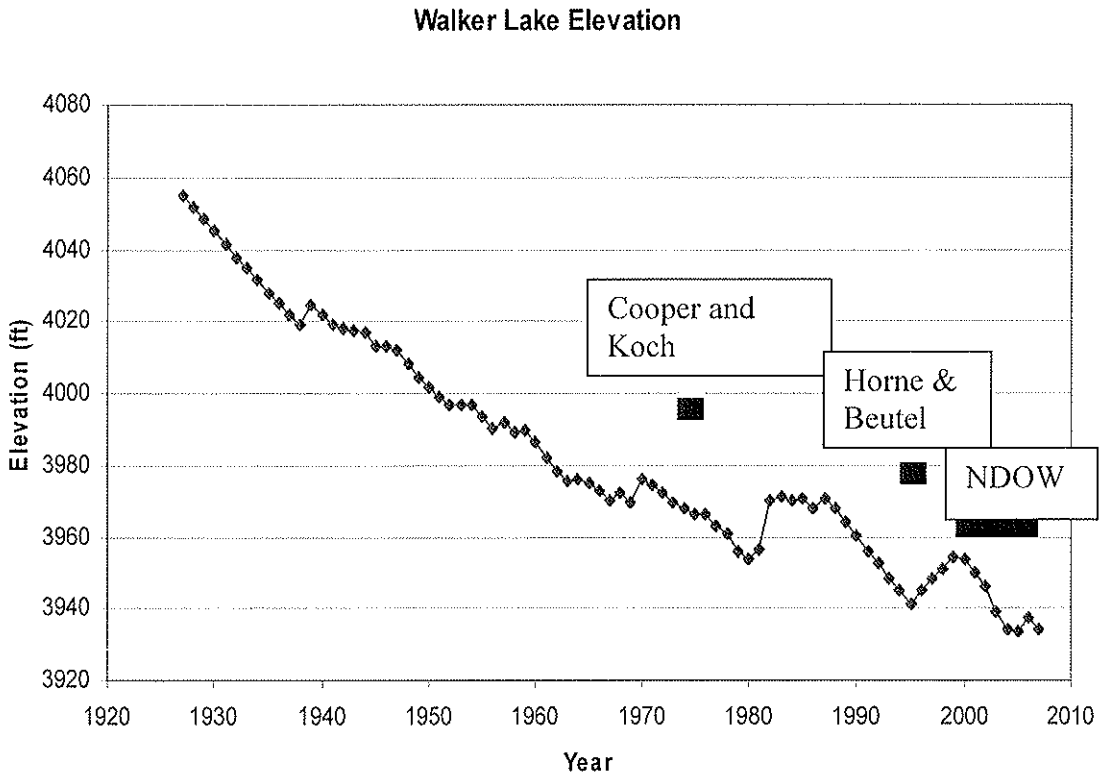
Fig. 24 N:P molar ratios of seston (particulate organic material) in the euphotic zone (2 m depth) at Station 3 during 2007



Conclusion

The physical, nutrient, and phytoplankton seasonal regimes during 2007 were similar to those observed in previous studies. This monitoring program conducted here will be valuable for detecting long-term trends that may affect higher trophic levels and ultimately the productivity of the LCT. Multi-year seasonal data were collected during two periods of somewhat lower salinity; 1975-1977 (Cooper and Cook 1984), 1992-1996 (Beutel et al. 2001), and more recently, 1999-present (NDOW) (Fig. 25). A detailed comparison to these previous studies is not warranted with this single year of data during an exceptionally low runoff year. However, we plan to conduct as detailed of a

comparison as possible after several years of data are collected. This will include the zooplankton data currently being collected by NDOW.



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Chapter 3
Walker Lake Benthic Macroinvertebrates

Introduction

Previous information on the littoral and benthic flora and fauna in Walker Lake documented abundant *Ruppia* growth in the littoral zone around much of the lake between 3 and 6 m depth (Horne et al. 1994) providing habitat for damselfly larvae, chironomids, and presumably other benthic invertebrates. Horne et al. (1994) also note the occurrence of an abundant *aufwuchs* (filamentous algae) community growing on *Ruppia*. Sevon (1988) reports *Hyalella azteca* as the only amphipod observed in the benthos and found that anchors set in 40 ft of water were colonized by them. He also notes the presence of damselflies, *Enallagma*, and midges of the genera, *Chironomus* and *Pelopia*. The relative contribution of the littoral region to overall lake primary and secondary productivity is not known. NDOW recently collected benthic samples and notes that *H. azteca* has disappeared (P. Solberger pers. comm.). The studies reported here provide a quantitative set of littoral (shallow, < 1 meter) and sub-littoral samples (depths from 2 to 16 meters), from early and late summer (June and September), and stratified by substrate types (sand, gravel-pebble, cobble, and algae-*Ruppia* beds). These data establish baseline conditions for monitoring further changes in the environment of Walker Lake. The benthic fauna are critical components of the food web supporting the population of LCT in Walker Lake. These surveys of the distribution and abundance of benthic invertebrates provide background on the availability of benthic food resources.

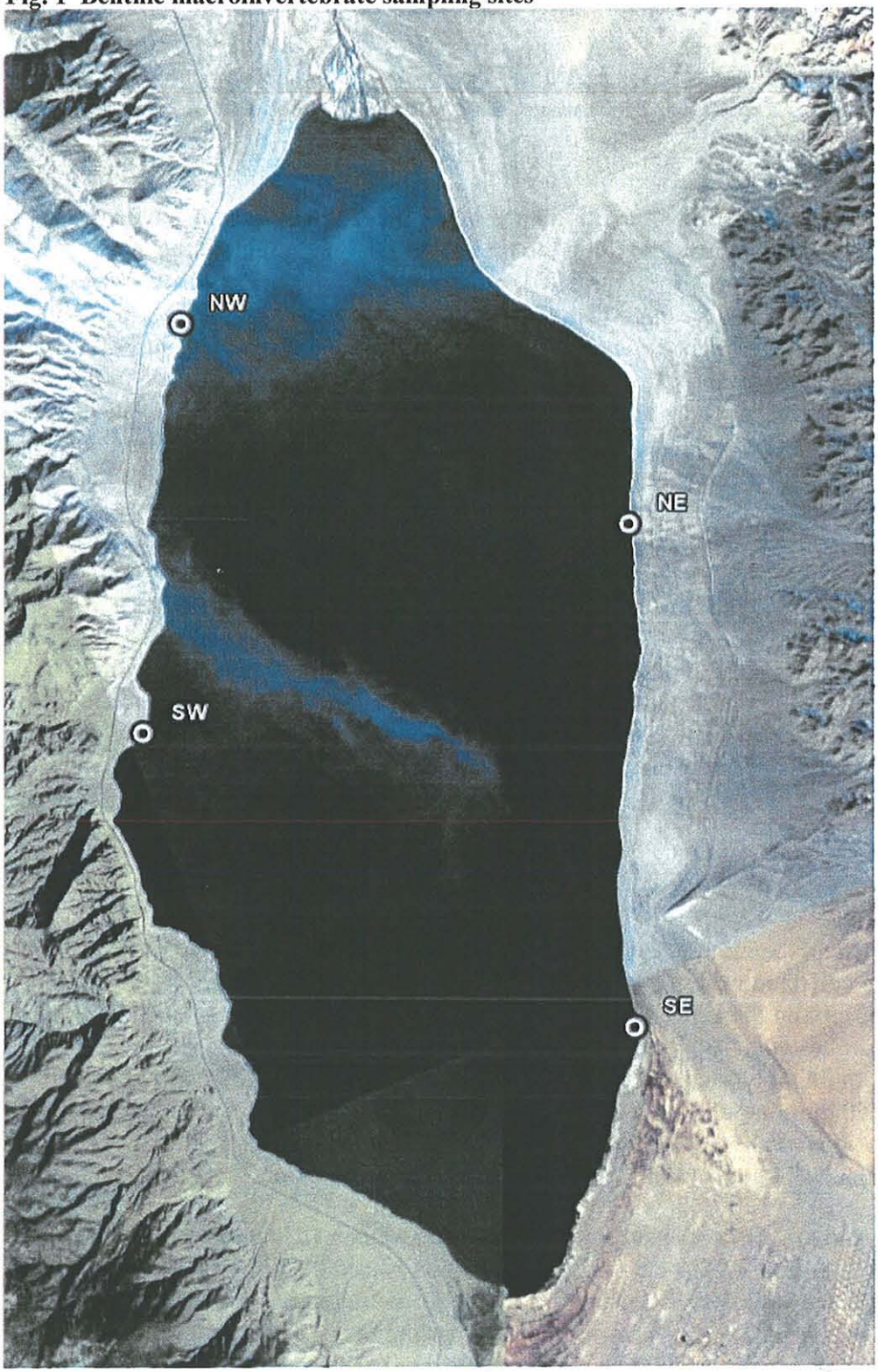
Methods

Littoral sampling

During early summer (16 and 28 June), and late summer (18 September) of 2007, samples were collected from the shallow littoral zone in less than 1 meter water depth at four locations around the lake (1 SW, 2 SE, 3 NE, and 4 NW; Fig. 1). At each location, different substrates were sought to obtain 12 substrate-specific stratified samples. We identified 4 dominant types: sand (<2 mm), gravel mixed with pebble (2-65 mm range), cobble (65-250 mm range), and beds of filamentous algae usually mixed with the macrophyte *Ruppia maritima* (often entwined, but sometimes found separately). Depth of collection as well as substrate type was recorded for each sample.

Sand and gravel-pebble substrates were sampled using a bucket from which the bottom had been removed (20 cm diameter), that was placed over the sample area, and pushed into the substrate. Surface substrate materials including invertebrates were then removed with repeated sweeps of a fine-mesh aquarium net (100 micron) over and through the stirred substrates. These repeated sweeps were placed in a bucket of clean water and with further stirring, the lighter fraction containing invertebrates was poured through the fine mesh net and the collected material then preserved in 90% ethanol. Rose Bengal stain was also added to enhance contrast for later sample sorting in the laboratory.

Fig. 1 Benthic macroinvertebrate sampling sites



Cobble substrates were sampled individually by transfer of whole rocks into a fine-mesh aquarium net held underwater and brought quickly to the surface so no

invertebrates could escape. All material washed from the rock surface was then transferred as above into a fine mesh collecting net and preserved. Cobble dimensions were recorded as length (L, longest axis), width (W, max perpendicular axis), height (H, z-axis to length and width), and circumference (C, longest perimeter in xy plane). These were used to calculate surface area as (LW+LH+WH)x(C/(L+W)), and used to compute density per area of associated invertebrates.

Beds of filamentous algae and *Ruppia* were sampled using a 4x5 cm fine mesh aquarium net. Clusters were selected, and with the net held underwater, the algae and/or *Ruppia* was detached at the substrate surface and the net used to capture the entire cluster by sweeping upward through the water column. This material was then placed in a bucket and carefully sorted in shallow white pans to separate and remove most of the algae-plant material before preservation of the remnant invertebrates. All algae-plant material removed was squeeze-dried (water wrung-out by hand) to remove adherent water, and wet-weighed with a Pesola scale. Density of the associated invertebrates can be expressed then in several ways, as numbers per area of the net (125 cm^2), per wet weight of algae-vegetation (grams), or volume of water sampled (in liters - as the volume the net passed through as sampled from the bottom attachment depth to the height reached by the algae-*Ruppia* cluster above the bottom).

Sample Stations:

1. SW - Sportman's Beach, 250 m north of launch [38°41'26"N & 118°45'56.7"W]
2. SE – Below E. road at access rd through dunes [38°38'42.5"N & 118°40'06.6"W]
3. NE – Below E. road at RR sign "Army 11" [38°43'21"N & 118°40'10.3"W]
4. NW - 20 Mile Beach campground [38°45'12.6"N & 118°45'30.05"W

[SW, NE & NW have mixed substrates while SE is predominantly sand]

Sub-littoral sampling

Sampling at depths below 1 meter, defined here as sub-littoral, were taken from a boat using an Ekman dredge (15 x 15 cm opening). At transects from shore toward the central lake basin, samples were taken at westshore and eastshore locations (see map) at depths of 2, 4, 6, 8, 10, 12, 14 and 16 meters on 16-17 June, and 24 October 2007. Sample processing consisted of placing each dredge sample in a bucket of clean water, stirring and pouring off the light organic fraction through a fine-mesh aquarium net. Most of the invertebrates were present in this fraction and these were then stored in collection jars in 90% ethanol. The heavier inorganic substrate fraction remaining in the bucket was then inspected in shallow white pans until all invertebrates were picked out and also placed in the collection jar.

Laboratory processing of samples

Samples were either sorted in their entirety, removing and identifying each invertebrate found, or subsamples were taken using a Folsom rotating drum splitter to handle samples with high densities of large amounts of remnant organic debris. Counts of larvae and pupae were made for midges (chironomidae) present, and for larval versus

adult forms of dytiscidae (beetles) and corixidae (water boatmen). Identifications were possible to the species level in most cases.

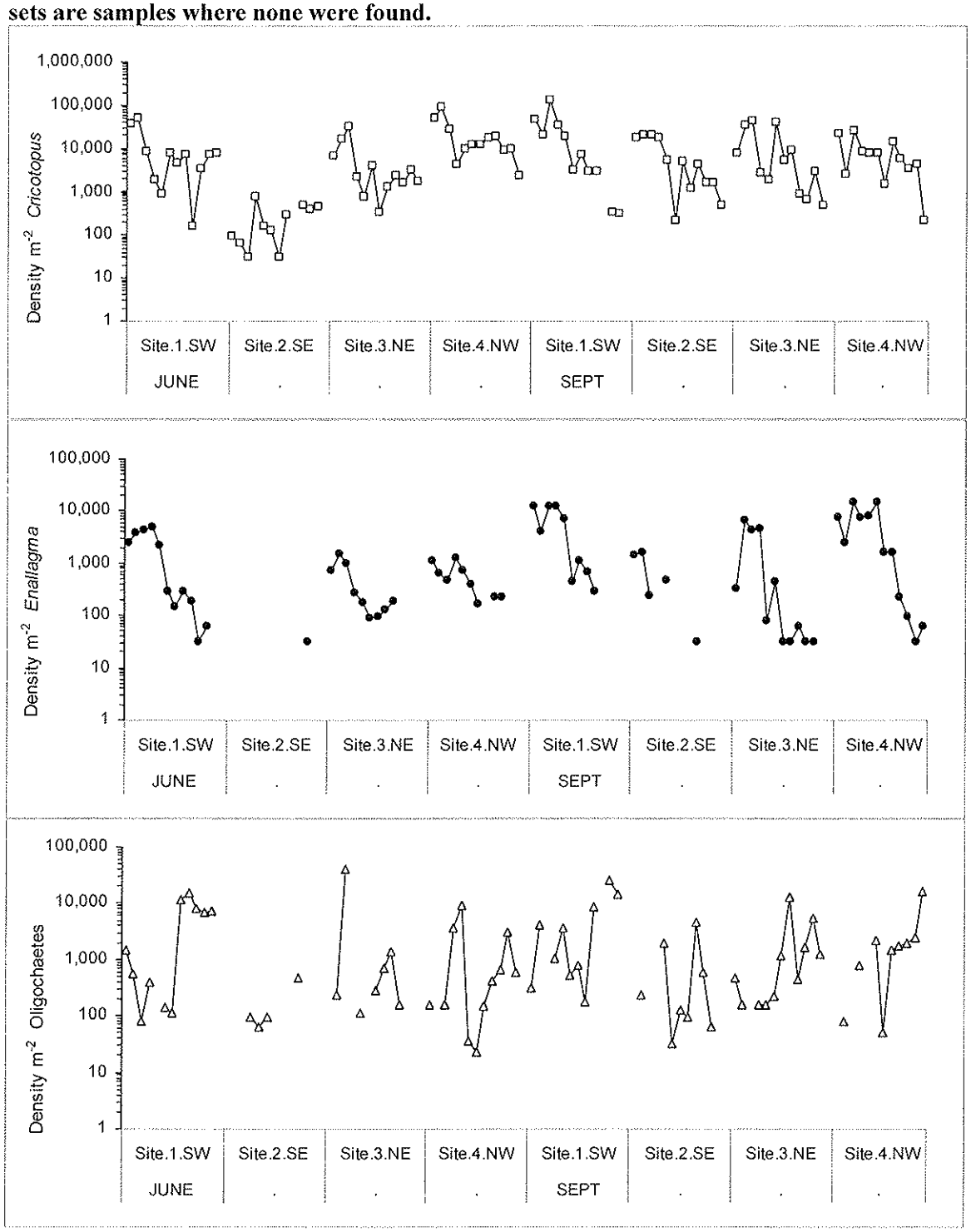
Results and Discussion

From the 96 littoral and 31 sub-littoral samples collected in 2007 we found 10 different invertebrate taxa, of which only 4 could be considered abundant (thousands per square meter) – the midges *Cricotopus* (*sylvestris* group) *ornatus* and *Tanypus grodhausi*, the damselfly *Enallagma clausum*, and an unidentified oligochaete worm. Adults and larvae of the dytiscid water beetle *Hygrotus masculinus* were fairly common at some sites (50 m^{-2} on average), but all other taxa densities averaged below 10 m^{-2} (water boatman *Corisella decolor*, the water beetle *Laccobius*, and various Diptera: *Ephydra*, *Culicoides* and *Chrysops* of unknown species as yet). While we found abundant valves of several types of ostracods, we never detected living specimens in any samples (and this was not an artifact of preservation as we have ethanol-stored samples of living ostracods from other studies). Our samples confirmed the absence of *Hyalella*, and question previous identifications of midges or indicate a change in species present. Though we found head capsules of *Chironomus* in deep sub-littoral samples (reported by Sevon 1988), no live specimens were found.

The midge *Cricotopus ornatus* was the most abundant littoral invertebrate (Fig. 2), with a mean density of about 11,500 m^{-2}, and there is a marked decline in abundance with depth in sub-littoral samples (Fig. 3). Though it has not been previously reported, it could have been missed in previous deeper water surveys. Pupae of this species become more abundant in the late summer compared to the early summer collections (Fig. 4), but adults do appear throughout the summer. This midge is known from other saline wetland environments such as the salt marshes and ponds around Owens Lake (Herbst 2001, 2003). At Walker Lake it is found primarily associated with algae-*Ruppia* substrates, but is also abundant on cobble and can be found on gravel-pebble and sand as well (Fig. 5). As pupae and emerging adults are often present in the water column, this may be when they are most vulnerable to predation, but plankton samples should be examined for their occurrence (though this may be restricted to near-shore areas where larvae are mostly found).

Tanypus could have been identified as *Pelopia* described from previous surveys (Sevon 1988) but this genus name has been discontinued and replaced after taxonomic revisions. In contrast to *Cricotopus*, *Tanypus* was abundant in deeper sub-littoral samples (mean density of about 15,000 m^{-2}) but nearly absent from the shallow littoral samples (Fig. 6). Unlike *Cricotopus*, *Tanypus* showed no clear preference for algae/vegetation cover in sub-littoral samples (Fig. 7). *Tanypus grodhausi* is known to thrive in wastewater ponds

Fig 2 Densities of common invertebrates in shallow littoral (< 1 meter depth zone) of Walker Lake organized by season of collection and site. Upper panel *Cricotopus* (*sylvestris* group) *ornatus*, middle panel *Enallagma clausum*, and lower panel oligochaetes (unidentified). Note differences in log scale densities. Within each site, substrate types were mixed but ordered in series as algae-*Ruppia*, cobble, gravel-pebble, and sand(except site 2.SE where mostly sand only was present). Gaps in connecting lines within site-date sample sets are samples where none were found.



with high levels of organic decomposition and anoxia (Grodhaus 1967), suggesting that Walker Lake sub-littoral sediments may have similar low redox habitat conditions.

The damselfly larvae of *Enallagma clausum* were the largest benthic invertebrates found and no doubt are an important food resource to fish, and as they emerge as adults and occur along the shoreline areas of the lake they may also provide food to birds. *Enallagma* was equally abundant on average in littoral and sub-littoral samples (mean densities of 1,657 and 1,574 m^{-2}, respectively) though they appeared to be most common in west shore algae-*Ruppia* (Fig. 2) and at moderate sub-littoral depths (Fig. 6). This damselfly has a distinct preference for algae and *Ruppia* vegetation in littoral samples (Fig. 5), but this seems to disappear in sub-littoral habitat (Fig. 7). If the algae and vegetation are being used as refuge from fish predation, this suggests the exposure may be more intense in shallow water than deep. This species is known from a variety of inland saline lakes and has been reported in salinities as high as 25 g/L in Soap Lake, Washington, and were shown, along with *Tanypus nubifer* to be weak osmoregulators in exposures up to about 30 g/L (Lauer 1969).

Oligochaetes were abundant in shallow littoral samples (average density over 2,400 m^{-2}) where they were most often associated with gravel-pebble substrates and sand (Figs. 2 & 5). While abundant in the sub-littoral at 2-4 meters, they declined at 6-10 meters, and were found in only a single sample deeper than this (Fig. 6). Where the worms did occur in deeper water, they were most often associated with vegetation and algae organic matter. While unidentified as yet, these worms were typically thin and small (0.5-1.0 mm width, 2-20 mm length).

Fig. 3 Depth distribution of sub-littoral *Cricotopus ornatus* larvae over both west and east Ekman sample transects by season.

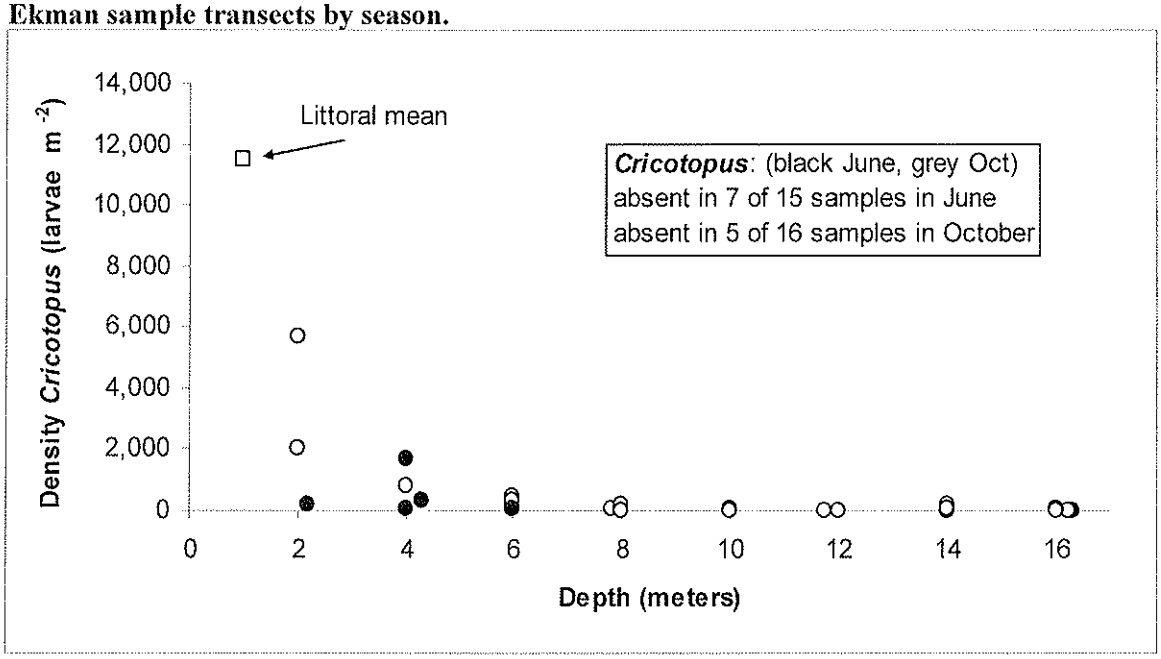


Fig. 4 Abundance of *Cricotopus ornatus* pupae by season and site in littoral samples

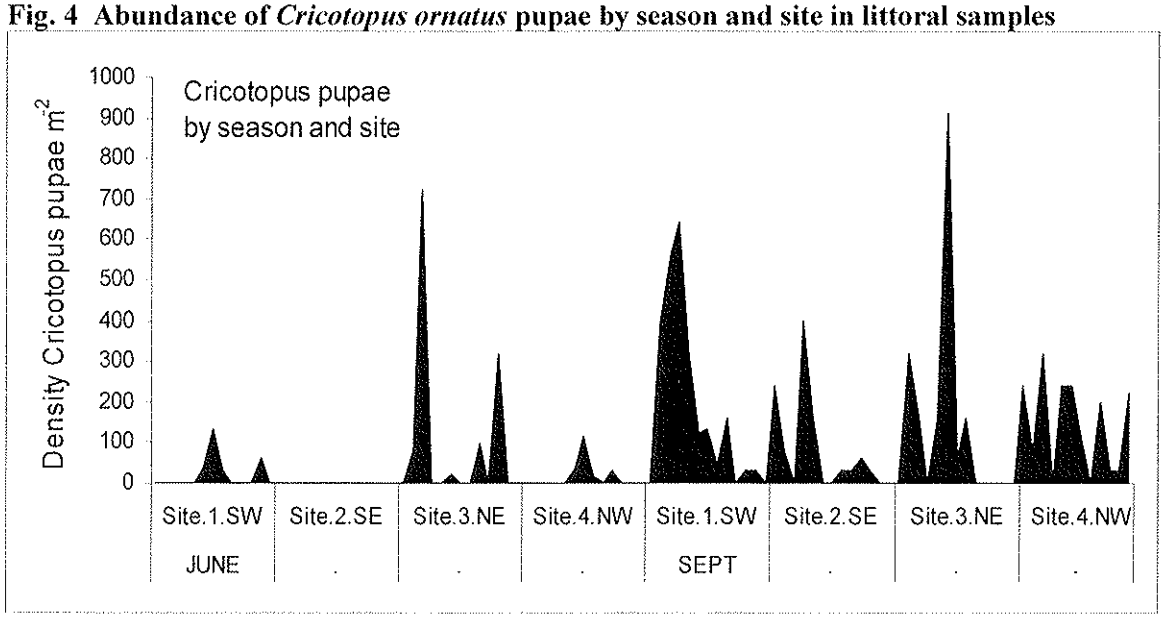


Fig.5 Substrate preferences of common benthic invertebrates in littoral samples at Walker Lake (as relative abundance over all seasons and sites), and the relative abundance overall of these taxa on all substrates, sample dates and sites (lower right).

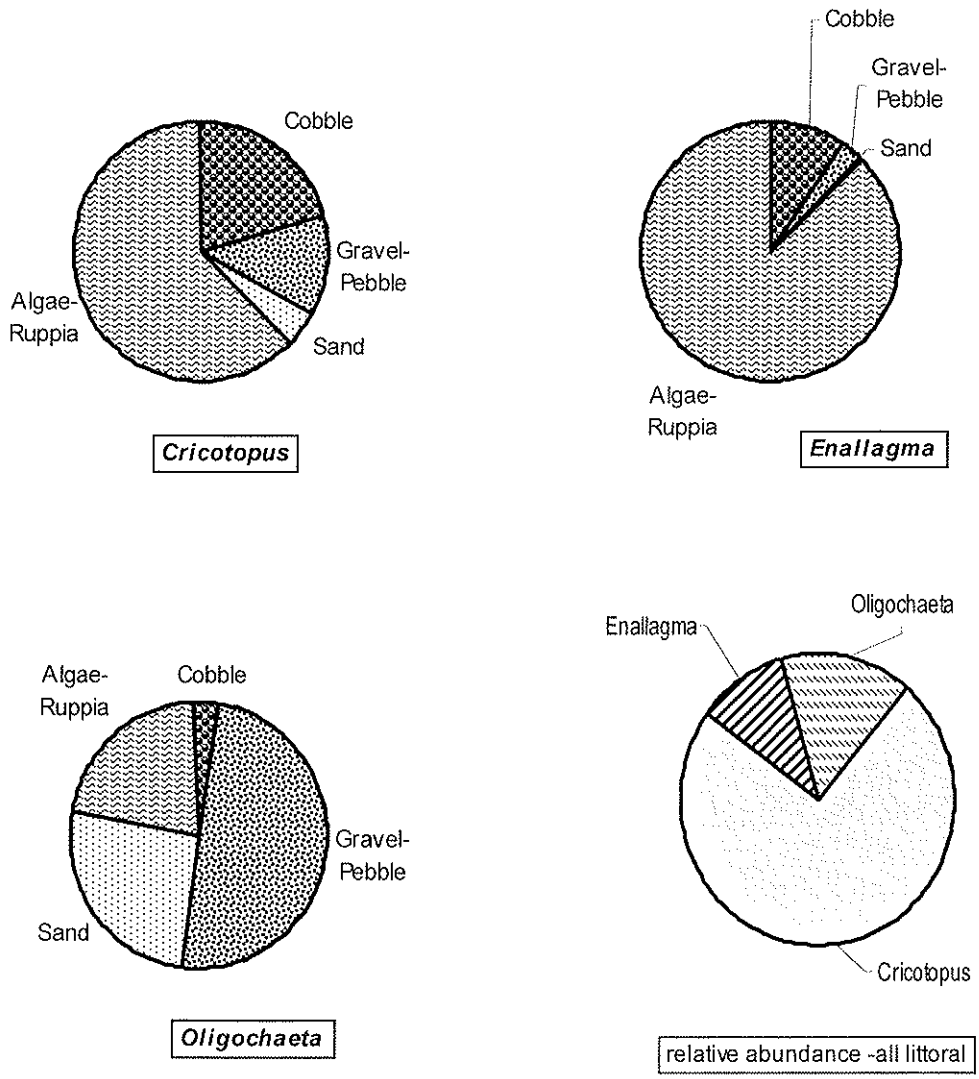


Fig. 6 Densities of common invertebrates in sub-littoral (2-16 meter depths) of Walker Lake over both June and October samples. Upper panel *Tanypus grodhausi*, middle panel *Enallagma clausum*, and lower panel oligochaetes (unidentified). Note that Oligochaetes were rare in water deeper than 10 meters.

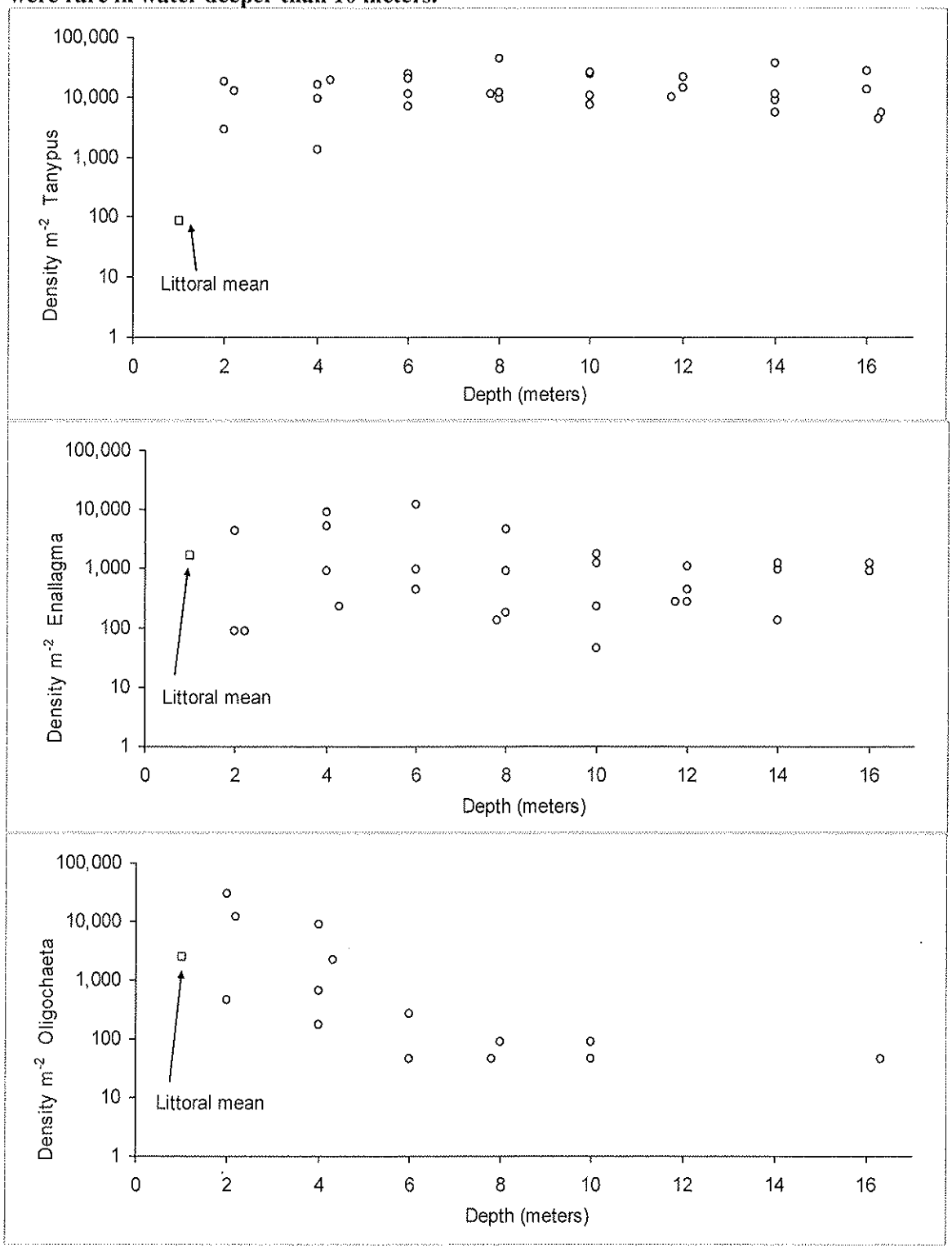
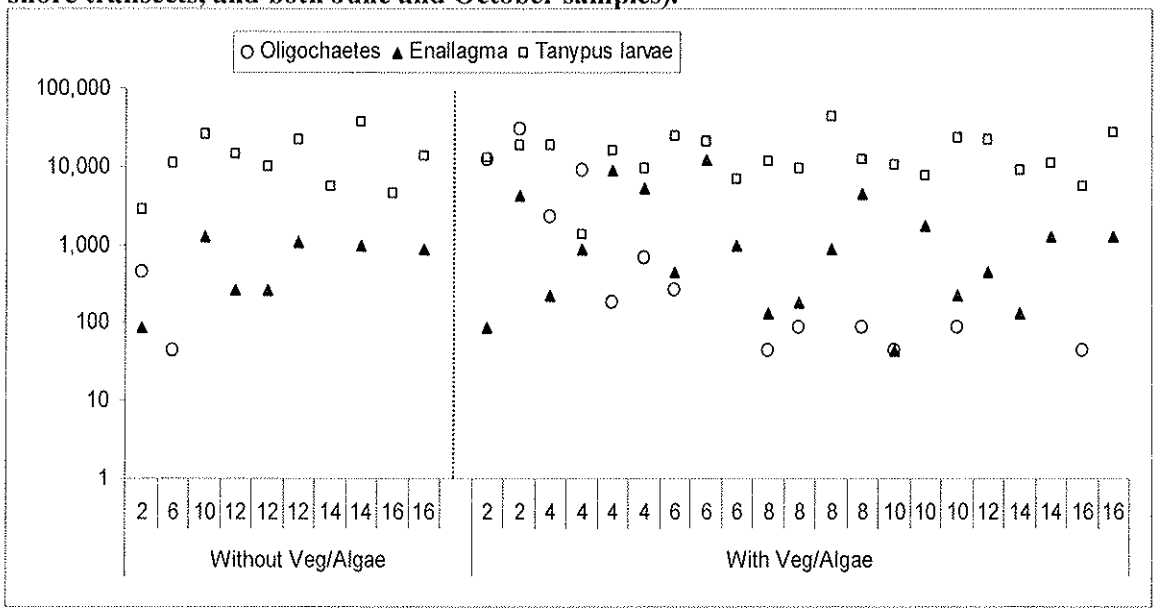


Fig. 7 Sub-littoral distributions of invertebrates at Walker Lake sorted by absence or presence of algae and macrophyte vegetation and depths (over data from both west and east shore transects, and both June and October samples).



Conclusions and Future Research

Substrate type and depth play important roles in the structure of benthic communities and distribution of particular species over gradients in Walker Lake. The environmental factors that contribute to these associations may be related to variables that have not been measured such as redox potential of the sediments (conditions where microbial metabolic activity produces reducing and anoxic micro-environments), exposure to predation pressure (selection of algae and macrophyte habitat by *Enallagma* to either or both avoid fish predation or locate midge larvae prey), or the thermal environment at the benthic surface, and wave exposure disturbance of different locations. Experiments may provide some insight to the role of these factors, and in particular it will be useful to examine expected changes in the physical and chemical environment of the lake. Predicting ecological effects of varied lake level and salinity may in part be examined from the influence of increased dissolved solute content on growth and survival of benthic species currently dominating Walker Lake.

Stratigraphic cores examining the distributions of ostracod and midge head capsules would be informative about responses of the aquatic community to salinity change at both the recent decadal scale while lake level has declined, as well as during suspected changes under "paleo-drought" conditions of 700-900 years before the present (Stine 2001). Such stratigraphic data could therefore aid in interpreting and confirming past conditions, and in anticipating ecological change that could come to pass.

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Chapter 4
Walker Lake Hydroacoustic Fish Surveys

Introduction

At the beginning of the 20th century Walker Lake contained five endemic fish species; Lahontan redside shiner (*Richardsonius egregious*), Lahontan speckled dace (*Rhinichthys osculus)*, Tahoe sucker (*Catostomus tahoensis*), tui chub (*Siphateles pectinifer*, formerly *Gila bicolor*), and Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*). The development of irrigated agriculture in the Walker Basin in the late 19th century has led to decreased freshwater inflows and rising salinity throughout the 20th century and continuing today. The rising salinity has extirpated the shiner, dace, sucker, and introduced carp and perch. Continuing salinity increases now threaten the remaining tui chub and existing population of Lahontan cutthroat trout (LCT) as well as the recreational fishery.

Native tui chub are a critical component of the Walker Lake food web and a significant component of the LCT diet. In 1975–76, Koch et al (Koch et al. 1979) found that LCT over 38 cm length switched from feeding on benthic invertebrates to a diet consisting mostly of tui chub. Thus while increasing salinity directly affects the survival of LCT, declines in the tui chub population may also impact the LCT population and fishery.

Tui chub are the dominant fish species in Walker Lake constituting >85 % of the fish netted in various gill-net studies (NDOW Walker Lake investigations, 1953 to 1958; DRI investigations, 1975-1978; NDOW 1980-1981, Sevon 1998; and 2002-present, P. Solberger, pers. commun.). Tui chub are omnivores with a wide range of items in their diets. Cooper (1978) found Walker Lake tui chub fed, in order of rank, on zooplankton (primarily *L. sicilis*), filamentous algae, chironimid larvae, detritus, the amphipod, *Hyalella azteca*, and tui chub.

There are two variants, the benthic form, *S. b. obesa*, with 8-24 gill rakers and the pelagic form, *S. B. pectinifer*, with 29-40 gill rakers adadpted for planktonic food sources (Moyle 2002). While Cooper (1978) classified the tui chub in Walker Lake as *G. b. obesa* (now *S. b. obesa*), he noted that only the fine gill-raker variant was present. Sollberger (2003) found 85 % of a 67-fish sample to have more than 27 gill rakers per arch. More recently, K. Wright found a mean gill raker count of 33 (range 20-38) in 113 individuals collected during October 2007. Thus, Walker Lake chub would seem to be mostly *S. b. pectinifer*, the lake variant.

Continuing increases in salinity threaten the tui chub population in Walker Lake. Tui chub in Walker Lake generally become sexually mature at age 3 (Koch et al. 1979) and spawning activity occurs from late May through mid-summer. Laboratory salinity assays with Pyramid Lake tui chub yielded 100% mortality of eggs at 15.5 g l^{-1} (LOSL 1982). A large fish kill of tui chub was documented in the Carson Sink during 1986-1987

when salinity reached 20 g/l (Rowe and Hoffman 1987). However, 2002-2007 gill and trap net sets in Walker Lake continue to capture tui chub recruited in recent years.

Beginning in 2002, NDOW have set gill nets during October to census tui chub and estimate recruitment and survivorship based on size-frequency analysis. Assuming reasonable estimates of adult survival suggests recruitment has declined during the recent rise in salinity. However, the number of fish caught has generally been insufficient to derive statistically sound estimates of survivorship and recruitment. In 2007, we initiated hydroacoustic surveying to provide an alternative method of determining population size, survivorship, and recruitment.

Hydroacoustic technology is increasingly being employed to answer a wide range of fisheries questions. Using modern split-beam echosounders, fish density and size frequency have been determined in a wide range of inland lakes and reservoirs (e.g. (Beauchamp et al. 1997; Burczynski et al. 1987; Eilers and Gubala 2003; Eilers and Eilers 2004; Gangl and Whaley 2004). Hydroacoustic sampling has several advantages over traditional net-based sampling. It provides non-invasive synoptic sampling of an entire lake and it avoids biases introduced by net efficiencies and behavioral differences among age classes and species. However, scattering of acoustic signals is complex and a wide variety of factors make interpretation of acoustic signals difficult. The stochastic nature of acoustic scattering by fish limits the ability to differentiate among species and can make size frequency analyses more difficult than active sampling techniques. Also, scattering from other sources (e.g. gas bubbles, vegetation, and plankton) limits its utility under some conditions.

We conducted hydroacoustic surveys in autumn of 2007 and spring of 2008 to estimate lakewide fish densities and assess the feasibility of employing hydroacoustic techniques to monitor changes in tui chub recruitment and survivorship. Our initial protocol was modeled after a similar hydroacoustic study of tui chub in Diamond Lake, Oregon (Eilers and Gubala 2003). However, detailed analysis of our autumn 2007 surveys revealed significant acoustic target size overlap between abundant gas bubbles and the target species, tui chub. Comparisons and similarities to Eilers and Gubala (2003) data indicate their population and size frequency estimates are almost certainly in error and also significantly contaminated by scattering from gas bubbles. We show during the spring 2008 surveys that this difficulty can largely be mitigated by surveying at slow speeds, conducting surveys in late winter/early spring when gas bubbles are at a minimum, and by employing detailed tracking analysis of individual targets.

Methods

Instruments

The hydroacoustic surveys were conducting using a 200 kHz, digital 6° split-beam echosounder (BioSonics, Inc.; Model DT-X). Positional data were acquired with a differential GPS unit (JRC-Corp. D-GPS212) linked with the Biosonics surface unit for direct integration with the echograms via a field computer (Panasonic Toughbook CF30) running Biosonic's visual acquisition software (Visual Acquisition Ver. 5.0). The

acquisition threshold was set at the maximum sensitivity, -130 dB, to allow maximum flexibility in post-processing.

The transducer was deployed in a vertical orientation with the face of the unit 25 cm below the surface of the water. The ping rate was set to 5 pings s^{-1} with pulse duration of 0.4 ms during 2007 and 0.3 ms during 2008. The pulse duration was slightly lessened in 2008 to increase the vertical resolution of individual target analysis. Survey speeds were generally 3-4 kts (1.5-2.0 m s^{-1}) during 2007 except when in shallow water in close proximity to the shore. During 2008, several surveys were conducted at much slower speeds (~0.5 m s^{-1}) to enable the differentiation of gas bubbles from small fish (see fuller discussion below in Results).

The target strength readings of the hydroacoustic unit was checked against a standardized tungsten-carbide calibration sphere (36 mm) on three dates, 11 October 2007, 5 November 2007, and 13 April 2008. On the first two dates the calibration sphere was lowered directly below the transducer on a fishing line at 2-m depth intervals from 2 to 20 m with 150-300 pings recorded and analyzed at each depth. The actual and calculated depths were exactly (r^2=1.0000) correlated with an offset of -14 cm when measured to the top of the transducer or +6 cm when measured from the face. The measured and theoretical standardized targets strengths were within 0.8% of each other. During the 3rd calibration on 13 April 2008, the target readings were taken from a single depth (~9 m) and measured readings were slightly (6%) lower than theoretical (-42 dB versus -39.5 dB).

Analysis

Individual target analysis was performed using Biosonic's visual analysis software (Visual Analyzer 4.1) with typical target recognition parameters (see Appendix B for list of parameters). Each echogram was visually examined in detail to ensure the bottom was properly tracked. In most cases the automatic bottom finding algorithm required manual editing. Detailed visual inspection of every echogram was also required to ensure irregular bottom features, surface noise, bubble plumes, schools of fish, and other features were not improperly counted as individual targets.

Reported fish densities and size-frequency data herein are all based on individual target tracking where echoes from sequential pings in close proximity of each other are counted as a single individual. As Biosonic's software does not incorporate individual target tracking, this was manually performed by grouping echoes from sequential pings within 0.1 m vertical distance of each other with supporting verification by close visual inspection of the associated echogram for all targets in the intensity range of interest. While this procedure was made feasible by the low target densities observed in Walker Lake, it was time-intensive and sophisticated automated tracking software should be employed in future analyses.

The algorithms in Biosonic's analysis software do not calculate fish densities based on individual tracking of targets. Rather a mean acoustic cross-section is determined from analysis of individual targets and applied to the integrated echo. As we manually counted individual fish by tracking sequential targets, we calculated the volume

sampled to derive a total population estimate. A computer algorithm was coded in Matlab to calculate transect length, average velocity, and volume sampled within specified depth layers (e.g. 0-5 m, 5-10). The algorithm accounted for the overlap of the conic ensonified volumes given the average boat speed as determined from continuously recorded GPS readings. GPS coordinates were derived from the echogram files using Biosonic's EcoSAV2 software. The transect length was extracted as the sum of the distances between successive GPS coordinates 20 s or 100 pings apart.

The target strength (TS) of individual fish was derived by averaging in the linear backscattering domain (see Simmonds and MacLennan for discussion 2005). Thus, we converted the TS's calculated by the Biosonic's software to the equivalent backscattering cross-sections for averaging and then converted the average backscattering cross-section back to TS.

Target strength versus fish length

The acoustic scattering properties of fish depend on a wide range of species-specific variables including age, size, orientation, and physiological condition (see Simmonds and MacLennan 2005 for review and thorough discussion). As such, target strength must be considered a stochastic variable in which only ensemble properties are correlated with the actual size-frequency distribution of a fish population. Field validations of target strength versus fish-length relationships are difficult to conduct and most studies still employ the relationships derived in the classic studies of Love (1971, 1977).

At Walker Lake, we proposed to use concurrent fish trapping data to verify the relationship between target strength and tui chub length. Trap netting was conducted from autumn 2007 through spring 2008 as part of the USFWS's LCT monitoring and survivorship study. Between 12 October and 27 November 1,694 tui chub were caught and measured (Fig. 1). The tui chub population displays a marked bimodal size distribution. Similar results were obtained by a gill net set conducted by NDOW on 18 October (Fig. 2).

A subset (n = 137) of the netted fish were aged based on analysis of opercles annuli (Fig. 3). The striking absence of fish in the 200-250 mm range corresponds to 4 to 9-yr olds. Although this might be assumed due to multiyear differences in recruitment, the impact of LCT predation on intermediate size classes is also a likely factor. Individual tui chub that avoid predation during their first several years escape later predation due to their large size. As tui chub are long-lived, even low rates of escapement will result in the second peak as growth slows and individuals accumulate in these large size classes. The second peak in the size distribution corresponds to a wide range of ages (10-23 yrs).

Fig. 1. Size (FL, mm) of tui chub caught from 12 October – 27 November 2007 as part of USFWS LCT study.

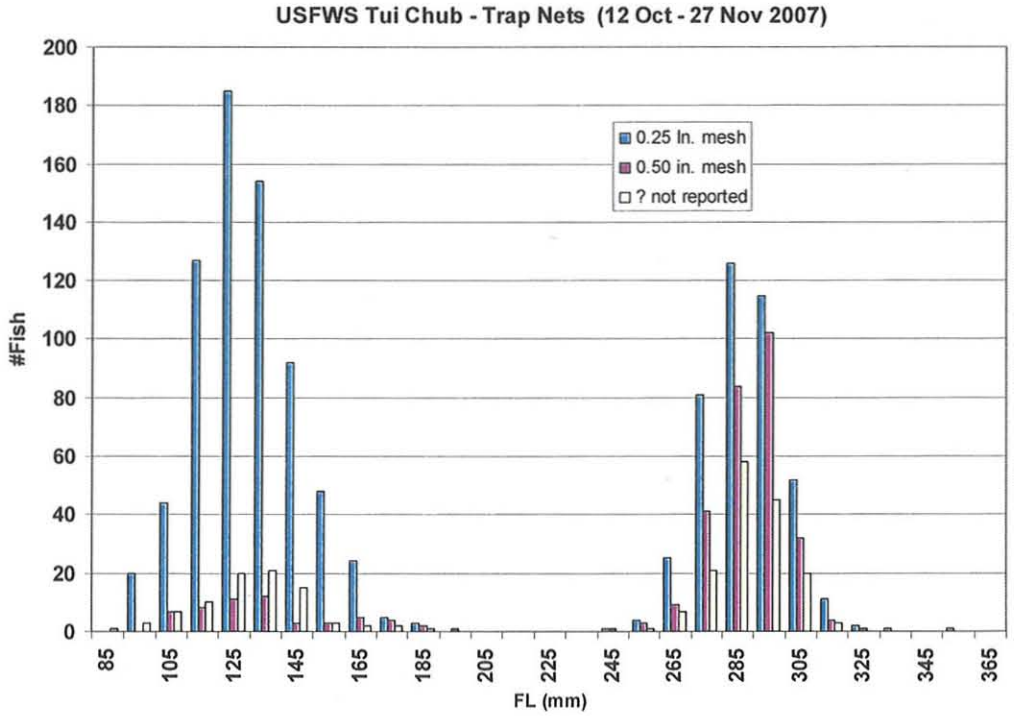


Fig. 2. Size (FL, mm) of tui chub from gill net set on 18 October 2007 (Source: NDOW Walker Lake Project)

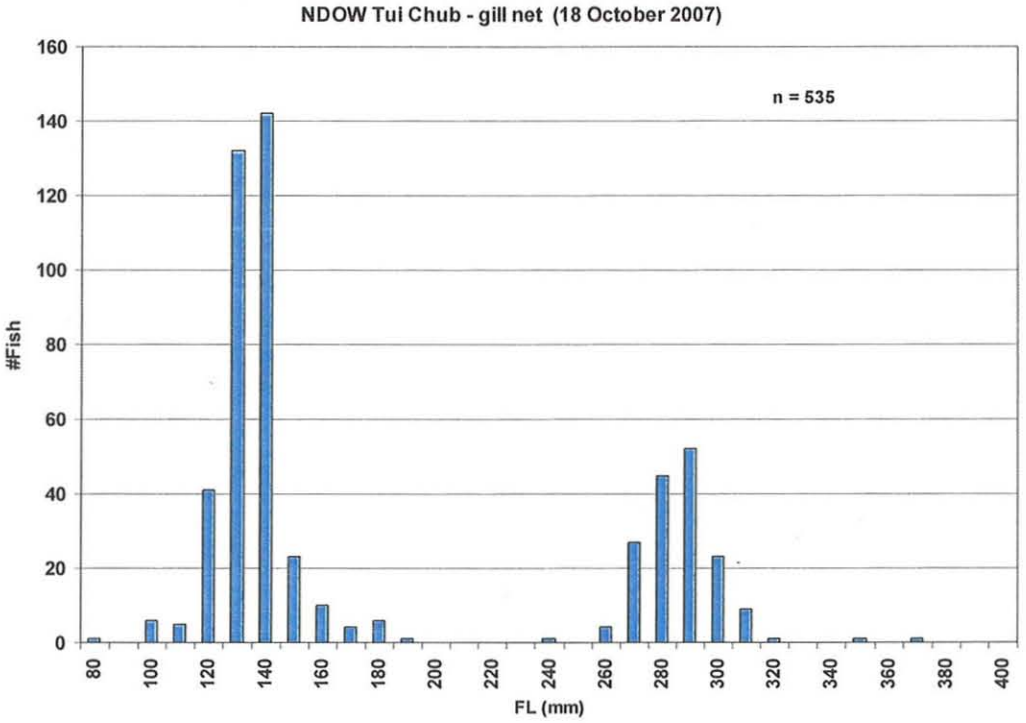
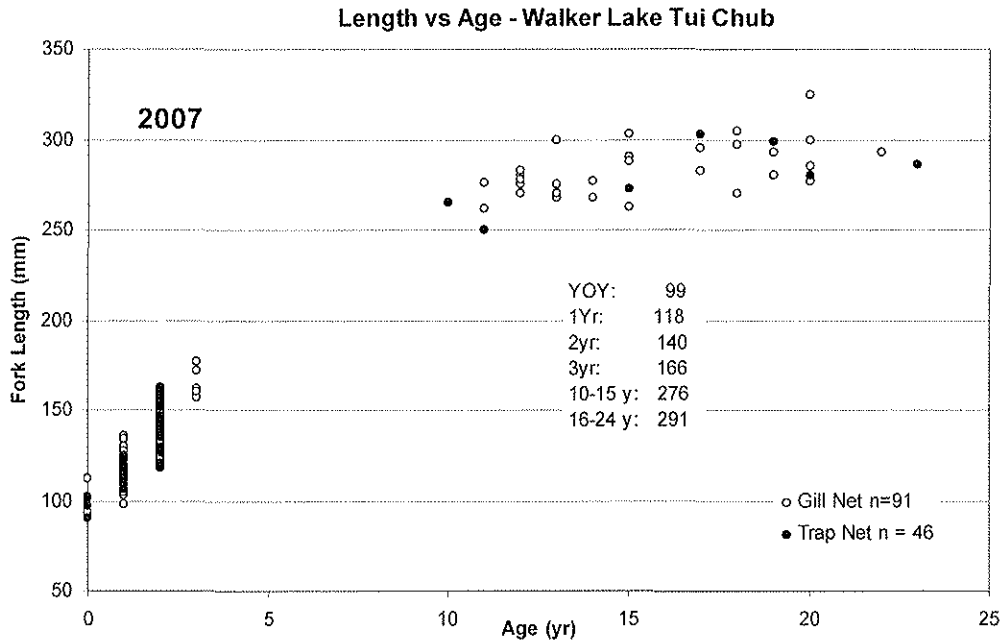


Fig. 3. Fish ages based on opercles (Source: K. Wright, NDOW Walker Lake Project)



Using a variant of Love's (1977) equation for 200 kHz predicts there should be peaks in the frequency of target strength near -41 dB and -35 dB. There is some uncertainty in the expected size of YOY tui chub as YOY are reported to be smaller in several other lakes and observations of small (38 mm) YOY were reported during August 2006 snorkeling surveys (P. Solberger, pers. commun.). Also, gill and trap nets with 0.25 in. mesh size may under-sample small (<90 mm) fish. Thus, target strengths closer to -50 dB could be associated with tui chub in late summer.

$$\text{Total Length (cm)} = 10^{((TS+64.1)/20)} \quad \text{where TS is in dB} \qquad (1)$$

Results

Early August

Several preliminary transects were collected during a Biosonics, Inc. training session at Walker Lake midday on 2 August 2007. Two were collected along the "Cliffs" between the Sportsman's Beach ramp and the town of Walker Lake and two off the southwestern shore (Fig. 4). These August nearshore transects are noteworthy in that they reveal a large number of small acoustic targets in the -58 to -75 range and smaller (Fig. 5). Many of these small targets do not exhibit the constant rising velocity we observed as a characteristic of bubbles later in the year. These targets are in the range of those observed in other studies for zooplankton and suggest the potential for assessing zooplankton or damselfly larvae abundance in Walker Lake. However, small targets may also be due to suspended clumps of algae possibly with attached small bubbles observed during the survey. Further work would be necessary to differentiate among potential small target sources.

Fig. 4. Preliminary hydroacoustic surveys taken on 2 August 2007

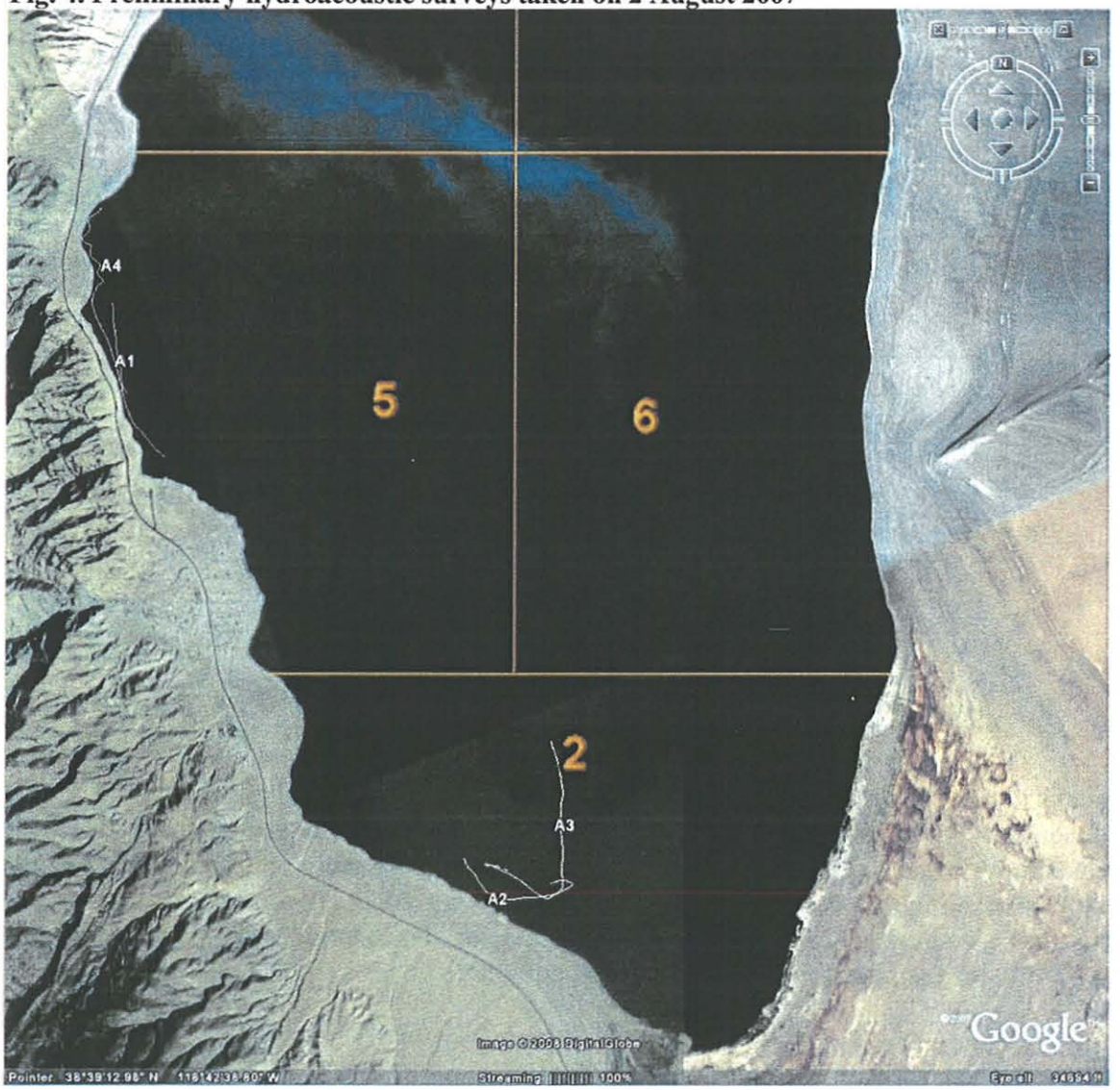
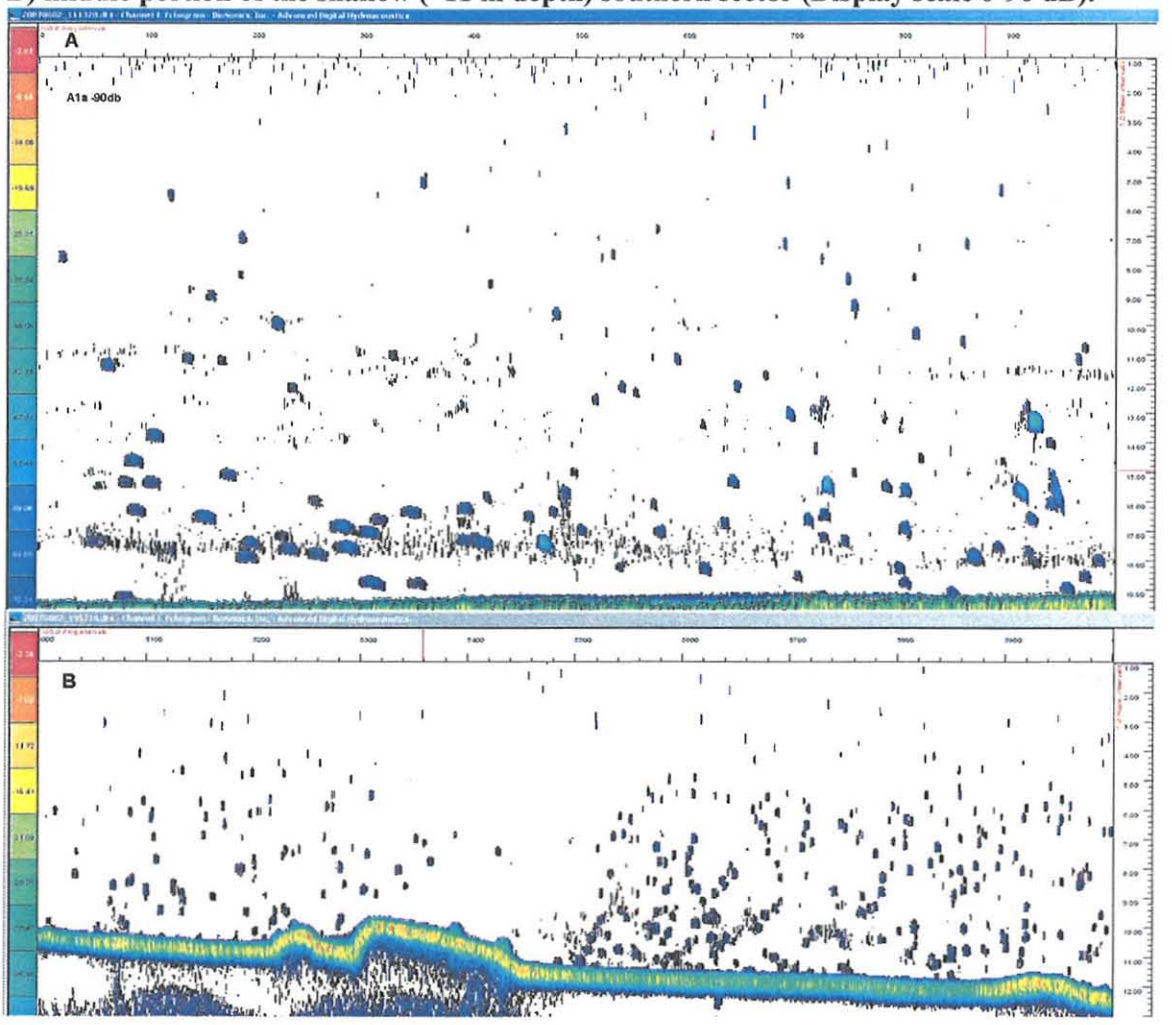
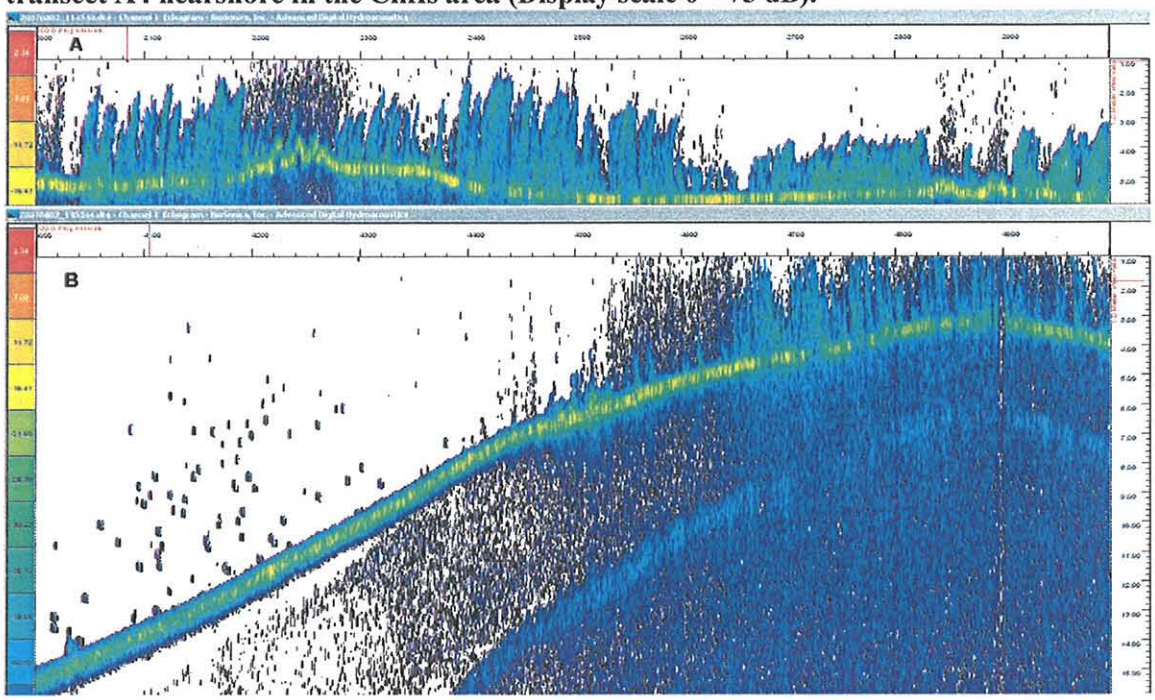


Fig. 5. Small targets (-75 to -58 dB) observed at the A) Cliffs area (~19 m depth) and in the B) middle portion of the shallow (~11 m depth) southern sector (Display scale 0-90 dB).



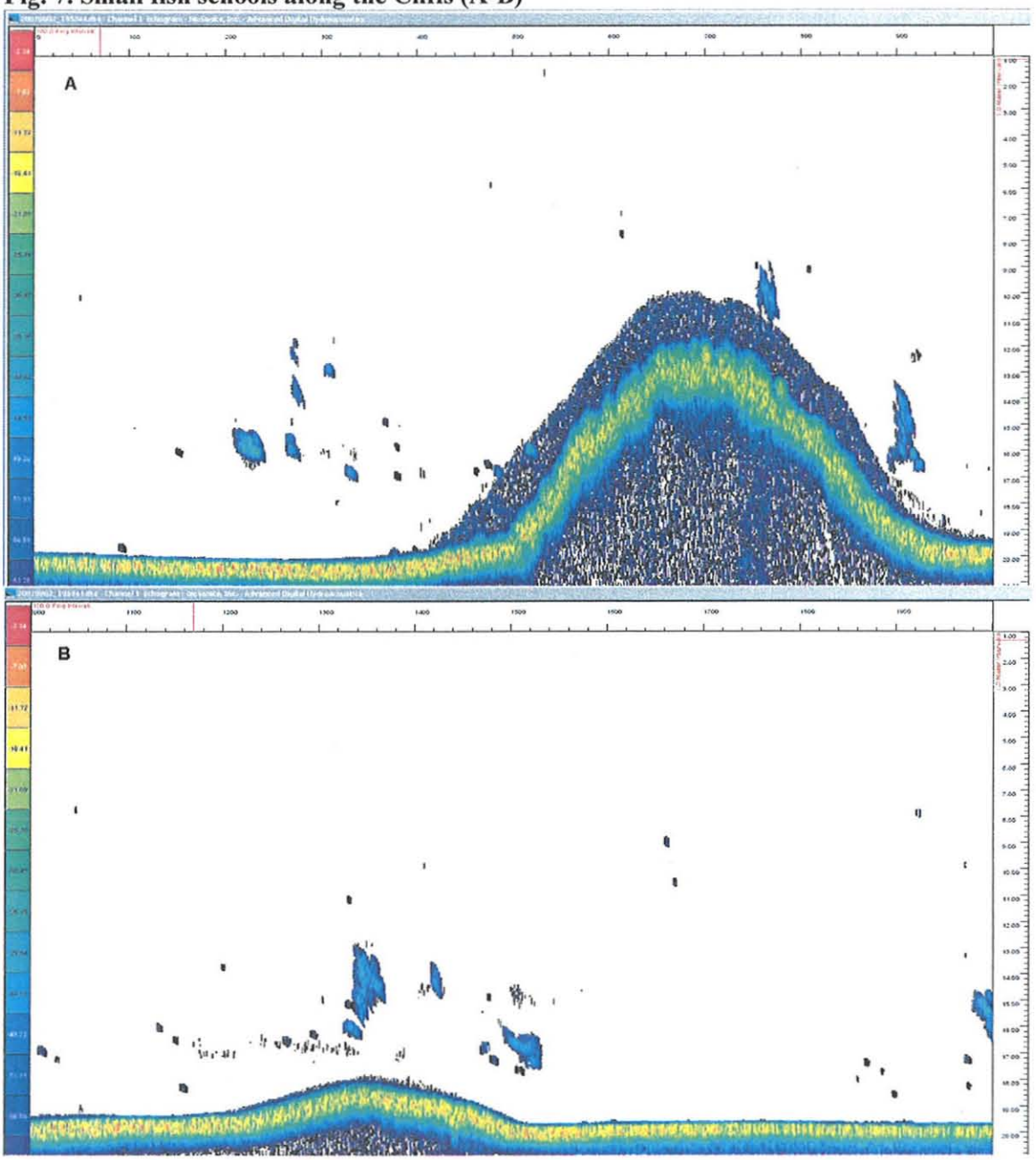
Along other transect portions macrophytes are clearly evident and would obviously interfere with fish target analysis (Fig 6A-B). Also note the large target (-30 dB) within the macrophytes (Fig. 7A). To minimize the difficulties associated with censusing fish in the presence of large macrophytes, lakewide surveys were scheduled for late autumn after most of the large macrophyte beds had died back and sloughed off. However, there were still significant macrophyte beds during the first October survey.

Fig. 6. Macrophyte growth in shallow regions A) Along A2 transect in Sector 2, B) Along transect A4 nearshore in the Cliffs area (Display scale 0 – 75 dB).



Many of the targets in the small fish range (-58 to -40 dB) are in close proximity of each other indicating schooling behavior during this daytime survey. Although closely aggregated fish were evident throughout the transects (Fig. 7A-B), no large schools were observed during this survey. Nighttime surveys were planned to reduce the effect of macrophytes and schooling behavior. Several studies have documented that forage fish often hide in macrophyte beds during the day and disperse out of them at night. Similarly, they school during the day to minimize predation risk and disperse at night. Elser and Gubala (2003) observed both these behaviors in tui chub at Diamond Lake, Oregon.

Fig. 7. Small fish schools along the Cliffs (A-B)

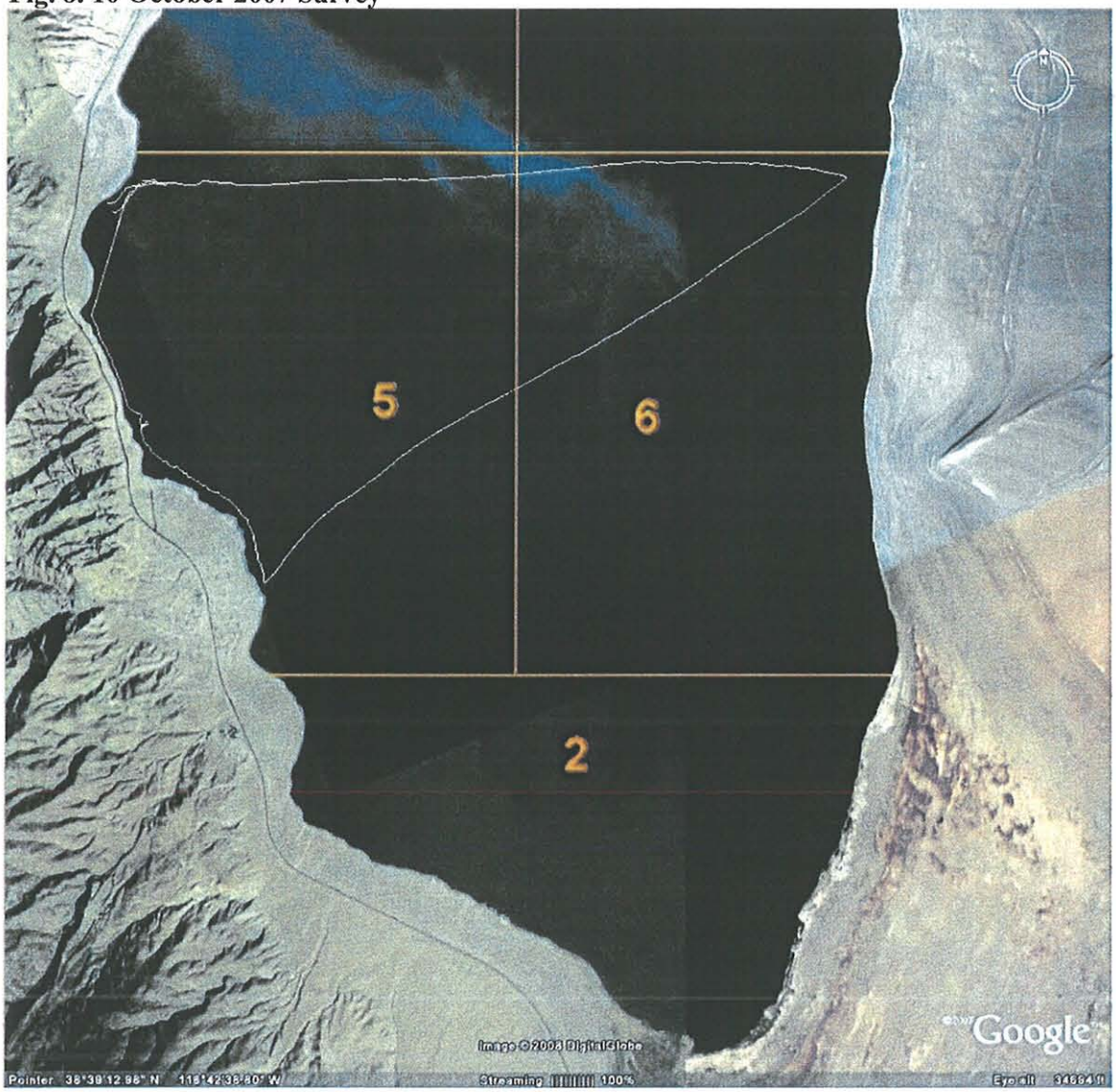


Gas bubbles, schooling and other acoustic anomalies

The first lakewide survey was conducted on 10-11 October 2007. A large triangular course was begun at 1400 on 10 October near Sportsman's Beach. The course ran due east to the far shore, diagonally back to the west shore near the town of Walker Lake and along the western shore including the well-known cliff area. The "Cliffs" are frequented by fisherman and considered among the best fishing spots in the lake by many anglers. The triangular survey took ~3 hrs to complete. A second circuit of the triangle was planned for after dark to compare day and nighttime target distributions with respect

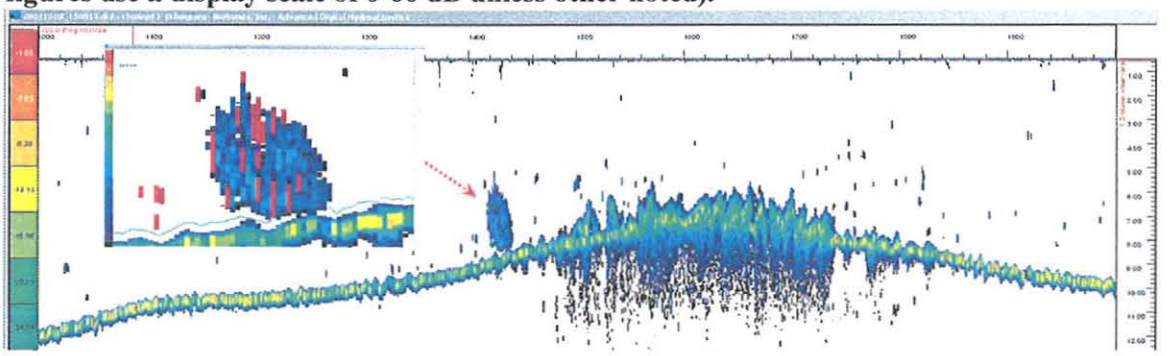
to schooling behavior. The second circuit was initiated at ~2000 but aborted shortly thereafter due to high winds and rough wave conditions.

Fig. 8. 10 October 2007 Survey



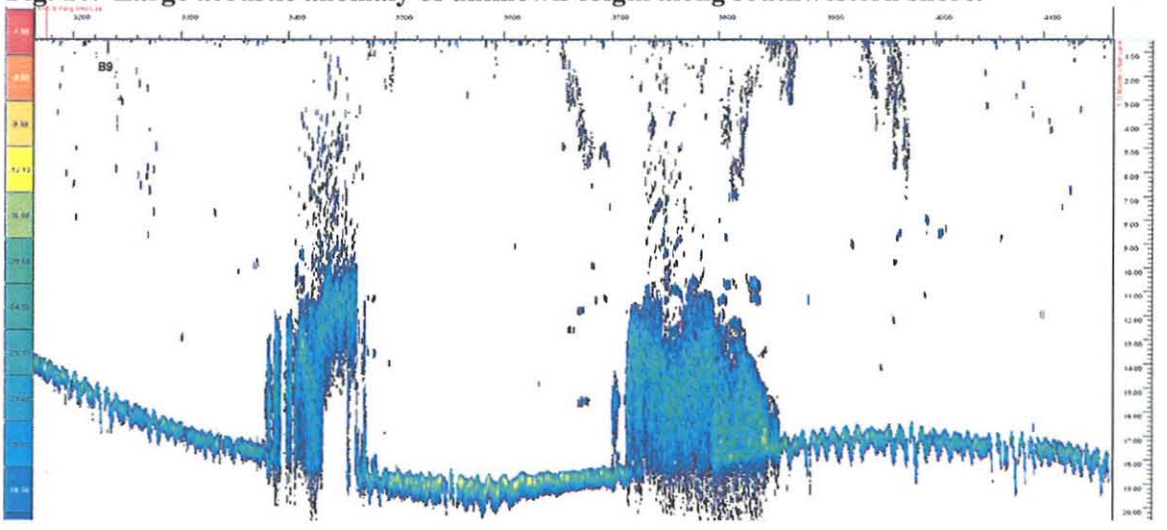
A small school of fish was observed near the eastern shore at ~7 m depth. It is not possible to accurately identify individual targets in a school because of the complex interference patterns of acoustic scattering from closely spaced objects. Even when individual targets are recognized as shown by red in the inset, the target strengths may not be accurate due to constructive and destructive interference. The most generally applied method is to calculate an average backscattering coefficient from a large number of individually identified targets and apply that factor to the integrated acoustic signal from the entire school. This will not be accurate if the school is densely packed. The presence of schools provides additional support for conducting the surveys at night.

Fig. 9. Small school of fish targets observed during daylight hours on 10 October 2007 (All figures use a display scale of 0-60 dB unless other noted).



A large bottom feature was observed within 40 m of a bottom anomaly noted in the USGS bathymetry (Fig. 10). The feature was ~7 m high and there are at least several large fishlike targets present immediately above it. This raises the question as to whether tui chub may be utilizing less saline micro-habitats associated with submarine freshwater inflows. However, despite the solid appearance and vertical extent, a dense school of fish cannot be completely ruled out as causing this feature. Also observed in this echogram is the apparent bottom roughness due to the rocking motion of the boat. Rocking caused by even relatively small waves (25 cm) waves can make it difficult to accurately detecting targets on or near the bottom. Thus, surveying in even moderately windy conditions is not warranted in this study.

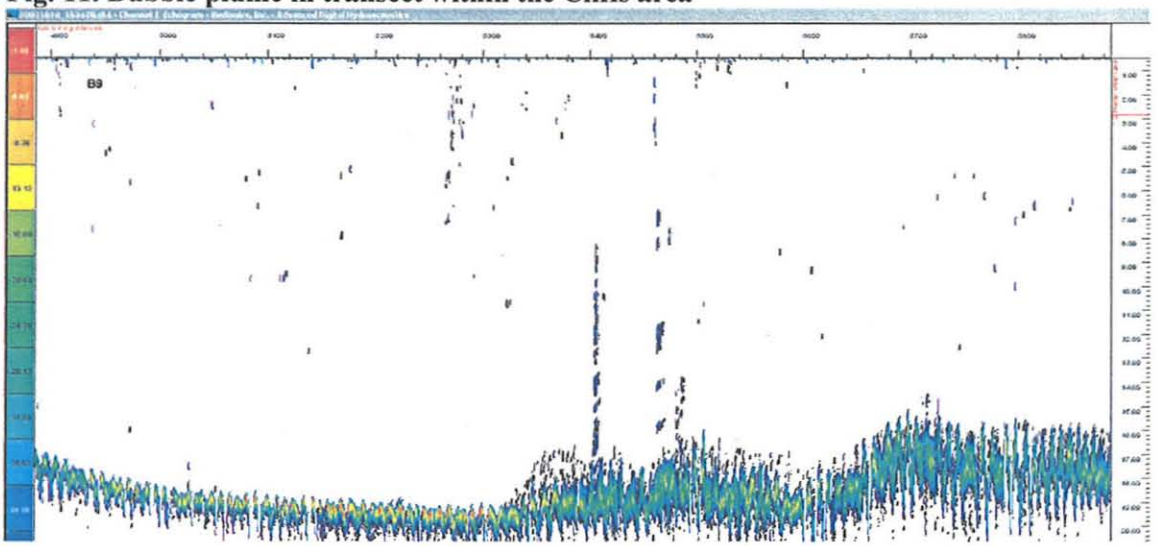
Fig. 10. Large acoustic anomaly of unknown origin along southwestern shore.



A large bubble plume was observed on the same transect in the Cliffs area (Fig. 11). The twin characteristics of vertically stacked targets with constant rising velocities (slopes up to the right on consecutive ping) are defining characteristics of bubble plumes. Even small gas bubbles are fairly strong acoustical targets due to the density discontinuity between gas and water. During analysis of the October and November surveys, bubble plumes were manually excluded from the analysis region. However, detailed inspection of echograms indicated isolated targets which also showed this

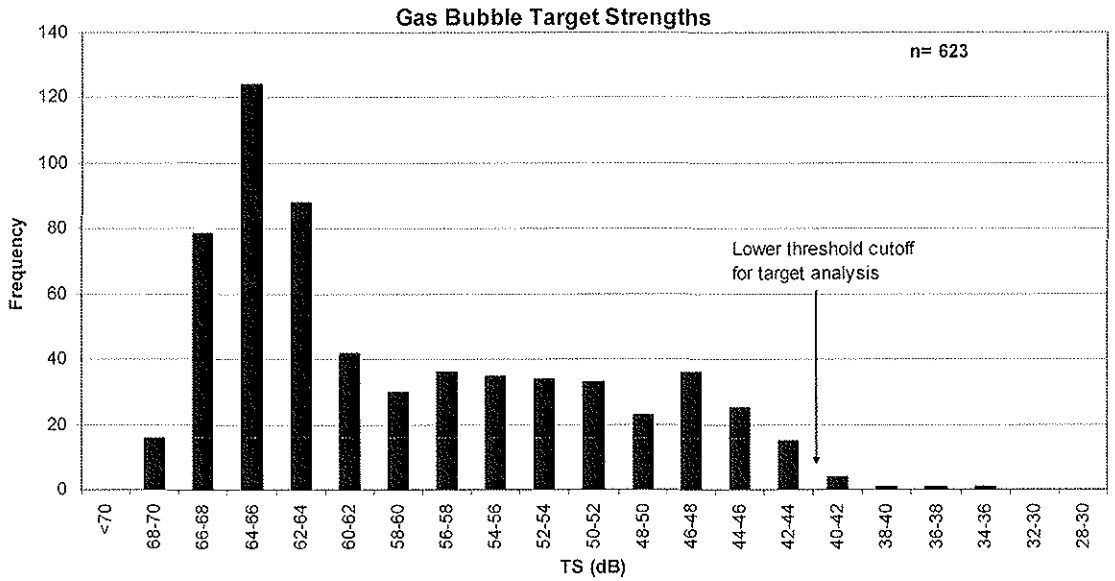
upward diagonal trend diagnostic of rising bubbles. Given the low densities of fish, even isolated bubbles have the potential to strongly bias results.

Fig. 11. Bubble plume in transect within the Cliffs area



In general bubble target strengths are lower than those for fish of interest and many authors simply use a lower threshold cutoff to censor out echoes from gas bubbles. We analyzed individual targets in a series of obvious bubble plumes to determine a conservative lower cutoff threshold. Target analyses of several plumes from each survey date were conducted providing the target strength distribution of gas bubbles in plumes (Fig. 12). While most (61 %) gas bubbles have target strengths smaller than -58 dB, the theoretical strength of a 2 cm fish, a large percentage have target strengths in the -58 to -42 dB range. This latter range (-58 to -42 dB) corresponds to 20 to 127 mm (TL) fish based on Love's (1977) equation. Thus, while obvious bubble plumes can be manually excluded from the analysis, the unknown bias of isolated bubbles cannot be completely eliminated. For this reason, we employed a -42 dB lower cutoff threshold to the target analysis of the autumn surveys. This threshold eliminates 99% of the observed gas bubbles. Some of the largest bubble targets likely arise from constructive interference of closely spaced bubbles in plumes and manual exclusion of all obvious bubble plumes is likely to reduce any bias further. While this cutoff threshold eliminate bubble targets, it also removes YOY and smaller 1-yr old tui chub from the autumn hydroacoustic surveys based on the age-size relationship observed in the tui chub net data.

Fig. 12. Target strengths of individual targets in bubble plumes sampled from each of the October-November surveys.



Autumn hydroacoustic surveys

10 October 2007

The large triangular survey conducted on 10 October 2007 (Fig. 8) included 21.4 km of transects taken at an average speed of 1.74 m s^{-1} (range, 1.2-2.0 m s^{-1}). Only 39 individual fish larger than -42 dB (theoretical size >127 mm TL) were found. An additional 3 to 7 individual fish were likely in the ensonified volume appearing as a small school of fish in shallow waters near the eastern shore (Fig. 9). Most fish targets were observed in the nearshore transects with only 0-2 individuals being found in any of the individual offshore 800-900 m transects.

Although a total distance of 21.4 km was surveyed, the actual ensonified volume is relatively small when using a narrow split-beam transducer in a vertical orientation. The total volume sampled on this survey was only 480,000 m^{-3} or ~0.02 % of the lake's volume.

11 October 2007

Given the virtual absence of fish targets in offshore waters observed the previous evening, transects run on the following day along the western shore to the mouth of the Walker River and nearshore on the southwestern shore in Sector 2 (Fig. 13). Only 17 individual targets >-42dB were found along the 18 km of transects. These were scattered among transects with no single transect having more than 5.

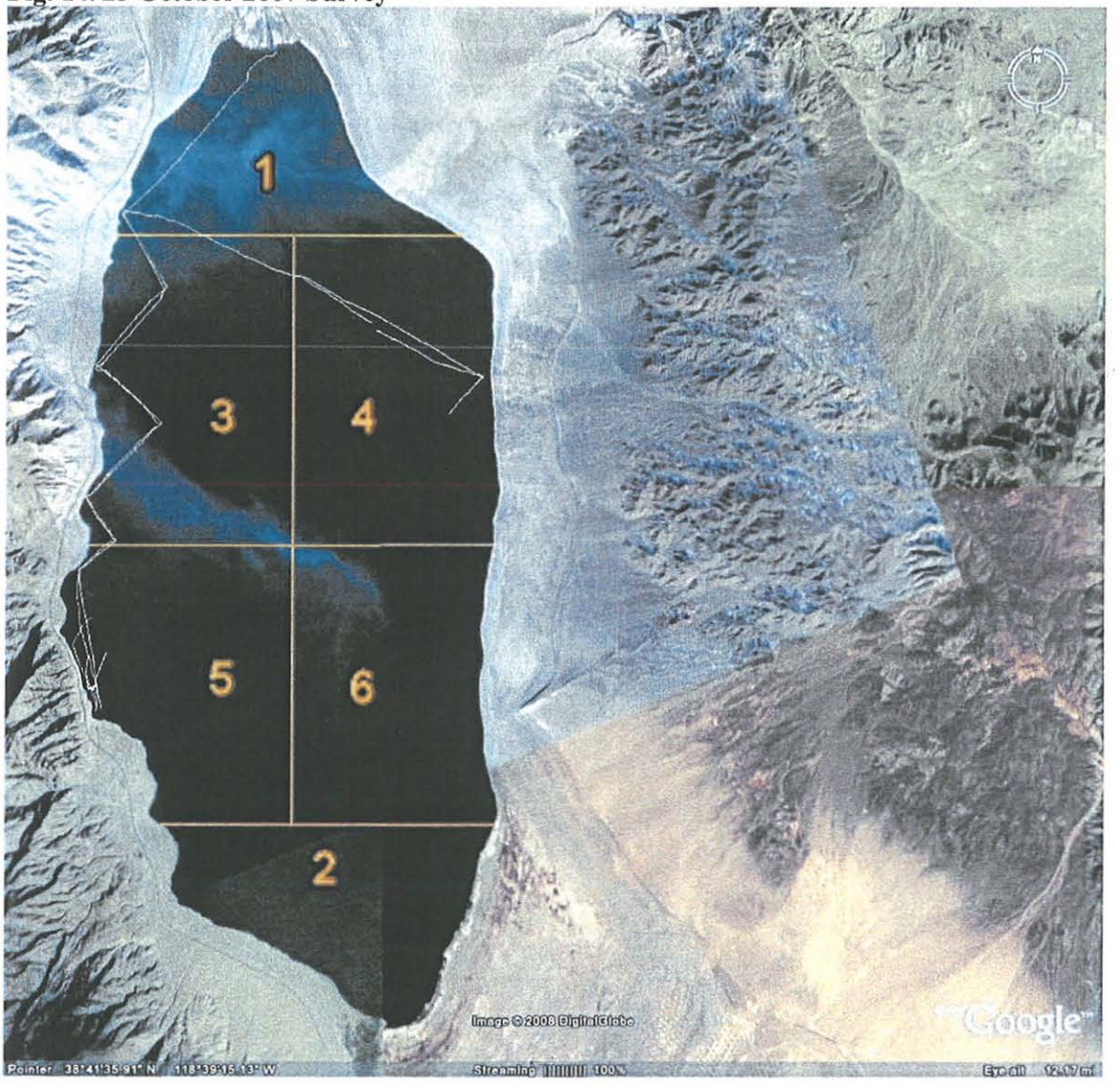
Fig. 13. 11 October 2007 Survey

23 October 2007 – Daytime versus nighttime

The 23 October 2007 survey was designed to test whether we could detect a difference between day and night surveys. All the previous transects, except for the one aborted transect on 10 October, were conducted during the day. As fish were virtually absent in the center of the lake on previous surveys, transects were plotted in a zig-zag

fashion along the western shore extending from ~1 m depth inshore to over 20 m depth offshore except for the northernmost transect in the shallow sector 1. These first 9 transects were taken from 1300-1600 hr. Transects 10-12 were plotted from the central portion of sector 4 to the eastern shore and run at 1600-1700 hr still under daylight conditions. A second transect was run in the cliff area which had been in the shadows of Grant Mountain for some time at dusk (~1715). Six more transects were run between 1900 and 2100 retracing the earlier western shore transects followed by three segments extending across the lake and retracing the earlier segment 4 transect between 2100 and 2200. Two final transects were run at the cliffs area in close proximity (30-50 m) to the shore and slightly further out at 2200-2300.

Fig. 14. 23 October 2007 Survey



Although this survey included over 47 km of transects, a total of only 38 individual fish were detected. Almost half of these (16 fish) were found along the transect in the Cliffs area taken at dusk after the area had been in the shade for a couple hours.

There were too few individual fish detected along the western shore transects to compare day versus nighttime abundance.

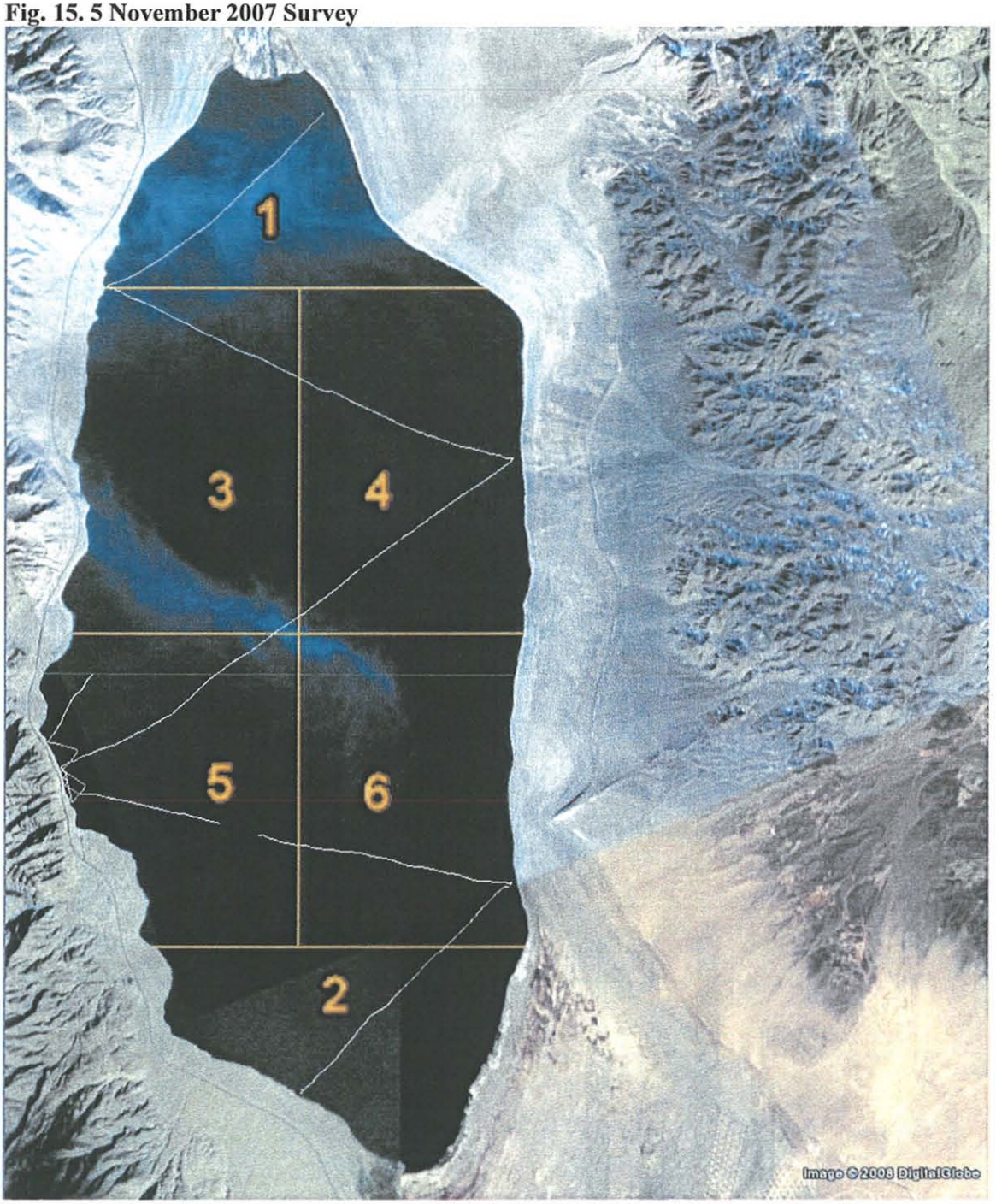
5 November 2007 – Lakewide nighttime survey

A lakewide nighttime survey was conducted on 5 November 2007 (Fig. 15). During late afternoon prior to the survey, two transects were taken in the "Cliffs" area during 1530-1615 for comparison to nighttime transects of the area taken at 1930-2000. The lakewide survey was begun at 1630 near the mouth of the Walker River and consisted of ~2 km transects along 5 diagonal courses extended across the lake to both shores ending at the southwestern shore near the southernmost tip of the lake. The 41 km of transects were collected from 1630 to 2200 at an average speed of 2 m s^{-1}.

No individual targets >-42 dB were found in the 1st two transects taken in the Cliffs area in late afternoon. Long (~2 km) transects in Sectors 1 through 5 found only 0 to 3 until reaching the Cliffs at 1915 hr at which time 36 individual fish (>42 dB) were found in a short distance nearshore. Only a few individuals were detected in the offshore waters across Sector 5 and into Sector 6, but 28 individual fish (>42 dB) were detected approaching the eastern shore and 48 on the transect leaving the eastern shore. Thirteen more large fish were detected approaching the southwest shore during the final transect. A total of 146 individual targets (>42 dB) were detected on this survey.

The difference between the early afternoon transects at the Cliffs and those taken later was striking. There was also a strong difference between the northern and southern portions of the lake which could be related to beginning in the north just at sunset and finishing at the southern end 6 hr later well after complete darkness.

Fig. 15. 5 November 2007 Survey



Autumn (October – November) Summary

A total of 128 km of hydroacoustic survey transects were conducted over 4 days between 10 October and 5 November 2007. Gas bubble plumes and numerous isolated gas bubbles were present during all the surveys. While obvious bubble plumes can be omitted from the target analysis, isolated bubbles could not be easily differentiated from small fish targets with the survey boat speeds employed. Ninety-nine percent of individual targets analyzed from bubble plumes had a TS of less than >42 dB. Therefore,

only targets >-42 dB (predicted fish TL >127 mm) were considered from the autumn surveys to avoid introduction of biases or errors arising from gas bubbles. The remaining 239 individual targets ranged from -42 dB to -26 dB (Fig. 16). Converting to estimated fish length (TL) based on Love's (1977) equation suggests that most tui chub are in the smaller size classes (Fig. 17).

Fig. 16. October - November individual fish targets >-42 dB

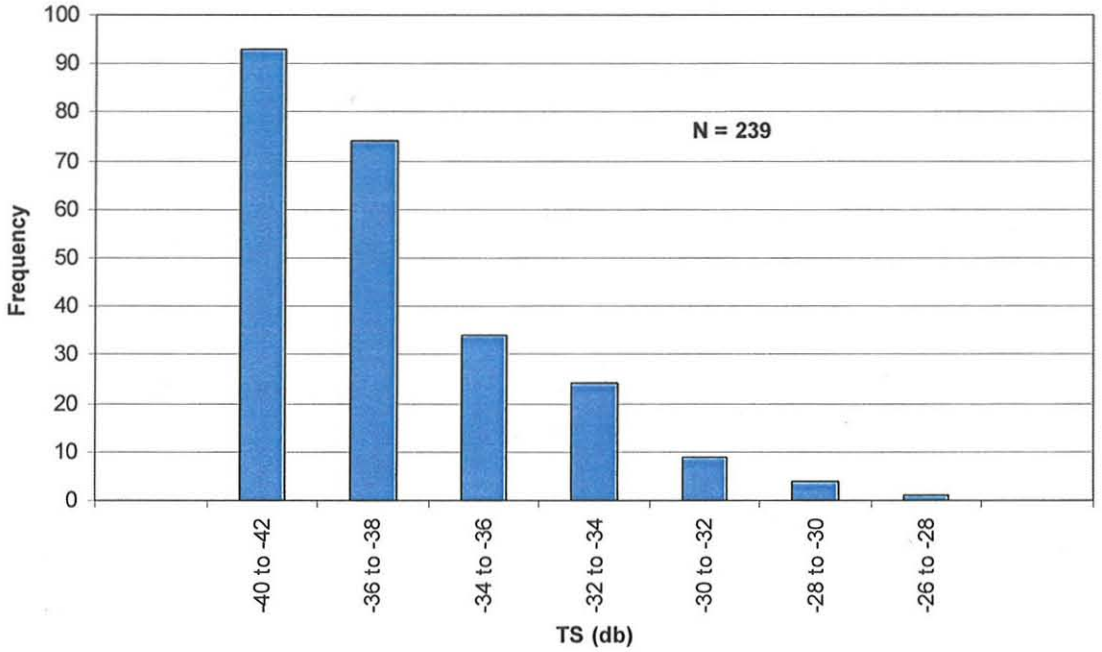
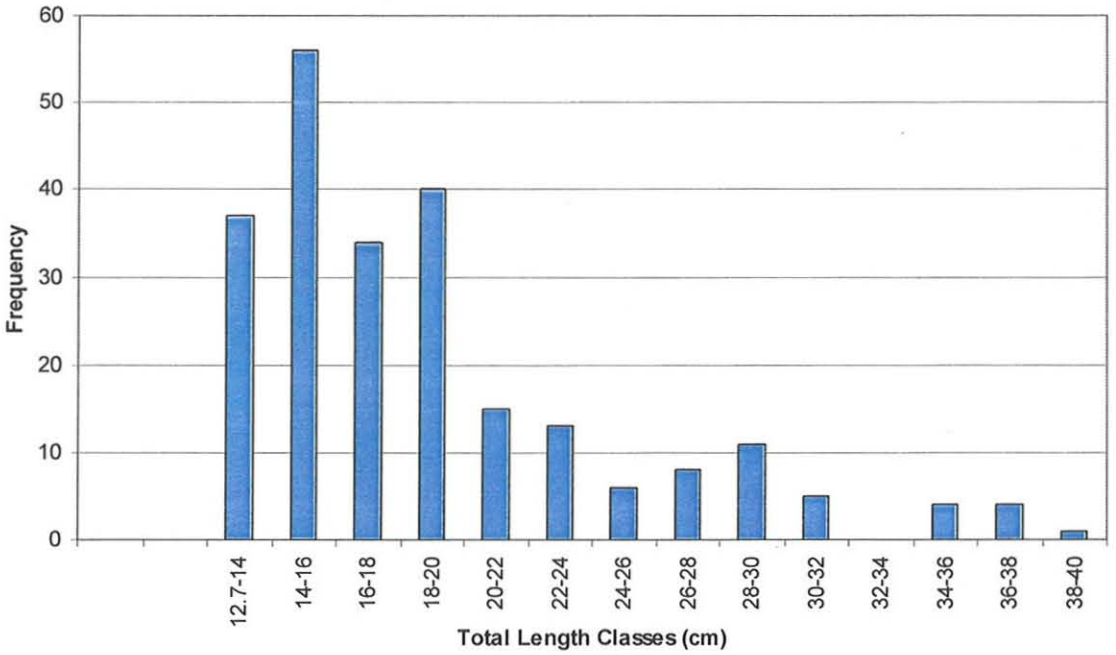


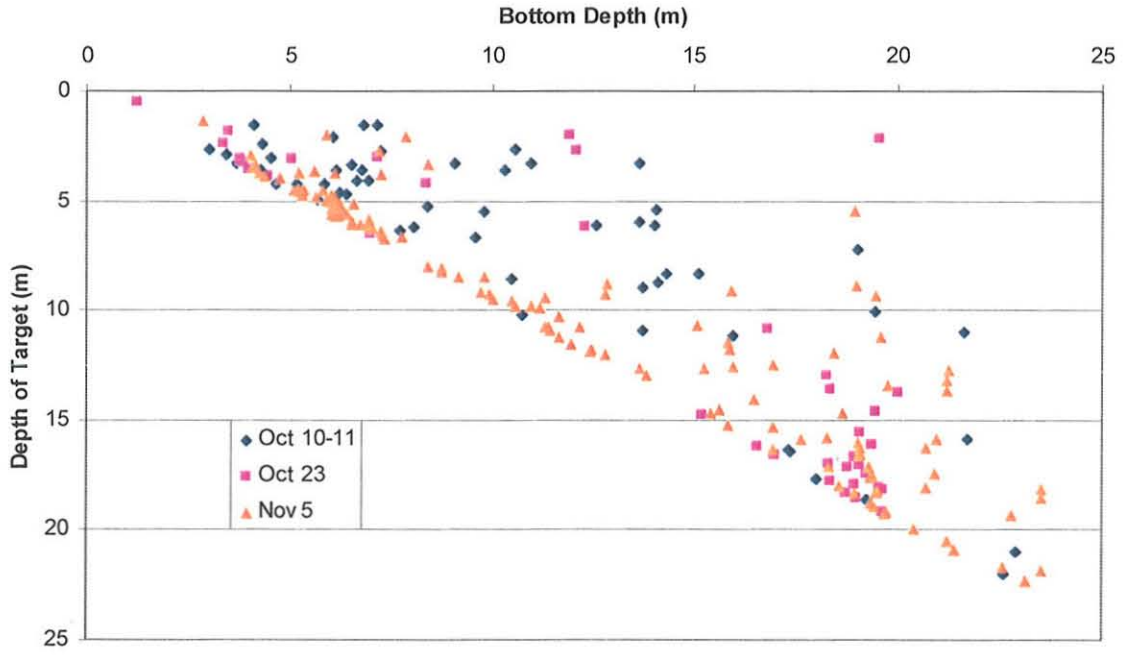
Fig. 17. Size distribution of individual fish targets (>-42 dB) predicted by Love's (1977) equation



The predicted size distribution is mostly consistent with that derived from trap and gill netting (Fig. 1 & 2) except that the smaller sizes (1-4 yr olds) make up a larger portion of the entire population. The peak at 28-30 cm (9-24 yr olds) followed by a gap with some larger fish, presumably LCT, are both consistent with the net data. However, with 239 targets only weak validation of Love's TS-length equation is possible.

The 239 individual targets were found throughout the water column from nearshore to offshore on all four dates (Fig. 18). While most were found deeper in the water column, this partially reflects the larger ensonified volume with depth.

Fig. 18. Location of individual fish targets (>-42 dB)



27 March 2008 – Bubble Plume Surveys

Gas bubbles display a characteristic rising velocity that can be used to differentiate between bubbles and small fish targets if survey speeds are conducted at a slow enough speed to obtain multiple echoes from individual targets. While bubbles of a particularly size rise at constant rate, fish swim mostly horizontally and when moving vertically will often have variable and quite different velocities. Ostrovsky et al. (2008) did a hydroacoustic analysis of methane bubbles and fish targets in productive Lake Kinneret (area, 166 km^2; max depth, 43 m) and were able to screen out fish targets to estimate methane flux. Through extensive measurements of the target strength of bubbles of different diameters in the laboratory, they found 0.034 to 3 ml bubbles produced echoes in our range of interest (-60 dB to -42 dB). Bubbles of these diameters have narrowly constrained rising velocities of ~22 – 30 cm s^{-1} (Fig. 19). We found similarly constrained velocities of the rising velocities of gas bubbles in Walker Lake (Fig. 20).

Fig. 19. Bubble velocities (Reprinted from Ostrovsky et al. 2008)

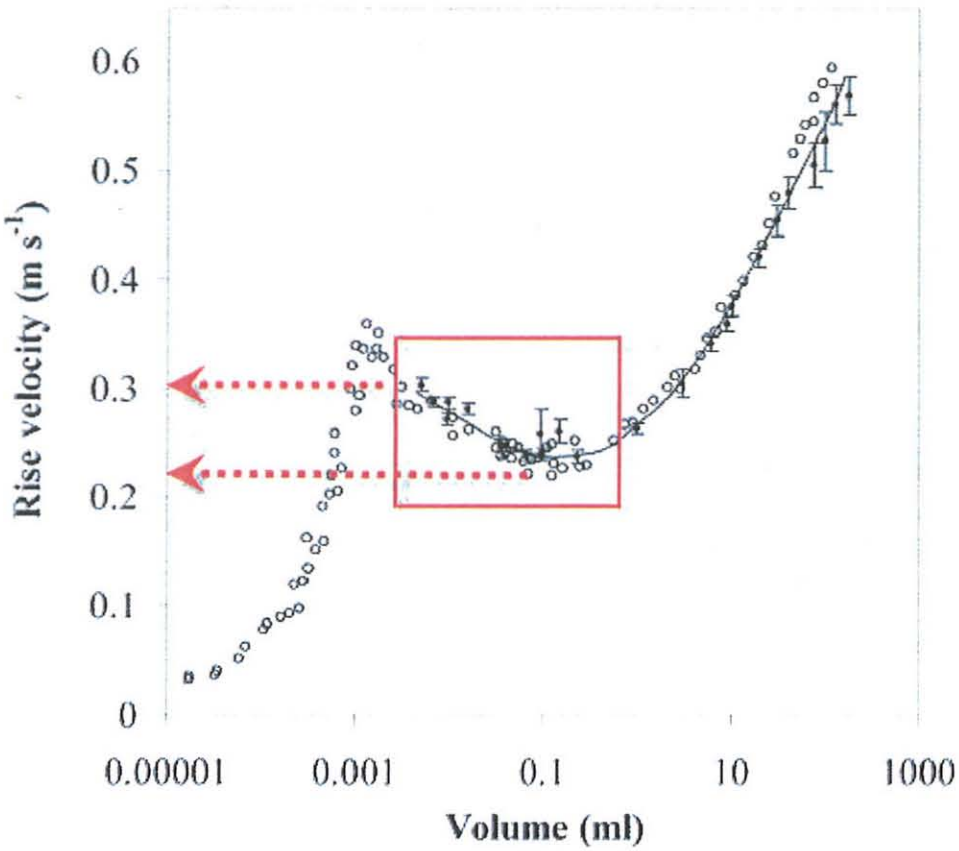
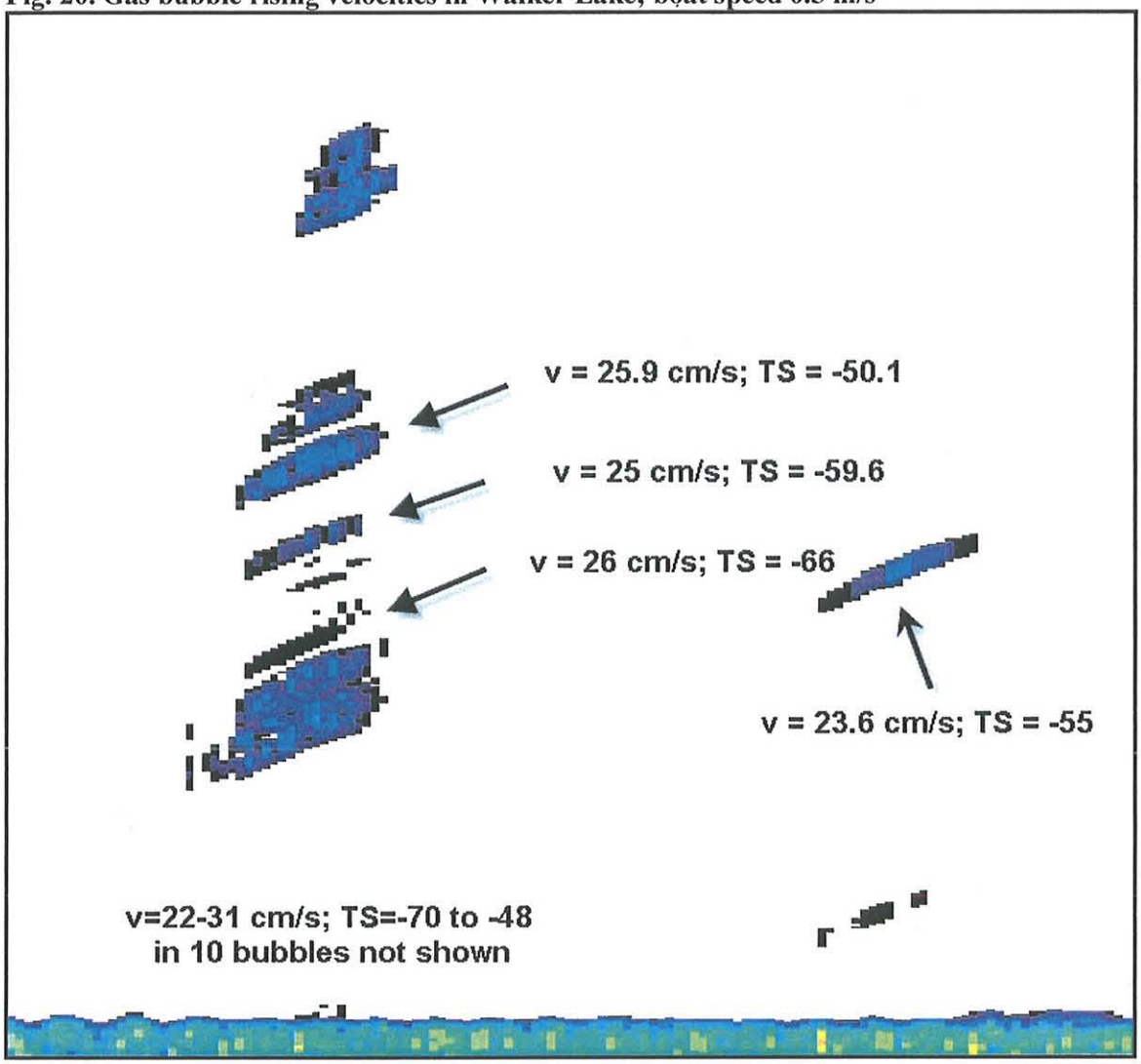


Fig. 6. Relationships between rise velocity and bubble volume. Filled circles are acoustic measurements at water temperature of 18.5 ± 1.5°C (this study). Standard errors are shown as bars. Empty circles are data obtained for tap water at 20°C by Haberman and Morton (1954).

Fig. 20. Gas bubble rising velocities in Walker Lake; boat speed 0.5 m/s



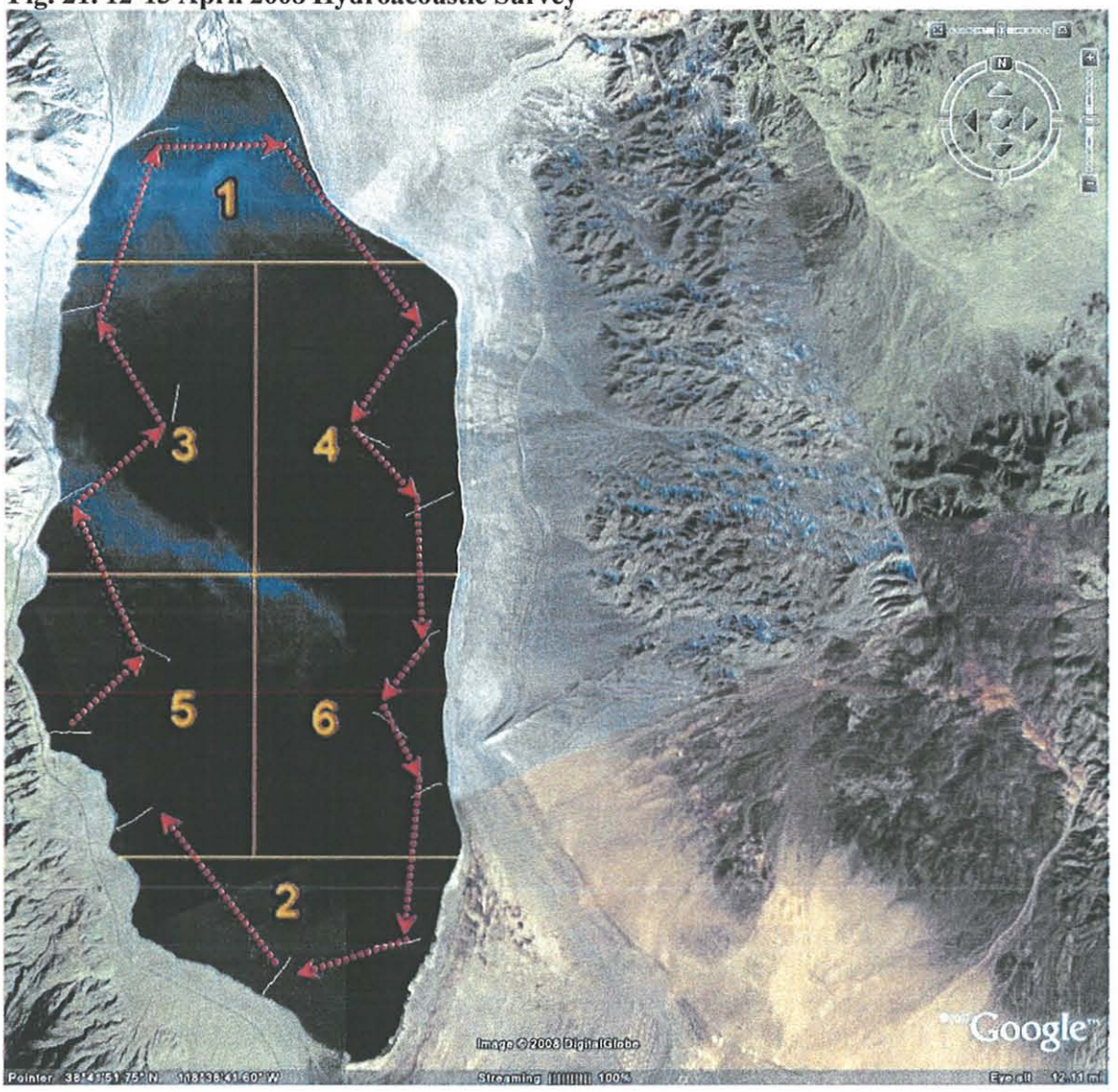
In March 2008 we conducted surveys at varying speeds over gas bubble plumes located in the Cliffs area to determine the optimum speed for bubble identification. Visual analysis of echograms taken from a stationary boat above a plume and at varying speeds from 1.1 to 3.8 kts indicates that positive identification of isolated bubbles is only achievable at the slowest speeds (Fig. 20). At speeds much higher than 1 kt (0.5 m s^{-1}), many bubbles, especially higher in the water column, will return only 1 or 2 echoes.

12-13 April 2008 – Lakewide Nighttime Survey at slow speeds

A nighttime lakewide survey was conducted 12-13 April 2008 employing very slow (0.45-0.68 m s^{-1}) survey speeds to allow differentiation between small fish and gas bubble targets. Sixteen approximately 25-minute transects were taken across the lake beginning at nightfall (2045) near the State Park's ramp and proceeding clockwise around the lake ending near the town of Walker Lake at 0630 in the morning (Fig. 21). Three transects were located in each of the four central sectors of the lake (Sectors 3-6), two

beginning at shore and extending offshore to deep water, and one located in deep water well offshore. In each of the shallower northern and southern sectors of the lake (Sectors 1-2), two transects were conducted beginning at the shore and extending 850-950 m offshore. The decision to locate more transects in the nearshore region was based on previous findings of very few fish in the central portions of the lake.

Fig. 21. 12-13 April 2008 Hydroacoustic Survey



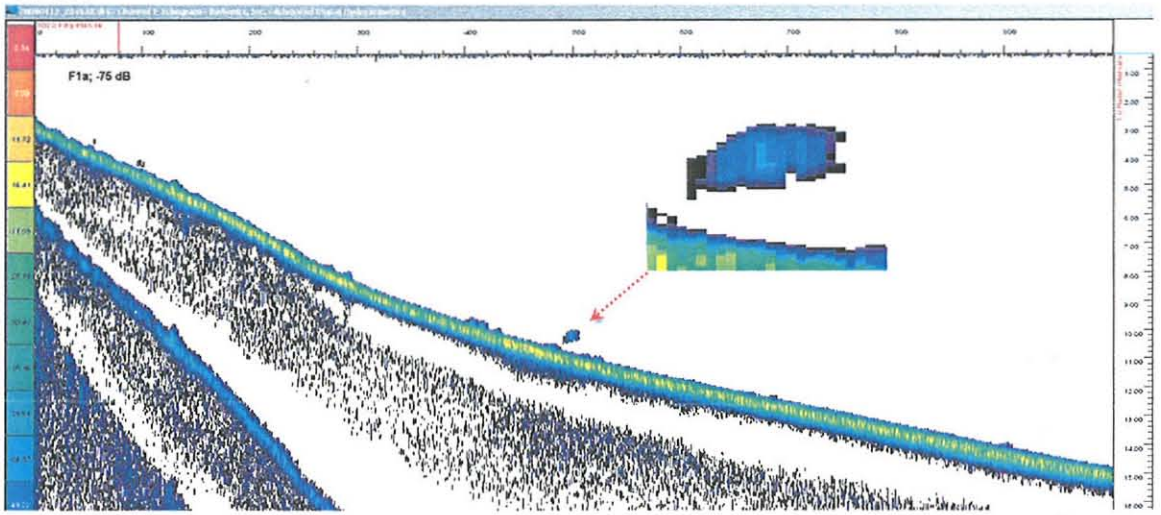
Target recognition

In stark contrast to autumn surveys, acoustic targets in the -75 to -60 dB range were virtually absent in all of the April transects, both near and offshore. This is illustrated by the first portion of the northern nearshore transect in Sector 5 (Fig. 22) where only two small (-72 to -68 dB) targets are present at about 4 m depth. The absence of small targets greatly facilitated individual target recognition and tracking.

The fish target (-40 db) at 10 m depth illustrates the discriminatory abilities associated with slow survey speeds. The first 5-7 pings of this target are rising at ~18 cm s^{-1}, somewhat slower than expected for a gas bubble, and the next 9 pings are at constant depth. Thus, we can conclude this is not a gas bubble.

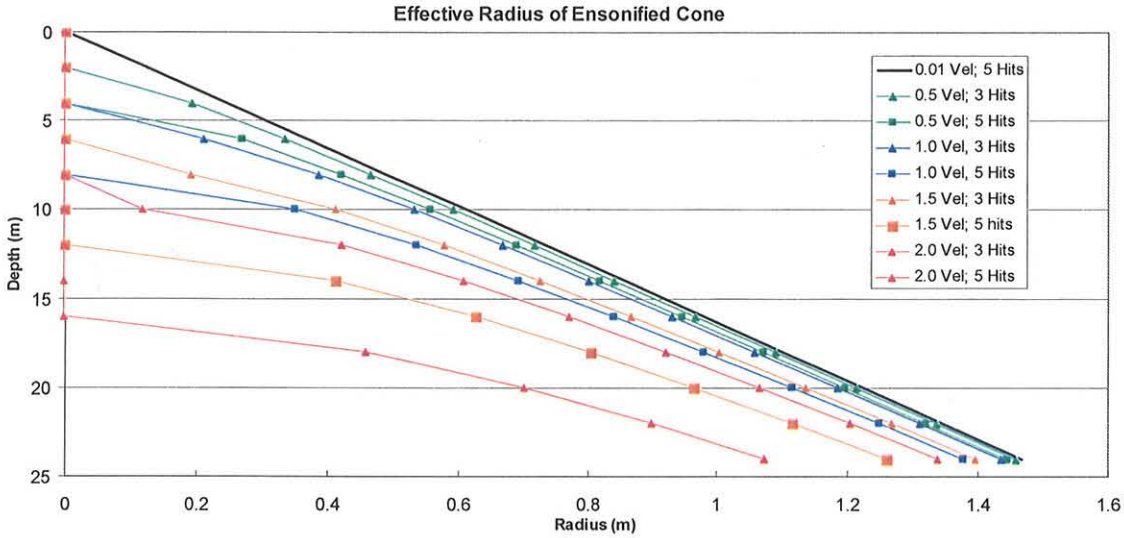
A couple of small (-69 to -66 dB) targets in the next portion of the transect at 2-3 m depth only reflected 2-3 pings and could not be definitely classified as plankton or gas bubbles.

Fig. 22. Portion (1-1000 pings) of northern nearshore transect in Sector 5. Display scale 0 to -75 dB.



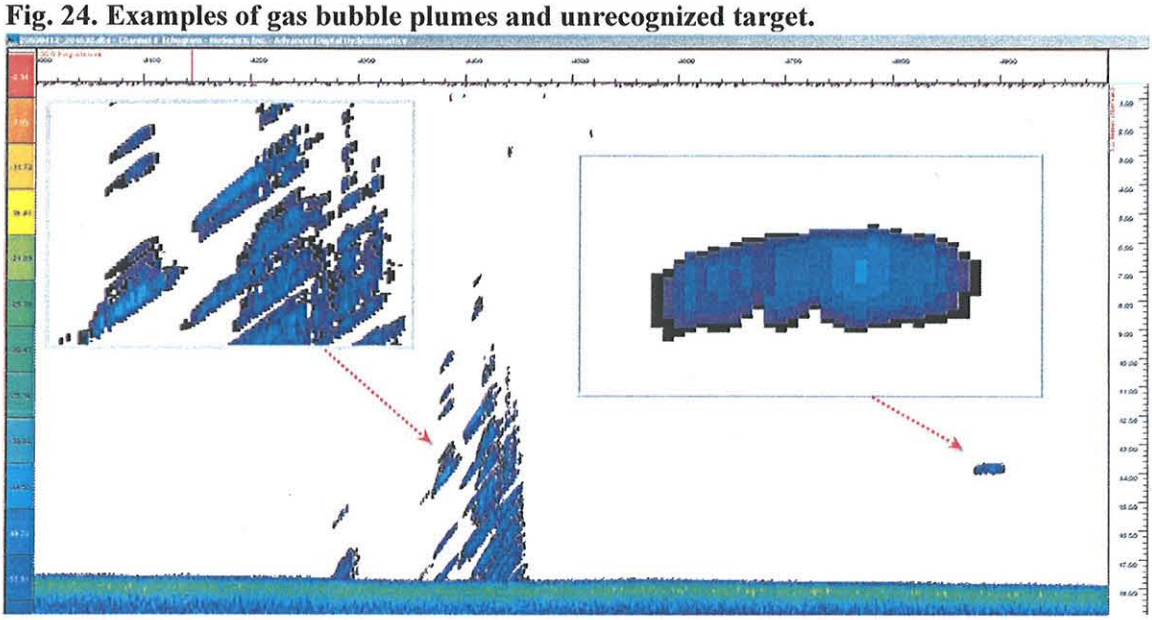
The number of multiple acoustic reflections ("hits") from individual targets depends on the ping rate, boat speed, target depth, and location within the cone of the ensonified volume (Fig. 23). At a boat speed of 0.5 m s^{-1}, no stationary targets above 2 m depth will produce 3 sequential hits as the narrow cone will pass too quickly and no target above 4 m will produce 5 hits. At higher boat speeds, multiple hits from stationary objects only become possible at the deeper depths. While analysis could be limited to those targets displaying multiple sequential hits, this comes at a high cost in terms of the effective volume sampled. The ensonified volumes of vertically-oriented, narrow-beam, split beam tranducers are already quite small. Thus, there is a significant tradeoff between faster boat speeds which sample a larger volume and slower speeds which allow better discrimination of targets.

Fig. 23. Effective radius of ensonified cone for varying velocities and number of "hits".



Further along the same transect a pronounced bubble plume is evident (Fig. 24). The rising velocities of all the targets within this plume were similar (~29 cm s^{-1}). Two of the individual targets within the plume are in the -40 to -44 dB range.

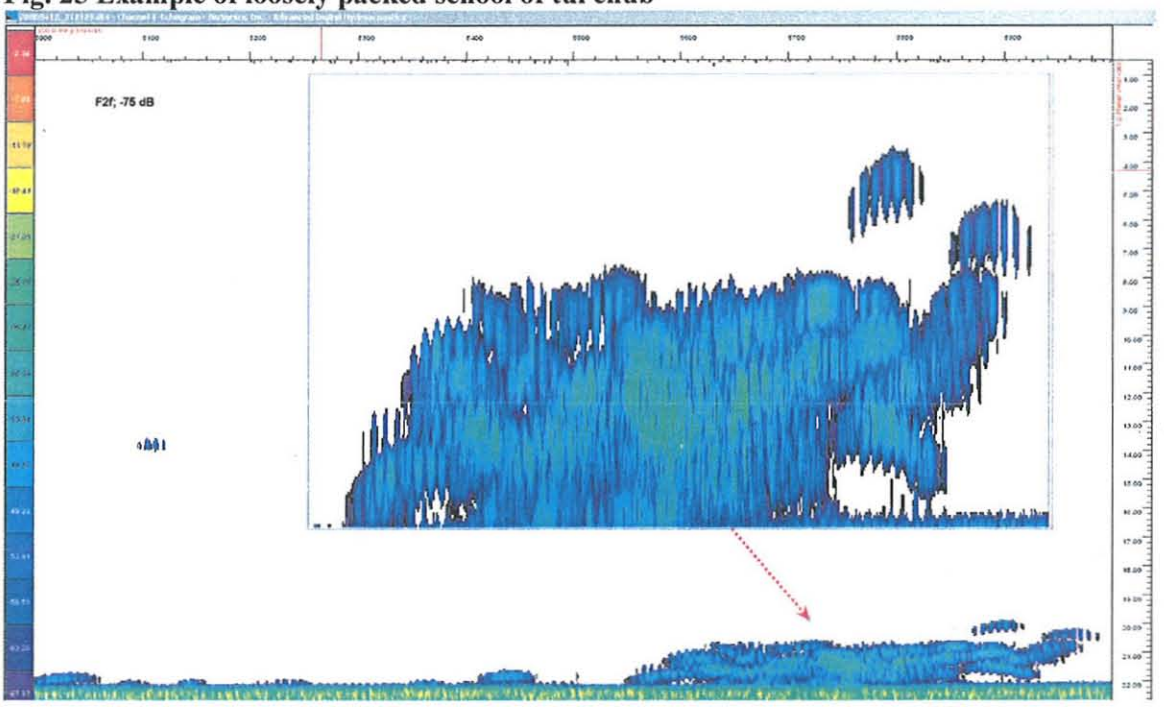
Fig. 24. Examples of gas bubble plumes and unrecognized target.



Within the same portion of this transect an obvious "fish" candidate is present with a strength of -47 dB. However, Biosonic's target recognition program would not recognize this target even when all the optional target recognition parameters were relaxed. The software does not provide information on which criteria excluded this target. There were 41 other "fish" targets like this one among the sixteen April transect that were manually assigned a TS value. While two more bubble plumes were encountered along this transect there were no other isolated targets >-60 dB.

There were two schools of tui chub encountered in offshore transects (Fig. 25). In these cases, the number of individual targets and their target strengths cannot be accurately determined. However, an estimate of the number of individuals can be made based on the visual patterns of the echoes. In this example, 15-25 individuals are estimated to be within the ensonified volume. This is a loosely packed school of fish as the horizontal dimension of this feature is ~40 m. Commercially available 3-dimensional tracking software (e.g. Sonar 5 Pro) would not only facilitate the analysis of widely dispersed individual fish but also enable individual tracking within these loosely packed schools.

Fig. 25 Example of loosely packed school of tui chub



All acoustic targets were classified as gas bubbles, fish, or unknown based on the above considerations. A nominal cutoff of -50 dB (~5 cm) was used to estimate the densities and abundance of tui chub.

Shallow northern and southern sectors (1 & 2)

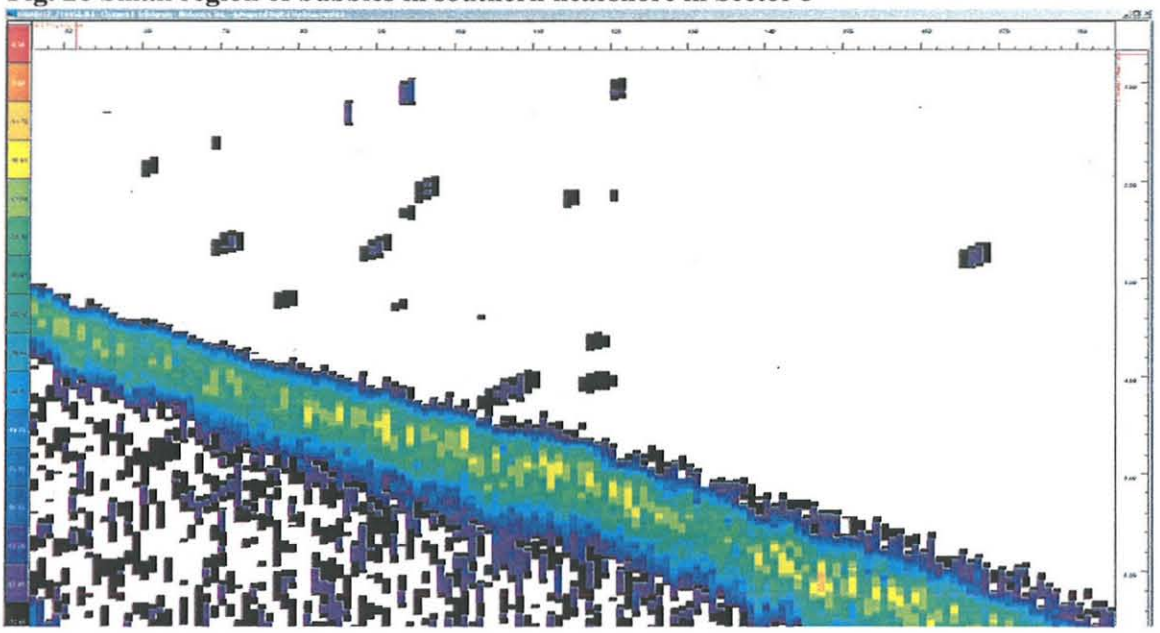
The northwestern nearshore transect of Sector 1 had no targets larger than -56 dB and only four small targets (<-56 dB) of which two had multiple hits and could be identified as non-bubbles. Similarly the northeastern nearshore transect had four small targets (<-56 dB) with two having multiple hits showing zero rising velocity.

The southern shallow portion of the lake (Sector 2) also had no fish targets >-50 dB (~5 cm). Even smaller targets were rare on this transect; only 6 targets in the range -54 to -67 dB.

Northwest (Sector 3)

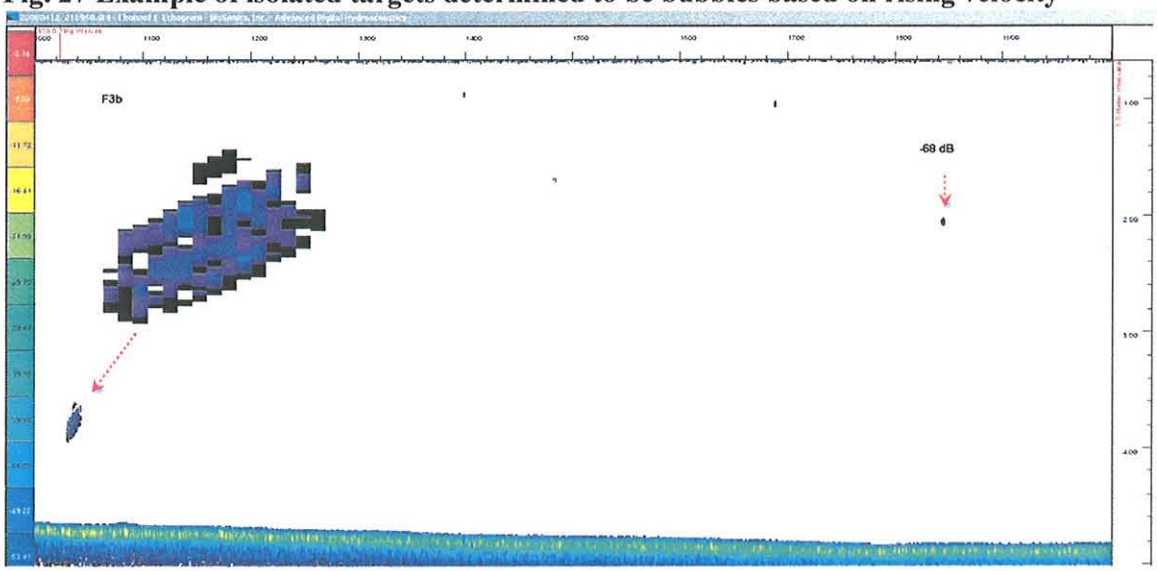
At the beginning of the southern nearshore transect, there was a region of small bubbles (-68 to -63 dB) with average rising velocities of 23.3 cm s^{-1} (Fig. 26). Those bubbles nearer to the surface in the smaller section of the ensonified volume reflected only one or two pings, generally not enough to verify their velocities. While all the targets here were smaller than the range of interest, it will not in general be possible to differentiate between bubbles and small fish in near surface waters where the radius of the ensonified cone is too small to register more than a few hits from individual targets.

Fig. 26 Small region of bubbles in southern nearshore in Sector 3



Further along this transect a pair of small targets (-57 dB) are clearly bubbles given their size and characteristic rising velocity (Fig. 27). There were no probable fish targets >-60 dB along this entire nearshore transect.

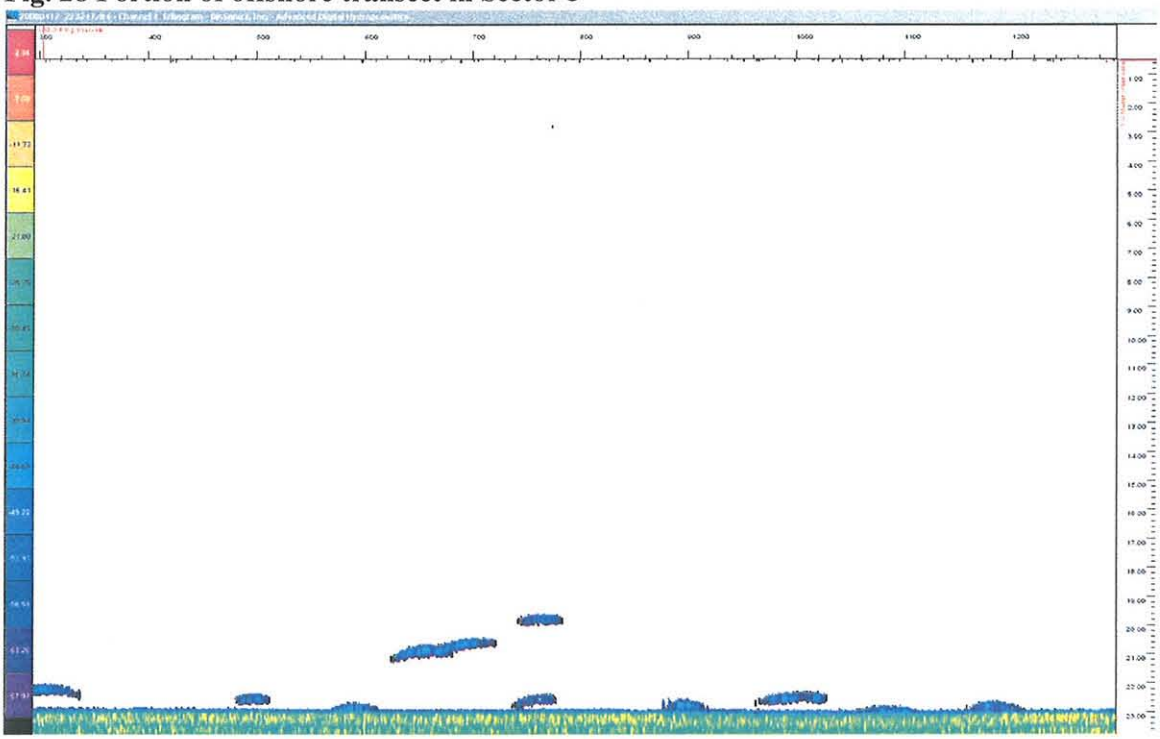
Fig. 27 Example of isolated targets determined to be bubbles based on rising velocity



The northern inshore transect had several small (-66 to -61 dB) shallow targets with too few hits to determine a rising velocity and a single large fish (-42.8 dB) was detected at 12 m depth.

The offshore transect had 19 fish targets ranging from -50 dB (our lower threshold) to -36 dB with no bubble targets greater than -70 dB present (Fig. 28).

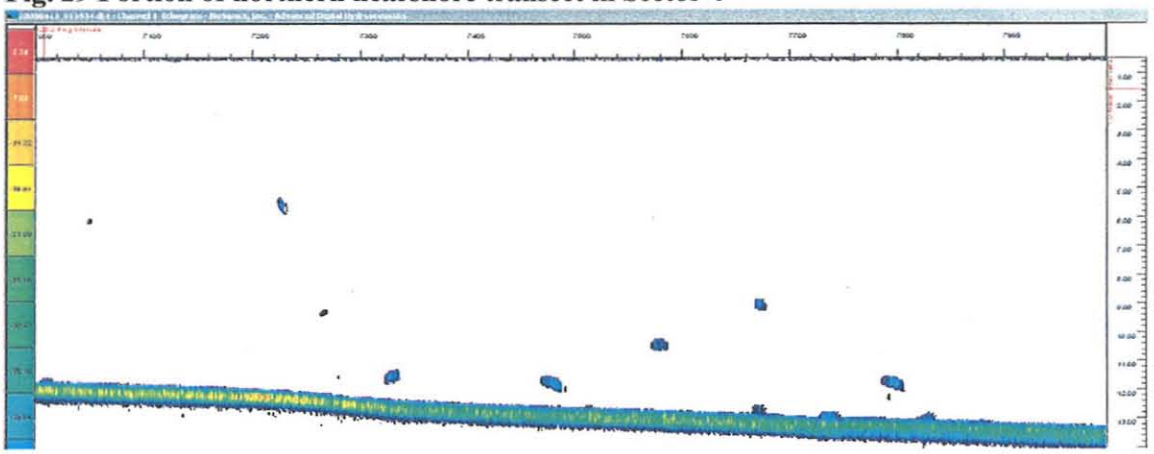
Fig. 28 Portion of offshore transect in Sector 3



Northeast (Sector 4)

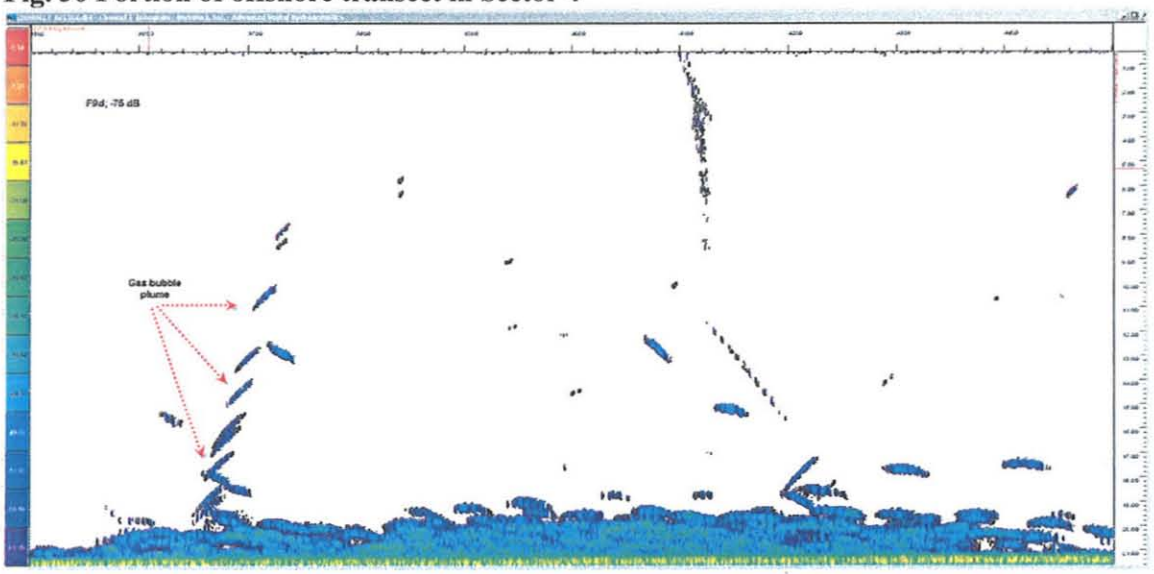
The northern nearshore transect of Sector 4 had a couple small single hit targets nearshore and then a modest (16) number of fish targets (-52 to -34 dB) mostly below 5 m depth (Fig. 29). The southern nearshore transect in this sector had similar (15 targets > -50 dB) abundances and distributions.

Fig. 29 Portion of northern nearshore transect in Sector 4



The offshore transect had much higher abundance as observed in offshore transects in both sectors 3 and 5. There was one particularly large and densely-packed school at 21 m depth adjacent to a large gas bubble vent (Fig. 30). It is not possible to accurately estimate the number in this school without 3-dimensional tracking but the overall pattern suggests 75-125 individuals in the ensonified volume within 2 m of the bottom. While this observation raises the possibility that fish are congregating around vents but there were certainly other gas vents observed with no associated schools of fish.

Fig. 30 Portion of offshore transect in Sector 4



Southwest (Sector 5)

Although several small fish targets were observed in the two nearshore transects in Sector 5, only the single fish target (>-50 dB) discussed above (Fig. 23) was found. Thirty-three individual fish targets (>-50 dB) were found in the offshore transect with an additional 15-25 estimated to be in the previously discussed small school (Fig. 25). Many of the targets are on or near the bottom. Most of the near-bottom targets can be differentiated from the bottom and their target strength estimated. These surveys were collected with a ping duration of 0.3 ms as opposed to the more standard value of 0.5 ms to enhance vertical resolution. It may be possible to achieve even higher vertical resolution with 0.2 ms duration.

Southeast (Sector 6)

The southeast sector was somewhat anomalous in that 6 fish targets >-50 dB were observed along the northern nearshore transect and only 7 fish targets (>-50 dB) were found in the offshore transect. As observed with most the other nearshore transects, only a single fish (>-dB) was observed along the southern nearshore transect.

18 April Repeat Survey of Offshore Stations

On 18 April the four offshore transect were taken at approximately the same locations as those on 12 April. All four offshore transects were remarkably devoid of individual fish (>-50 dB); 1, 0, 1, and 4 at NW, NE, SW, and SE, respectively. Three large unidentified acoustic targets were observed that were 12, 6, and 4 m long (Fig. 31 shows the largest). These may be dense schools of tui chub, reflecting differences in their nighttime versus daytime behavior. By relaxing Biosonic's target recognition parameters 52 individual targets were identified within this object. They are scattered about in both horizontal directions as you would expect in a school (Fig. 32). The ensonified volume is ~2.5 m in diameter at that depth. However, this does not allow a definitive conclusion as to daytime schooling and nighttime dispersal as it is also possible that the tui chub simply moved out of the deep waters as the water temperature warmed in the intervening week.

Fig. 31 Large acoustic object that may be a dense school of tui chub

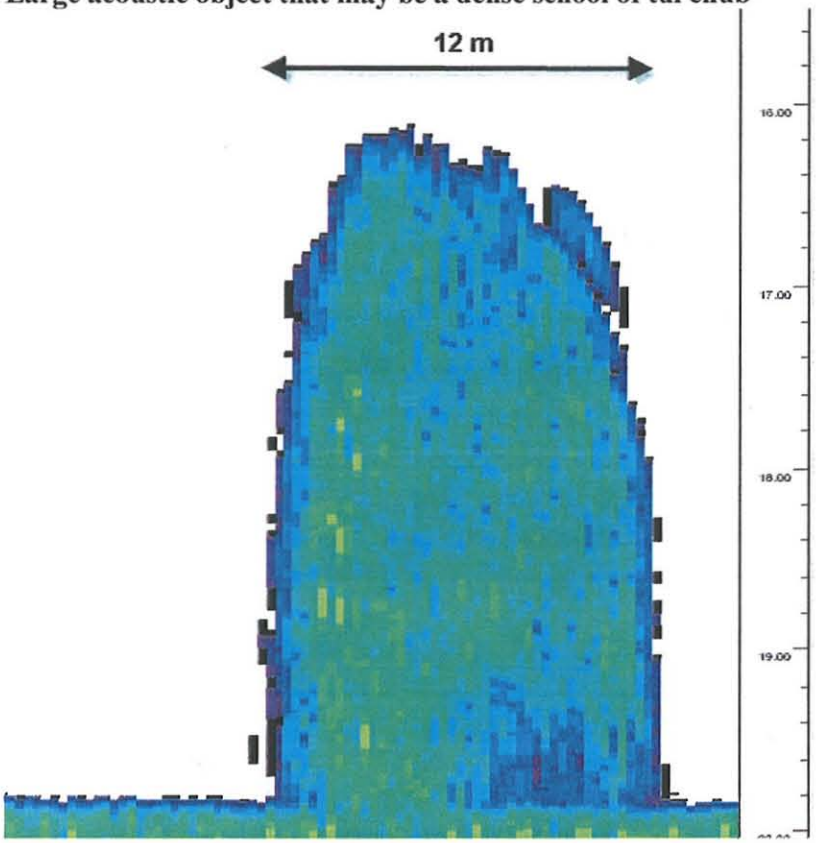
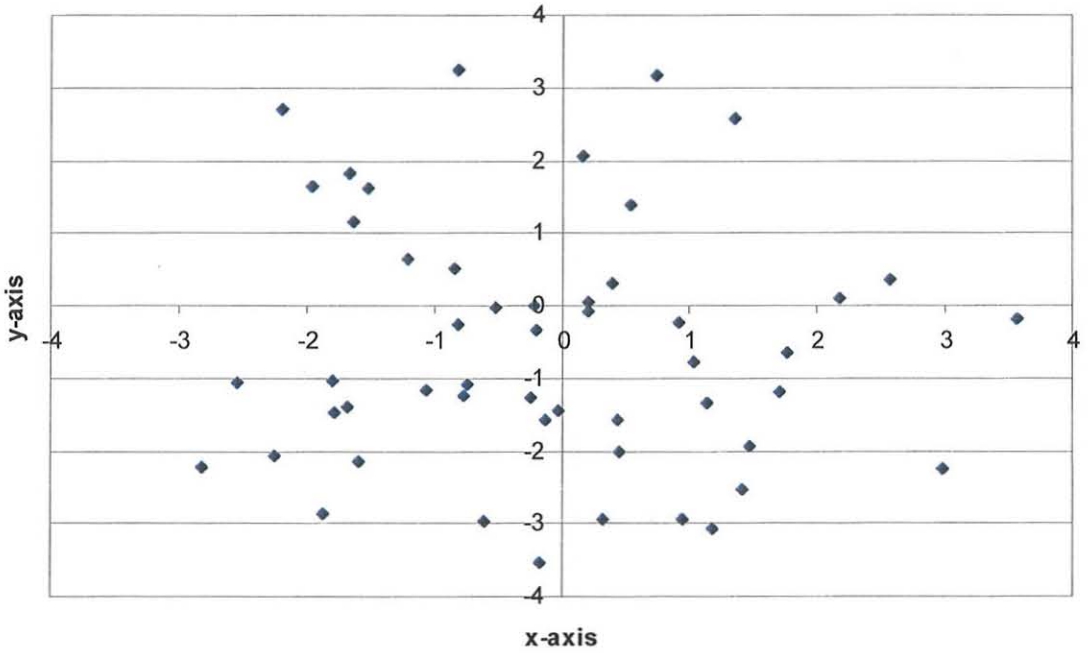


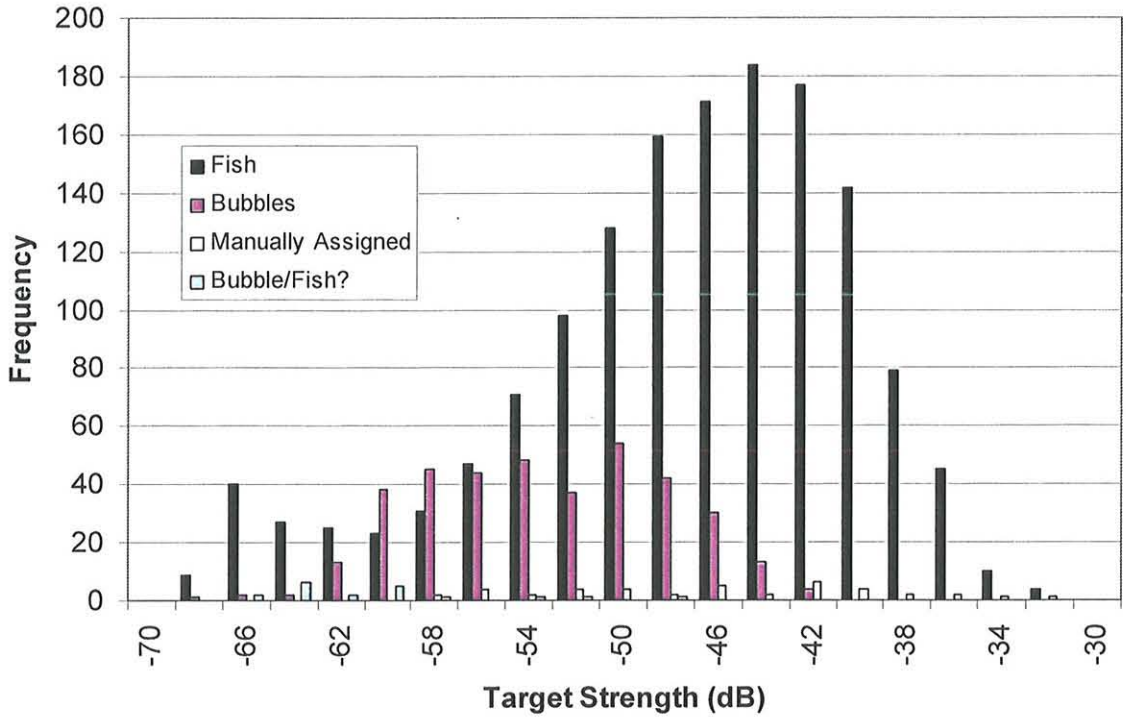
Fig. 32 Breakdown of targets identified during April daytime survey



April Survey Summary

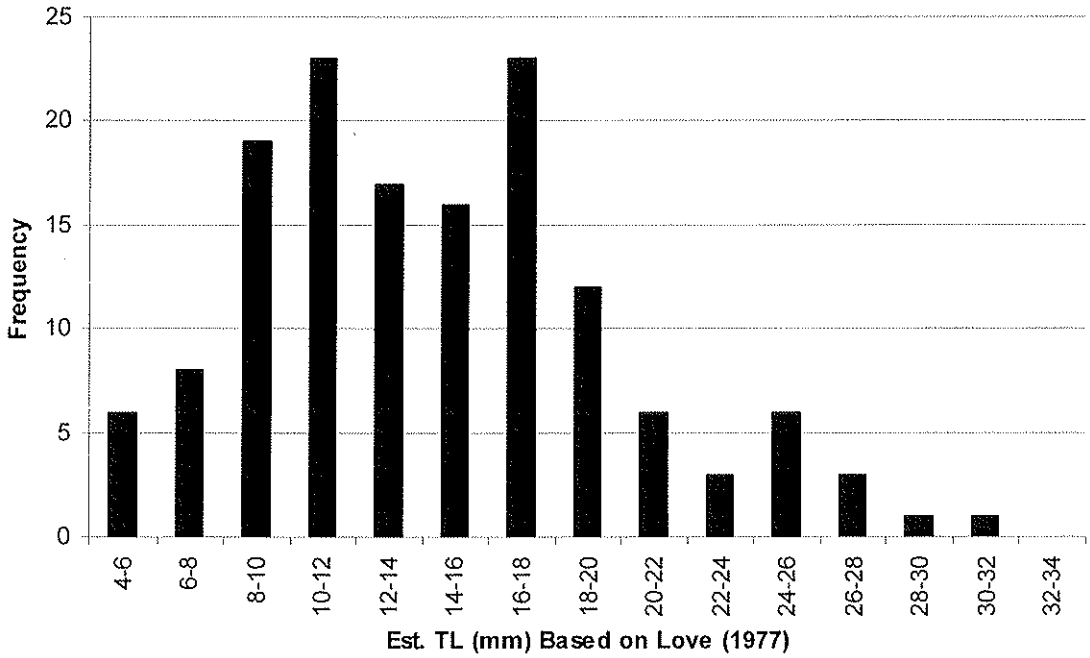
Sixteen transects dispersed across the entire lake and totaling 14.1 km were taken during a nighttime hydroacoustic survey on 12-13 April 2008. The transects were collected at an average speed of only 0.57 m s^{-1} to allow discrimination between fish and gas bubbles. A total of 1903 targets >-70 dB were recorded; 1470 fish targets recognized by Biosonic's target analysis program, 41 fish targets identified manually, 373 gas bubbles, and 19 small targets whose rising velocity could not be determined due to too few ping echoes (Fig. 33). As observed in the autumn transects, gas bubbles significantly overlapped with the target strengths of small fish. The manually assigned fish were scattered across the TS distribution and the indeterminate targets were almost all <-50 dB.

Fig. 33 Breakdown of targets identified during April nighttime survey



Many of the fish targets were multiple echoes from the same individual and target tracking analysis resulted in only 156 individual fish from the 1470 fish echoes giving an average of 9.4 echoes from each individual fish target. The size distribution of these individuals, including the 41 manually identified targets, show a population dominated by 1-4 yr olds not unlike that derived from the autumn surveys (Fig. 34).

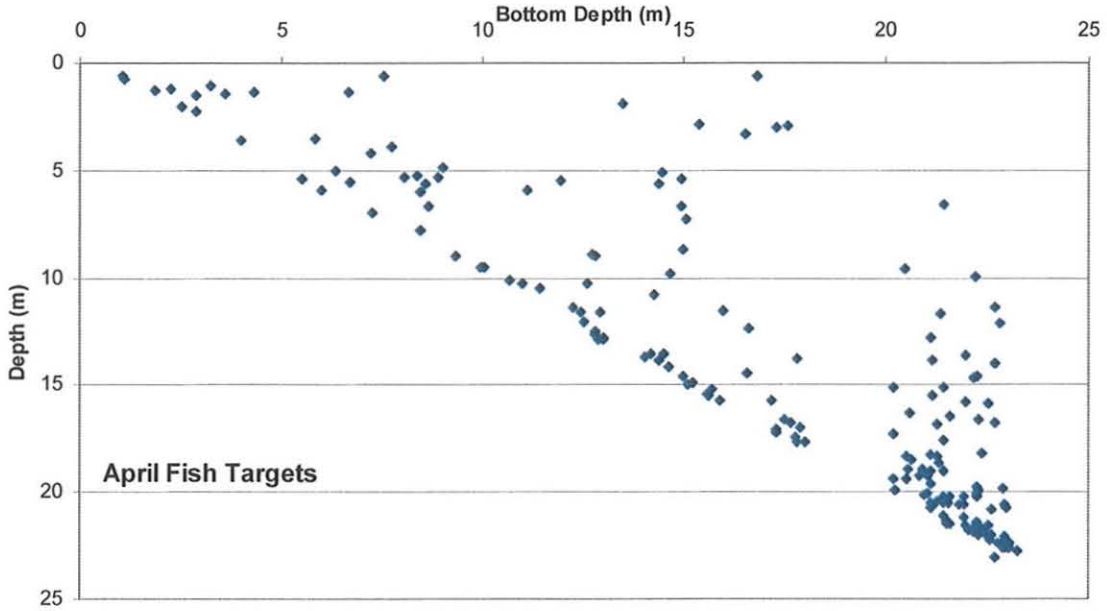
Fig. 34 Size distribution of individual fish targets from the 12-13 April 2008 survey



The individual targets were found throughout the water column from nearshore to offshore (Fig. 35). While 64% of individual targets were found below 10 m depth, this is almost exactly proportional to the larger volume ensonified at greater depths. Sixty-two percent of the total ensonified volume of 167,000 m^3 was beneath 10 m depth. However, this does not include the 120 individuals estimated in the two observed schools.

While a larger sample size is required to make an accurate estimate of lakewide fish density, we provide a tentative estimate here to put the current numbers in context. The average fish densities in 5-m depth intervals based on the 16 transects were 0.1, 0.4, 1.5, 1.7, and 11.7 per 1000 m^3 for 0-5, 5-10, 10-15, 15-20, and 20-25 m depth respectively. The total lakewide estimate is 3.2 million fish or ~250 fish ha^{-1}.

Fig. 35. Location of individual fish targets (>-50 dB)



Discussion & Recommendations

The goals of this hydroacoustic study were to estimate lakewide tui chub density and assess the feasibility of employing hydroacoustic techniques to monitor changes in tui chub recruitment and survivorship. In addition to the large size of Walker Lake and often windy conditions, several other features of Walker Lake complicate achieving these goals. These include 1) extensive macrophyte development around the lake, 2) numerous gas seeps and isolated gas bubbles (presumably methane) throughout the water column during much of the year, 3) unknown size distribution of YOY and 1-yr olds coupled with an uncertain TS versus length relationship, 4) abundant small non-bubble acoustic targets, and 5) behaviors of tui chub including schooling, seeking refuge in macrophytes, and lying close to the bottom. Although none of these problems are insurmountable, a cost is associated with addressing each of these difficulties.

It is unreasonable to estimate tui chub abundance during the period when large areas of macrophytes are present. In the Diamond Lake hydroacoustic study of tui chub abundance, Eilers & Gubala (2003) simply sampled the open water (>6 m depth). However, based on fish counts following a rotenone treatment they suggest that up to 90% of the population might have been in the macrophyte beds. They also observed up to a 10-fold change in open-water densities between day and night transects. Given these factors only a very rough population estimate could be made without knowing the details of tui chub behavior and exactly what proportion of the population is within the macrophyte beds at any given time. For this reason, we scheduled surveys in autumn after a large part of the macrophytes had died back. The April surveys were even better in this respect with the additional benefit that almost all the smaller non-fish, non-bubble targets were absent during cold spring conditions.

Walker Lake is a productive water body lying in a highly faulted basin. The presence of abundant gas bubble plumes and isolated methane bubbles will severely bias results unless sophisticated analyses are used. In some hydroacoustic studies, authors simply censor data to eliminate bubble targets. However, the target strength of a large portion of bubbles in Walker Lake overlap those expected from YOY and 1-yr old fish (-50 to -40 dB). Therefore, we conducted surveys at slow (0.5 m s^{-1}) speeds which allowed the calculation of rising velocities based on multiple echoes from individual targets. As the rising velocity of bubbles in the observed size ranges is tightly constrained (22-31 cm s^{-1}) this allowed us to censure the bubbles from the target data. It provided the added benefit of being able to calculate a mean backscattering coefficient for individual targets based on an average of 9-10 echoes. This procedure was very labor intensive in absence of 3-dimensional tracking software. More sophisticated 3-d target tracking software (e.g. Sonar 5 Pro) should be used in the future.

Bubble ebullition in lakes is affected strongly by changes in hydrostatic pressure (Mattson & Likens 1987). Bubble production increases during periods of falling lake level or low pressure systems. The March-April period of stable or slightly increasing lake level is better suited to this work then autumn when lake levels are declining.

The exact relationship between TS and fish length for tui chub is not known. While many hydroacoustic studies employ the general relationships derived by Love (1971, 1977) others have noted significant variation among different species (see Simmonds & MacLennan 2005 for a thorough review). The size-frequency distribution of acoustical targets >-42 dB collected during the autumn surveys was consistent with the NDOW and FWS gill and trap net results. However, a more comprehensive validation is warranted. During the 18 April survey, hydroacoustic readings were taken adjacent to the trap netters as they released measured tui chub. Although 8-10 approximately 125 mm (FL) tui chub were released in the proximity of the echosounder only a single fish swam through the beam. Nineteen echoes were recorded from this fish ranging from -53 to -33 dB with a mean of -41.4 dB. The estimated FL of a -41.4 dB fish target is 125 mm. While a single fish cannot provide confirmation of the relationship, this does illustrate how a fuller validation could be achieved. I propose to hang a 2 m diameter open-bottomed limno-corral beneath the echosounder into which individuals of known length can be inserted one at a time.

Early April conditions were optimal for estimating lakewide abundance of tui chub. Macrophytes were almost entirely absent and gas bubbles and other non-fish targets greatly reduced. Conducting the surveys at slow speeds allowed differentiation between bubbles and fish targets. However, 14 km of transects did not produce enough fish targets to derive a lakewide estimate with reasonable confidence limits especially given the presence of schooling behavior. I suggest a Monte Carlo bootstrap procedure in which the statistics of many random subsets of transects are calculated is the most appropriate procedure for estimating confidence limits. Four times as many transects with 800-1000 total targets is probably appropriate for this analysis. This could probably be accomplished over a week-long period of nightly surveys.

Fig. 36. Released tui chub (~125 mm) detected swimming down beneath the echosounder

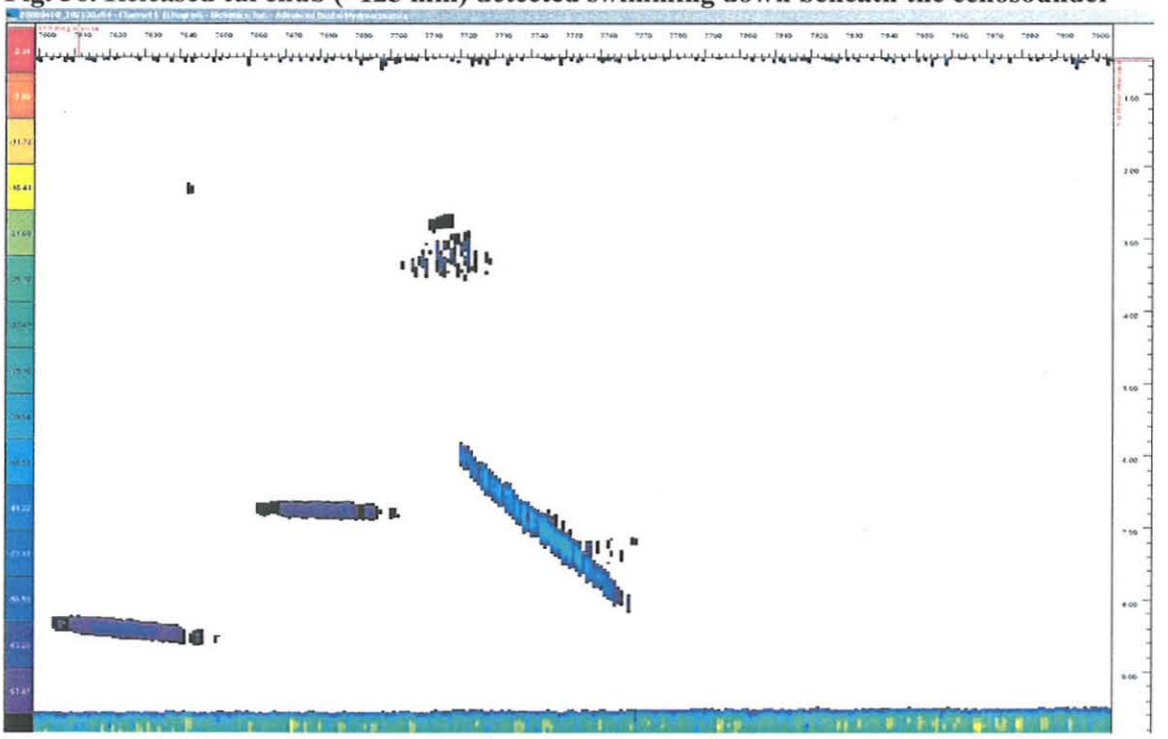
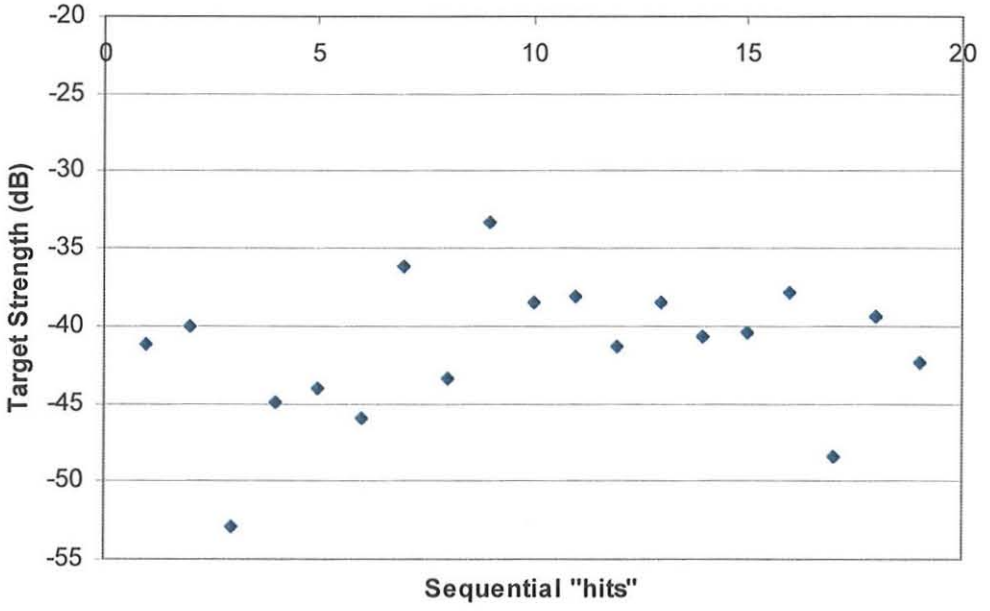


Fig. 37. Target size readings of released tui chub (TS -41.4 dB; est. TL = 136 mm)



Although little confidence can be placed on a lakewide estimate based on so few fish, our estimate of 3.2 million fish or ~250 fish ha^{-1} is not unreasonable based on other studies. Jackson et al. (2003) estimated 600,000 tui chub (489 fish ha^{-1}) in the much smaller Diamond Lake based on mark-recapture methods. Although Eilers & Gubala (2003) estimated over 10,000,000 tui chub in Diamond Lake, it is clear from their size-frequency data (Fig. 38) and one of their echograms that they were mostly counting gas

bubbles (Fig. 39). Note that nearly all the targets in their nighttime echogram display the characteristic constant upward velocity of gas bubbles. I found no other hydroacoustic studies of tui chub for comparison.

Fig. 38. Frequency distribution of acoustic targets in Diamond Lake (Reprinted from Eilers and Gubala (2003))

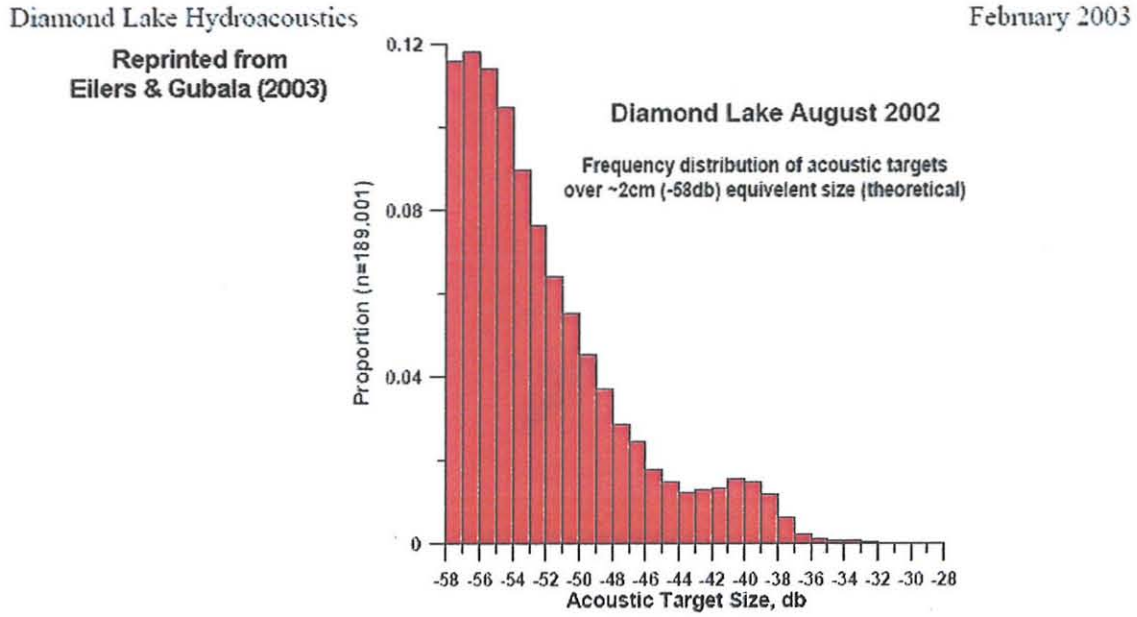


Figure 15. Frequency distribution of acoustic targets, greater than -58 db.

Fig. 39. Echogram from Diamond Lake showing daytime schools and dispersed "tui chub" at night Diamond Lake (Reprinted from Eilers and Gubala (2003))

Diamond Lake Hydroacoustics February 2003

Reprinted from Eilers & Gubala

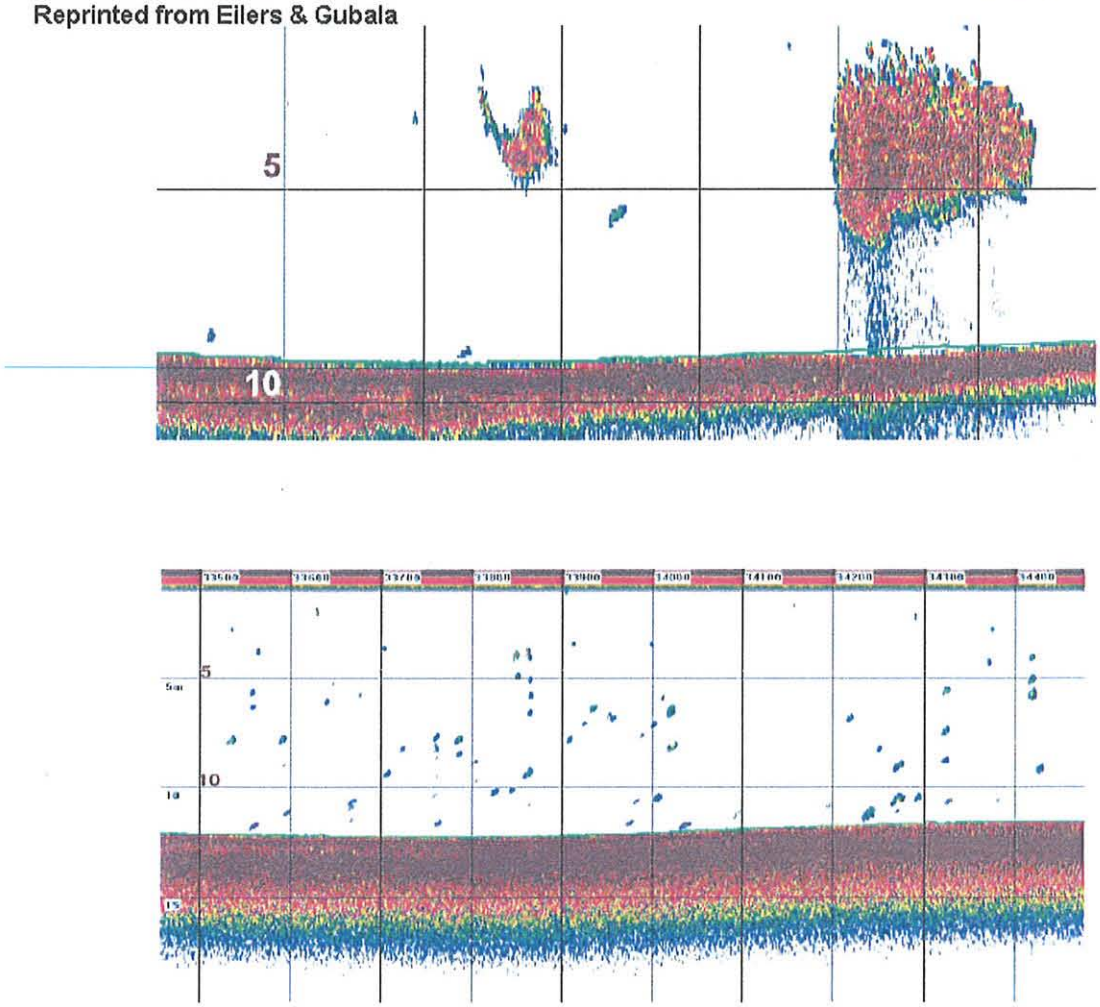


Figure 6. Echograms of Diamond Lake showing a school of tui chub observed during the day (top) and dispersed tui chub targets observed during the night (bottom)

Although a number of hydroacoustic studies of salmonids have been published there are only a few of forage fishes. Beauchamp et al. (1997) found kokanee and shiner densities of 140-760 ha^{-1} across a series of lakes in Idaho. Hrabik (2006) found densities of prey fish in the upper 80 m of several management areas in Lake Superior to be 447 ha^{-1}. Taylor et al. (2005) found shad and herring at 56-60 ha^{-1} in a 21 km^2 impoundment in North Carolina.

Hydroacoustic surveys at Walker Lake have the potential to provide management and monitoring information not easily obtained by active net-based methods. However,

this first year has highlighted the difficulties and limitations of employing hydroacoustic methods to assess tui chub population dynamics. I propose the following activities and modifications of the survey protocols this year to allow a full evaluation of it's efficacy versus more traditional net-based methods.

Recommendations

1) An experiment in which trap-netted individuals are placed in a limno-corral mounted below the hydroacoustic transducer be carried out to derive a tui chub specific TS vs length relationship.

2) Sonar5 Pro, or other tracking software which includes 3-d individual target tracking, be evaluated for purchase.

3) An annual tui chub survey be conducted in late March or early April over a period of 4-5 consecutive nights to provide enough targets for a lakewide population estimate and evaluation of confidence intervals.

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Chapter 5
Distribution of Walker Lake macrophytes

Introduction

Horne et al. (1994) noted the presence of extensive beds of the aquatic grass, *Ruppia marina*, and the filamentous green alga, *Cladophora*, in the littoral zone at 3-6 m depth. They estimated a mean biomass of 880 g wet weight m^{-2} along 50-m transects perpendicular to the shore. These extensive beds represent a significant proportion of the lake's primary production and directly affect the benthic macroinvertebrate community and tui chub population by providing food and refuge. Changes in the extent and productivity of these beds accompanying salinity and lake levels changes is likely to directly affect all trophic levels including the LCT.

We proposed to map the spatial extent of macrophytes during the peak annual biomass using hydroacoustic methods similar to those employed at Diamond Lake, Oregon (Eilers and Gubala 2003).

Methods

Following consultation with Biosonic's technical support we initially proposed to run lakewide transects parallel and at several different distances from shore to map the spatial extent and height of macrophytes. We began taking hydroacoustic transects on 27 August and it quickly became apparent that it would not be possible to take transects over long distances through fully-developed macrophyte beds. We modified the proposed sampling design to taking 28 transects perpendicular to the shore at ~ 2 km intervals around the lake. Each transect was begun at a depth beyond the growth of macrophytes (~10 m depth) and run directly toward shore (Fig. 1).

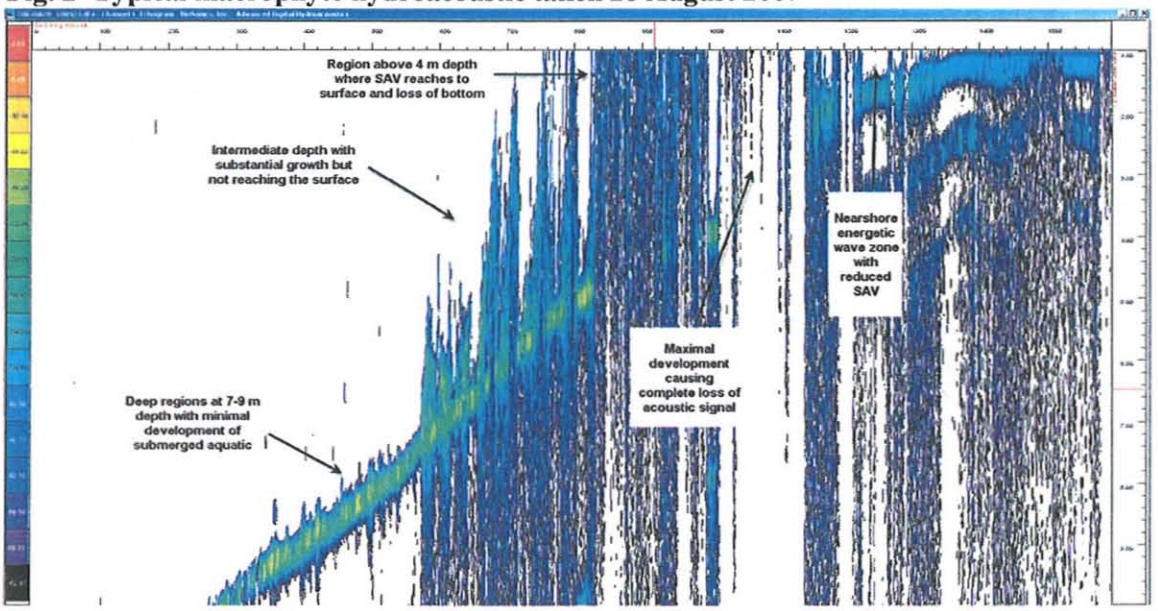
Results & Discussion

A representative echogram illustrates the main features of these transects (Fig. 2). Some submerged aquatic vegetation (SAV) appears between 7 and 9 m in most transects. More extensive development occurs at 5-7 m depth but few plants reach the surface. At 4-5 m depth SAV mostly reaches the surface and the bottom acoustic signal is lost. At 1.5 – 4 m depth maximal SAV development occurs and the entire acoustic signal is lost due to reflection right at the surface. Shallower than 1.5 m depth a zone of energetic wave action reduces the SAV percent cover to 10-50% or even less in sandy areas. We attempted to apply Biosonic's EcoSAV software in an automated fashion to determine both percent cover and vegetation height. However, comparison between output using recommended default parameters and the visual inspection of the echograms revealed significant discrepancies. The plant recognition algorithm of the software has a suite of tunable parameters which we are currently experimenting with to achieve better results. We do not expect to have this completed before the end of the year.

Even if the automated algorithm does not produce reliable results of Walker Lake's Ruppia beds, the echograms clearly show that information necessary to mapping the extent of the macrophyte beds can be extracted. Thus, we are proceeding with this year's macrophyte surveys as proposed in the task agreement extension. This includes taking repeated hydroacoustic measurements over a selected subset of the original transects at roughly two week intervals to determine the replicability of the data and how much the areal extent of the macrophyte beds change during the presumed period of maximum development. We are planning to conduct hydroacoustic surveys on three dates approximately two weeks before, on or about 29 August, and two weeks after to assess late seasonal change.

Fig. 1 Macrophyte hydroacoustic transects taken 28 August 2007

Fig. 2 Typical macrophyte hydroacoustic taken 28 August 2007



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