# Chapter 5

# Mono Basin Waterfowl
# Habitat and Population Monitoring
# 2008-09

# Mono Lake Waterfowl Restoration Project
# Compliance Checklist
# 2008

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Brian White

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† Several weekly elevation reads missed due to inclement weather.

‡ Due to equipment malfunctions, some CTD and meterological data were not collected

# APPENDIX 1

# Limnology

## 2008 ANNUAL REPORT

# MIXING AND PLANKTON DYNAMICS IN MONO LAKE, CALIFORNIA

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# EXECUTIVE SUMMARY

Limnological monitoring of Mono Lake was conducted during 2008 as part of a long-term monitoring program begun in 1982. Chapter 1 describes the seasonal plankton dynamics observed from 1979 through 2007, a period which encompassed a wide range of varying hydrologic and annual vertical mixing regimes including three periods of persistent chemical stratification or meromixis (1983–1988, 1995–2003, 2005–2007). In brief, long-term monitoring has shown that Mono Lake is highly productive compared to other temperate salt lakes, that this productivity is nitrogen-limited, and that year-to-year variation in the plankton dynamics has largely been determined by the complex interplay between varying climate and hydrologic regimes and the resultant seasonal patterns of thermal and chemical stratification which modify internal recycling of nitrogen. The importance of internal nutrient cycling to productivity is highlighted in the years immediately following the onset of persistent chemical stratification (meromixis) when upward fluxes of ammonium are attenuated and during the breakdown of meromixis when ammonium supply is increased.

Local climatic variation and these year-to-year variations in the mixing and nutrient environments have largely prevented accurate assessment of the effects of changing salinity over the range observed during the period of regular limnological monitoring (1982-present). However, the last five years confirm that there has been a significant increase in the size of the 1st generation of adult *Artemia* and a more rapid autumn decline in *Artemia* accompanying the general decrease in salinity from 1982 to present.

Laboratory, field, and analytical methods are described in Chapter 2 and the results of the 2008 limnological monitoring program including a number of integrative measures encompassing the long-term record (1982–2008) are presented in Chapter 3.

During 2008, limited hatching of over-wintering cysts had already begun by the 21 February survey, and increased during both March and April. While the abundance of 1st generation adults was lower than that observed in 2004–2007, it was still higher than most years of record. A large pulse of ovoviviparous reproduction by 1st generation adults occurred in late May and early June, but recruitment of these young into the adult population was low and there was no midsummer July increase in adults. The abundance of adults declined through July and by September was the 2nd smallest adult population observed and were virtually absent ($<200$ m$^{-2}$) in mid-October. Adult abundance was also near zero in October 2002, 2006, and 2007. While the virtual absence of adult *Artemia* in mid-October is unusual, low ($<5{,}000$ m$^{-2}$) mid-October abundances were also observed in 1986, 2000, 2003, and 2004. This pattern continues the recent trend of larger first generations followed by little late summer recruitment and rapid autumn declines.

The estimated 2008 primary production was 1,189 g C m$^{-2}$. This was significantly lower than observed in 2007 during the breakdown of 2-yr episode of meromixis, but well above the long-term (1982–2008) mean of 659 g C m$^{-2}$. Annual average *Artemia* biomass in 2008, an index of secondary production, was 5.8 g m$^{-2}$ or 36 % below the long-term mean of 9.0 g m$^{-2}$. Total annual cyst production in 2008 (3.1 million m$^{-2}$) was 29 % below the long-term mean of 4.3 million m$^{-2}$.

Annually-filtered (365-day running mean) mixed-layer chlorophyll *a* concentration and adult *Artemia* abundance provide two measures of long-term ecological trends. They both highlight the role of year-to-year changes in the annual mixing regime (meromixis/monomixis), the muted response of *Artemia* relative to phytoplankton, and the absence of any marked long-term trend over the period 1982–2008. While neither measure indicates a long-term trend in phytoplankton or *Artemia* abundance, it is clear that abundance of adult *Artemia* has shifted earlier in the year.

## ACKNOWLEDGMENTS

This work was supported by a grant from the Los Angeles Department of Water and Power to R. Jellison and J. M. Melack at the Marine Science Institute, University of California, Santa Barbara. Laboratory work was performed at the Sierra Nevada Aquatic Research Laboratory, University of California. Kimberly Rose assisted with all aspects of the monitoring program including field sampling, laboratory analyses, and data analysis.

# LIMNOLOGICAL MONITORING COMPLIANCE

This report fulfills the Mono Lake limnological monitoring requirements set forth in compliance with State Water Resources Control Board Order Nos. 98-05 and 98-07. The limnological monitoring program consists of four components: meteorological, physical/chemical, phytoplankton, and brine shrimp population data. Meteorological data are collected continuously at a station on Paoha Island, while the other three components are assessed on monthly surveys (except January) supplemented by additional surveys as conditions warrant. A summary of previous monitoring is included in Chapter 1, the methodology employed is detailed in Chapter 2, and results and discussion of the monitoring conducted during 2008 and long-term integrative measures presented in Chapter 3. The relevant pages of text, tables, and figures for the specific elements of each of the four required components are given below.

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# CHAPTER 1
# INTRODUCTION

## Background

Saline lakes are widely recognized as productive aquatic habitats, which in addition to harboring distinctive assemblages of species, often support large populations of migratory birds. Saline lake ecosystems throughout the world are threatened by decreasing size and increasing salinity due to diversions of freshwater inflows for irrigation and other human uses (Williams 1993, 2002); notable examples in the Great Basin of North America include Mono Lake (Patten et al. 1987), Walker Lake (Cooper and Koch 1984), and Pyramid Lake (Galat et al. 1981). At Mono Lake, California, diversions of freshwater streams out of the basin beginning in 1941 led to a 14 m decline in surface elevation and an approximate doubling of the lake's salinity.

In 1994, following two decades of scientific research, litigation, and environmental controversy, the State Water Resources Control Board (SWRCB) of California issued a decision to amend Los Angeles' water rights to "establish fishery protection flows in streams tributary to Mono Lake and to protect public trust resources at Mono Lake and in the Mono Lake Basin" (Decision 1631). The decision restricts water diversions until the surface elevation of the lake reaches 1,948 m (6391 ft) and requires long-term limnological monitoring of the plankton dynamics.

Long-term monitoring of the plankton and their physical, chemical, and biological environment is essential to understanding the effects of changing lake levels. Measurements of the vertical distribution of temperature, oxygen, conductivity, and nutrients are requisite for interpreting how variations in these variables affect the plankton populations. Consistent methodologies have been employed during the 29-yr period, 1979–2008, and have yielded a standardized data set from which to analyze seasonal and year-to-year changes in the plankton. The limnological monitoring program at Mono Lake includes the interpretation of a wide array of limnological data collected during monthly surveys conducted during February through December.

## Seasonal Mixing Regime and Plankton Dynamics

Limnological monitoring at Mono Lake can be divided into several periods corresponding to two different annual circulation patterns, meromixis and monomixis, and the transition between them.

### *Monomictic and declining lake levels, 1964–82*

The limnology of Mono Lake, including seasonal plankton dynamics, was first documented in the mid 1960s (Mason 1967). During this period Mono Lake was characterized by declining lake levels, increasing salinity, and a monomictic thermal regime. No further limnological research was conducted until summer 1976 when a broad survey of the entire Mono Basin ecosystem was conducted (Winkler 1977). Subsequent studies (Lenz 1984; Melack 1983, 1985) beginning in 1979, further described the seasonal dynamics of the plankton. During the period 1979–81, Lenz (1984) documented a progressive increase in the ratio of peak summer to spring abundances of adult brine shrimp. The smaller spring generations resulted in greater food availability and much higher ovoviviparous production by the first generations, leading to larger second generations. Therefore, changes in the size of the spring hatch can result in large changes in the ratio of the size of the two generations.

In 1982, an intensive limnological monitoring program funded by LADWP was established to monitor changes in the physical, chemical, and biological environments in Mono Lake. This monitoring program has continued to the present. Detailed descriptions of the results of the monitoring program are contained in a series of reports to LADWP (Dana *et al.* 1986, 1992; Jellison *et al.* 1988, 1989, 1990, 1991, 1994, 1995a, 1996a, 1997, 1998a, 1999, 2001, 2002, 2003; Jellison and Melack 2000; Jellison 2004, 2005, 2006) and are summarized below.

*Meromixis, 1983–87*

In 1983, a large influx of freshwater into Mono Lake resulted in a condition of persistent chemical stratification (meromixis). A decrease in surface salinities resulted in a chemical gradient of ca. 15 g total dissolved solids $l^{-1}$ between the mixolimnion (the mixed layer) and monimolimnion (layer below persistent chemocline). In subsequent years evaporative concentration of the surface water led to a decrease in this gradient and in November 1988 meromixis was terminated.

Following the onset of meromixis, ammonium and phytoplankton were markedly affected. Ammonium concentrations in the mixolimnion were reduced to near zero during spring 1983 and remained below 5 µM until late summer 1988. Accompanying this decrease in mixolimnetic ammonium concentrations was a dramatic decrease in the algal bloom associated with periods when the *Artemia* are less abundant (November through April). At the same time, ammonification of organic material and release from the anoxic sediments resulted in a gradual buildup of ammonium in the monimolimnion over the six years of meromixis to 600 to 700 µM. Under previous monomictic conditions, summer ammonium accumulation beneath the thermocline was 80–100 µM, and was mixed into the upper water column during the autumn overturn.

*Artemia* dynamics were also affected by the onset of meromixis. The size of the first generation of adult *Artemia* in 1984 (~31,000 $m^{-2}$) was nearly ten times as large as observed in 1981 and 1982, while peak summer abundances of adults were much lower. Following this change, the two generations of *Artemia* were relatively constant during the meromictic period from 1984 to 1987. The size of the spring generation of adult *Artemia* only varied from 23,000 to 31,000 $m^{-2}$ while the second generation of adult *Artemia* varied from 33,000 to 54,000 $m^{-2}$. The relative sizes of the first and second generation are inversely correlated. This is at least partially mediated by food availability as a large first generation results in decreased algal levels for second generation nauplii and vice versa. During 1984 to 1987, recruitment into the first generation adult class was a nearly constant but small percentage (about 1 to 3%) of the cysts calculated to be available (Dana *et al.* 1990). Also, fecundity showed a significant correlation with ambient algal concentrations ($r^2$, 0.61).

In addition to annual reports submitted to Los Angeles and referenced herein, a number of published manuscripts document the limnological conditions and algal photosynthetic activity during the onset, persistence, and breakdown of meromixis, 1982–90 (Jellison *et al*. 1992; Jellison and Melack 1993a, 1993b; Jellison *et al.* 1993; Miller *et al.* 1993).

*Response to the breakdown of meromixis, 1988–89*

Although complete mixing did not occur until November 1988, the successive deepening of the mixed layer during the period 1986–88 led to significant changes in the plankton dynamics. By spring 1988, the mixed layer included the upper 22 m of the lake and included 60% of the area and 83% of the lake's volume. In addition to restoring an annual mixing regime to much of the lake, the deepening of the mixed layer increased the nutrient supply to the mixolimnion by entraining water with very high ammonium concentrations (Jellison *et al.* 1989). Mixolimnetic ammonium concentrations were fairly high during the spring (8–10 μM), and March algal populations were much denser than in 1987 (53 vs. 15 μg chl *a* $l^{-1}$).

The peak abundance of spring adult *Artemia* in 1988 was twice as high as any previous year from 1979 to 1987. This increase could have been due to enhanced hatching and/or survival of nauplii. The pool of cysts available for hatching was potentially larger in 1988 since cyst production in 1987 was larger than in the four previous years (Dana *et al.* 1990) and significant lowering of the chemocline in the autumn and winter of 1987 allowed oxygenated water to reach cysts in sediments which had been anoxic since 1983. Cysts can remain dormant and viable in anoxic water for an undetermined number of years. Naupliar survival may also have been enhanced since chlorophyll *a* levels in the spring of 1988 were higher than the previous four years. This hypothesis is corroborated by the results of the 1988 development experiments (Jellison *et al.* 1989). Naupliar survival was higher in the ambient food treatment relative to the low food treatment.

Mono Lake returned to its previous condition of annual autumnal mixing from top to bottom with the complete breakdown of meromixis in November 1988. The mixing of previously isolated monimolimnetic water with surface water affected biotic components of the ecosystem. Ammonium, which had accumulated to high levels (> 600 μM) in the monimolimnion during meromixis, was dispersed throughout the water column raising surface concentrations above previously observed values (>50 μM). Oxygen was diluted by mixing with the anoxic water and consumed by the biological and chemical oxygen demand previously created in the monimolimnion. Dissolved oxygen concentration immediately fell to zero. *Artemia* populations experienced an immediate and total die-off following deoxygenation. Mono Lake remained anoxic for a few months following the breakdown of meromixis in November 1988. By mid-February 1989, dissolved oxygen concentrations had increased (2–3 mg $l^{-1}$) but were still below those observed in previous years (4–6 mg $l^{-1}$). The complete recovery of dissolved oxygen concentrations occurred in March when levels reached those seen in other years.

Elevated ammonium concentrations following the breakdown of meromixis led to high chlorophyll *a* levels in spring 1989. Epilimnetic concentrations in March and April were the highest observed (40–90 µg chl *a* $l^{-1}$). Subsequent decline to low midsummer concentrations (<0.5–2 µg chl *a* $l^{-1}$) due to brine shrimp grazing did not occur until late June. In previous meromictic years this decline occurred up to six weeks earlier. Two effects of meromixis on the algal populations, decreased winter-spring concentrations and a shift in the timing of summer clearing are clearly seen over the period 1982–89.

The 1989 *Artemia* population exhibited a small first generation of adults followed by a summer population over one order of magnitude larger. A similar pattern was observed from 1980–83. In contrast, the pattern observed during meromictic years was a larger first generation followed by a summer population of the same order of magnitude. The timing of hatching of *Artemia* cysts was affected by the recovery of oxygen. The initiation of hatching occurred slightly later in the spring and coincided with the return of oxygenated conditions. First generation numbers in 1989 were initially high in March (~30,000 individuals $m^{-2}$) and within the range seen from 1984–88, but decreased by late spring to ~4,000 individuals $m^{-2}$. High mortality may have been due to low temperatures, since March lake temperatures (2–6°C) were lower than the suspected lethal limit (ca. 5–6°C) for *Artemia* (Jellison *et al.* 1989). Increased mortality may also have been associated with elevated concentrations of toxic compounds ($H_2S$, $NH_4+$, As) resulting from the breakdown of meromixis.

High spring chlorophyll levels in combination with the low first generation abundance resulted in a high level of fecundity that led to a large second generation of shrimp. Spring chlorophyll *a* concentrations were high (30–44 µg chl *a* $l^{-1}$) due to the elevated ammonium levels (27–44 µM) and are typical of pre-meromictic levels. This abundant food source (as indicated by chlorophyll *a*) led to large *Artemia* brood sizes and high ovigerity during the period of ovoviviparous reproduction and resulted in the large observed summer abundance of *Artemia* (peak summer abundance, ~93,000 individuals $m^{-2}$). Negative feedback effects were apparent when the large summer population of *Artemia* grazed the phytoplankton to very low levels (<0.5–2 µg chl *a* $l^{-1}$). The low algal densities led to decreased reproductive output in the shrimp population. Summer brood size, female length, and ovigerity were all the lowest observed in the period 1983–89.

Small peak abundance of first generation adults were observed in 1980–83, and 1989. However, the large (2–3 times the mean) second generations were only observed in 1981, 1982, and 1989. During these years, reduced spring inflows resulted in less than usual density stratification and higher than usual vertical fluxes of nutrients thus providing for algal growth and food for the developing *Artemia* population.

### *Monomictic conditions with relatively stable lake levels, 1990–94*

Mono Lake was monomictic from 1990 to 1994 (Jellison *et al.* 1991, Dana *et al.* 1992, Jellison *et al.* 1994, Jellison *et al.* 1995b) and lake levels (6374.6 to 6375.8 ft asl) were similar to those in the late 1970s. Although the termination of meromixis in November 1988 led to monomictic conditions in 1989, the large pulse of monimolimnetic ammonium into the mixed layer led to elevated ammonium concentrations in the euphotic zone throughout 1989, and the plankton dynamics were markedly different than 1990–94. In 1990–94, ammonium concentrations in the euphotic zone decreased to levels observed prior to meromixis in 1982. Ammonium was low, 0–2 µM, from March through April and then increased to 8–15 µM in July. Ammonium concentrations declined slightly in late summer and then increased following autumn turnover. This pattern of ammonium concentrations in the euphotic zone and the hypolimnetic ammonium concentrations were similar to those observed in 1982. The similarities among the years 1990–94 indicate the residual effects of the large hypolimnetic ammonium pulse accompanying the breakdown of meromixis in 1988 were gone. This supports the conclusion by Jellison *et al.* (1990) that the seasonal pattern of ammonium concentration was returning to that observed before the onset of meromixis.

Spring and summer peak abundances of adult *Artemia* were fairly constant throughout 1990 to 1994. Adult summer population peaks in 1990, 1991, and 1992 were all ~35,000 $m^{-2}$ despite the large disparity of second generation naupliar peaks (~280,000, ~68,000, and ~43,000 $m^{-2}$ in 1990, 1991, and 1992, respectively) and a difference in first generation peak adult abundance (~18,000, ~26,000, and ~21,000 $m^{-2}$ in 1990, 1991, and 1992, respectively). Thus, food availability or other environmental factors are more important to determining summer abundance than recruitment of second generation nauplii. In 1993, when freshwater inflows were higher than usual and thus density stratification enhanced, the summer generation was slightly smaller (~27,000 $m^{-2}$). Summer abundance of adults increased slightly (~29,000 $m^{-2}$) in 1994 when runoff was lower and lake levels were declining.

### *Meromictic conditions with rising (1995-1999) and falling (1999-2002) lake levels*

#### 1995

The winter (1994/95) period of holomixis injected nutrients which had previously accumulated in the hypolimnion into the upper water column prior to the onset of thermal and chemical stratification in 1995 (Jellison *et al*. 1996a). During 1995, above normal runoff in the Mono Basin coupled with the absence of significant water diversions out of the basin led to rapidly rising lake levels. The large freshwater inflows resulted in a 3.4 ft rise in surface elevation and the onset of meromixis, a condition of persistent chemical stratification with less saline water overlying denser more saline water. Due to holomixis during late 1994 and early 1995, the plankton dynamics during the first half of 1995 were similar to those observed during the past four years (1991–94). Therefore 1995 represents a transition from monomictic to meromictic conditions. In general, 1995 March mixed-layer ammonium and chlorophyll *a* concentrations were similar to 1993. The peak abundance of summer adult *Artemia* (~24,000 $m^{-2}$) was slightly lower to that observed in 1993 (~27,000 $m^{-2}$) and 1994 (~29,000 $m^{-2}$). The effects of increased water column stability due to chemical stratification only became evident later in the year. As the year continued, a shallower mixed layer, lower mixed-layer ammonium and chlorophyll *a* concentrations, slightly smaller *Artemia,* and smaller brood sizes compared to 1994 were all observed. The full effects of the onset of meromixis in 1995 were not evident until 1996.

#### 1996

Chemical stratification persisted and strengthened throughout 1996 (Jellison *et al*. 1997). Mixolimnetic (upper water column) salinity ranged from 78 to 81 g $kg^{-1}$ while monimolimnetic (lower water column) were 89–90 g $kg^{-1}$. The maximum vertical density stratification of 14.6 kg $m^{-3}$ observed in 1996 was larger than any year since 1986. During 1996, the annual maximum in Secchi depth, a measure of transparency, was among the highest observed during the past 18 years and the annual minimum was higher than during all previous years except 1984 and 1985 during a previous period of meromixis. While ammonium concentrations were <5 µM in the mixolimnion throughout the year, monimolimnetic concentrations continued to increase. The spring epilimnetic chlorophyll *a* concentrations (5–23 µg chl *a* $l^{-1}$) were similar to those observed in previous meromictic years, but were much lower than the concentrations observed in March 1995 before the onset of the current episode of meromixis. During previous monomictic years, 1989–94, the spring maximum epilimnetic chlorophyll *a* concentrations ranged between 87–165 µg chl *a* $l^{-1}$.

A single mid-July peak in adults characterized *Artemia* population dynamics in 1996 with little evidence of recruitment of second generation *Artemia* into the adult population during late summer. The peak abundance of first generation adults was observed on 17 July (~35,000 $m^{-2}$), approximately a month later than in previous years. The percent ovigery during June 1996 (42%) was lower than that observed in 1995 (62%), and much lower than that observed 1989–94 (83–98%). During the previous meromictic years (1984–88) the female population was also slow to attain high levels of ovigery due to lower algal levels. The maximum of the mean female length on sampling dates through the summer, 10.7 mm, was shorter than those observed during 1993, 1994, and 1995 (11.7, 12.1, and 11.3 mm, respectively). In 1996, brood size ranged from 29 to 39 eggs $brood^{-1}$ during July through November. The summer and autumn brood sizes were smaller than those observed during 1993–95 (40 to 88 eggs $brood^{-1}$), with the exception of September 1995 (34 eggs $brood^{-1}$) when the brood size was of a similar size to September 1996 (33 eggs $brood^{-1}$).

### 1997

Chemical stratification continued to increase in 1997 as the surface elevation rose an additional 1.6 ft during the year. The midsummer difference in density between 2 and 28 m attributable to chemical stratification increased from 10.4 kg $m^{-3}$ in 1996 to 12.3 kg $m^{-3}$ in 1997. The lack of holomixis during the previous two winters resulted in depleted nutrient levels in the mixolimnion and reduced abundance of phytoplankton. In 1997, the spring (February–April) epilimnetic chlorophyll *a* concentrations at 2 m (2–3 µg chl *a* $l^{-1}$) were lower than those observed during 1996 (5–8 µg chl *a* $l^{-1}$), and other meromictic years 1984–89 (1.6–57 µg chl *a* $l^{-1}$), and much lower than those observed during the spring months in the last period of monomixis, 1989–95 (15–153 µg chl *a* $l^{-1}$). Concomitant increases in transparency and the depth of the euphotic zone were also observed. As in 1996, a single mid-July peak in adults characterized the *Artemia* population dynamics in 1997 with little evidence of recruitment of second generation *Artemia* into adults. The peak midsummer adult abundance (~27,000 $m^{-2}$) was slightly lower than 1996 but similar to 1995 (~24,000 $m^{-2}$). The mean length of adult females was 0.2–0.3 mm shorter than the lengths observed in 1996 and the brood sizes lower, 26–33 eggs $brood^{-1}$ in 1997 compared to 29 to 53 eggs $brood^{-1}$ in 1996.

## 1998

In 1998 the surface elevation of the lake rose 2.2 ft. The continuing dilution of saline mixolimnetic water and absence of winter holomixis led to increased chemical stratification. The peak summer difference in density between 2 and 28 m attributable to chemical stratification increased from 12.3 kg m$^{-3}$ in 1997 to 14.9 kg m$^{-3}$ in August 1998. The 1998 peak density difference due to chemical stratification was higher than that seen in any previous year, including 1983–84. The lack of holomixis during the previous three winters resulted in depleted nutrient levels in the mixolimnion and reduced abundance of phytoplankton. Chlorophyll *a* concentrations at 2 m generally decreased from 14.3 $\mu$g chl *a* l$^{-1}$ in February to 0.3 $\mu$g chl *a* l$^{-1}$ in June, when the seasonal chlorophyll *a* concentration minimum was reached. After that it increased to 1–2 $\mu$g chl *a* l$^{-1}$ during July–October and to ~8 $\mu$g chl *a* l$^{-1}$ in early December. In general, the seasonal pattern of mixolimnetic chlorophyll *a* concentration was similar to that observed during the two previous meromictic years, 1996 and 1997, in which the spring and autumn algal blooms are much reduced compared to monomictic years.

As in 1996 and 1997, a single mid-July peak in adults characterized the Artemia population dynamics in 1998 with little evidence of recruitment of second generation *Artemia* into adults. The peak abundance of adults observed on 10 August (~34,000 m$^{-2}$) was slightly higher than that observed in 1997 (~27,000 m$^{-2}$) and, while similar to the timing in 1997, approximately two weeks to a month later than in most previous years. The mean female length ranged from 9.6 to 10.3 mm in 1998 and was slightly shorter than observed in 1996 (10.1–10.7 mm) and 1997 (9.9–10.4 mm). Mean brood sizes in 1998 were 22–50 eggs brood$^{-1}$. The maximum brood size (50 eggs brood$^{-1}$) was within the range of maximums observed in 1995–97 (62, 53, and 33 eggs brood$^{-1}$, respectively), but was significantly smaller than has been observed in any other previous year 1987–94 (81–156 eggs brood$^{-1}$).

## 1999

Meromixis continued but weakened slightly in 1999 as the net change in surface elevation over the course of the year was -0.1 ft. The midsummer difference in density between 2 and 28 m attributable to chemical stratification declined from 14.9 kg m$^{-3}$ in 1998 to 12.2 kg m$^{-3}$. The lack of holomixis during the past four winters resulted in depleted inorganic nitrogen concentrations in the mixolimnion and reduced abundance of phytoplankton. In 1999, the spring (February–April) epilimnetic chlorophyll *a* concentrations at 2 m (10–16 $\mu$g chl *a* l$^{-1}$) were similar to those observed in 1998 but slightly higher than the two previous years of meromixis, 1997 (2–3 $\mu$g chl *a* l$^{-1}$) and 1996 (5–8 $\mu$g chl *a* l$^{-1}$). However, they are considerably lower than those observed during the spring months of the last period of monomixis, 1989–95 (15–153 $\mu$g chl *a* l$^{-1}$). As in all of the three immediately preceding years of meromixis, 1996–98, the *Artemia* population dynamics in 1999 were characterized by a single late-summer peak in adults with little evidence of recruitment of second generation *Artemia* into adults. The peak midsummer adult abundance (~38,000 m$^{-2}$) was slightly higher than 1996 (~35,000 m$^{-2}$), 1997 (~27,000 m$^{-2}$), and 1998 (~34,000 m$^{-}$2). The mean length of adult females was slightly longer (10.0–10.7 mm) than 1998 (9.6–10.3 mm) and similar to 1996 (10.1–10.7

mm) and 1997 (9.9–10.4 mm), while the range of mean brood sizes (27–48 eggs brood$^{-1}$) was similar (22–50 eggs brood$^{-1}$; 1996–98).

## 2000

In 2000, persistent chemical stratification (meromixis) continued but weakened due to evaporative concentration of the upper mixed layer accompanying a net 0.7 ft annual decline in surface elevation and slight freshening of water beneath the chemocline. The midsummer difference in density between 2 and 28 m attributable to chemical stratification declined from 12.2 kg m$^{-3}$ in 1999 to 10.5 kg m$^{-3}$ in 2000. Most likely of greater significance to the overall plankton dynamics is the marked midwinter deepening (ca. 2 m) of the chemocline. Not only were significant amounts of ammonium-rich monimolimnetic water entrained, but less of the lake is now effectively meromictic; only 38% of the lake's area and 16% of the volume were beneath the chemocline.

Algal biomass, as characterized by the concentration of chlorophyll *a*, was higher in 2000 compared to 1999 and varied in the mixolimnion from a midsummer low of 1.4 µg chl *a* l$^{-1}$ to the December high of 54.2 µg chl *a* l$^{-1}$. The December value is the highest observed during the entire 21 years of study. Although adult *Artemia* abundance (peak of ~22,000 m$^{-2}$) was anomalously low (50% of the long-term mean), *Artemia* biomass and total annual cyst production were only slightly below the long-term mean, 12 and 16%, respectively. Thus, while meromixis persisted in 2000, the combined effects of declining lake levels, the reduced proportion of the lake beneath the chemocline, and increased upward fluxes of ammonium due to the large buildup of monimolimnetic ammonium offset, to some degree, the effect of the absence of winter holomixis.

## 2001

Persistent chemical stratification (meromixis) continued but weakened in 2001 due to evaporative concentration of the upper mixed layer accompanying a net 0.8 ft decline in surface elevation and slight freshening of water beneath the chemocline. Colder than average mixolimnetic temperatures (1.5–2.2ºC) observed in February 2001 enhanced deep mixing. The midsummer difference in density between 2 and 28 m attributable to chemical stratification has declined from 10.5 kg m$^{-3}$ in 2000 to 8.9 kg m$^{-3}$ in 2001. Most likely of greater significance to the overall plankton dynamics was the marked midwinter deepening (ca. 2 m) of the chemocline. Not only were significant amounts of ammonium-rich monimolimnetic water entrained, but less of the lake was effectively meromictic. At the end of 2001, only 33% of the lake's area and 12% of the volume were beneath the chemocline. Ammonium concentrations in the monimolimnion continued their 6-year increase with concentrations at 28 and 35 m generally 900–1200 µM.

Algal biomass, as characterized by chlorophyll *a* concentration, was similar to that observed during 2000 except that the autumn bloom was somewhat later as adult *Artemia* were more abundant in September and October compared to 2000.

As in 2000, the 2001 *Artemia* population was characterized by fairly rapid development of the 1st generation, a pulse of ovoviviparous reproduction in June, peak of adult abundance in July at ~38,000 $m^{-2}$, followed by a decline to very low numbers by November. In 2000, the autumn decline was very rapid and resulted in the lowest seasonal mean abundance of any year studied. In 2001 the autumn decline was less rapid and resulted in a seasonal mean abundance identical to the long-term mean of ~20,000 $m^{-2}$. The 2001 mean annual *Artemia* biomass was 8.8 g $m^{-2}$ or 9 % below the long-term mean of 9.7 g $m^{-2}$ and slightly higher than calculated in 2000 (8.2 g $m^{-2}$).

In Mono Lake, oviparous (cyst) reproduction is always much higher than ovoviviparous (live-bearing) reproduction. Although adult *Artemia* were more abundant in 2001 compared to 2000, total annual cyst production was lower, 3.02 x $10^6$ $m^{-2}$ compared to 4.03 x $10^6$ $m^{-2}$ in 2000. While this is 37% below the long-term mean of 4.77 x $10^6$ $m^{-2}$, it is not expected to have a significant impact on 2002 abundance as food availability is a much stronger determinant of the spring generation of *Artemia.*

## 2002

Meromixis continued but weakened due to evaporative concentration of the upper mixed layer accompanying a net 0.8 ft decline in surface elevation and slight freshening of water beneath the chemocline. The peak difference in density between 2 and 28 m attributable to chemical stratification declined from 10.5 kg $m^{-3}$ in 2000 to 8.9 kg $m^{-3}$ in 2001 to 5.5 kg $m^{-3}$ in 2002. More importantly the chemical stratification between 2 and 32 m decreased to ~1 kg $m^{-3}$ and the chemocline was eroded downward several meters to ~30 m. Not only were significant amounts of ammonium-rich monimolimnetic water entrained, but only 14% by area and 3% by volume of the lake is below the chemocline.

Algal biomass, as characterized by chlorophyll *a* concentration, was high during both spring (60-78 µg chl *a* $l^{-1}$, February and March) and autumn (60-80 µg chl *a* $l^{-1}$, November). Annual estimates of lakewide primary production were 723 g C $m^{-2}$ $y^{-1}$ and continued the consistent upward trend from the lowest value of 149 g C $m^{-2}$ $y^{-1}$ in 1997.

As in 2000 and 2001, the *Artemia* population was characterized by fairly rapid development of the 1st generation, a pulse of ovoviviparous reproduction in June, adult abundance peak in August at ~26,000 $m^{-2}$, followed by a decline to very low numbers by November. In 2002, the mean annual *Artemia* biomass was 4.9 g $m^{-2}$ almost 50% below the long-term mean of 9.7 g $m^{-2}$. Recent analysis of seasonal *Artemia* dynamics indicates small changes in algal biomass immediately following maturation of the 1st generation, dramatically affects recruitment into the summer generation. In 2002, a larger spring hatch and spring adult generation lowered algal biomass and led to decreased recruitment into the summer adult population. This inter-generational compensatory interaction is a dominant feature of the seasonal and annual variation of adult abundance observed in the long-term monitoring (1982-present).

Total annual cyst production (2.5 x $10^6$ $m^{-2}$), along with abundance of ovigerous females, was less than in the previous three years (3.0-4.2 x $10^6$ $m^{-2}$), though the size of ovigerous females was larger than in these years. Annual cyst production was the same as in 1997, and was 53% below the long term mean of 4.77 x $10^6$ $m^{-2}$.

*Response to the breakdown of an 8-yr period of meromixis (2003–2004)*

### 2003

The persistent chemical stratification (meromixis) initiated in 1995 nearly broke down early in the year (February-March) prior to the onset of seasonal thermal stratification. This resulted in an upward pulse of nutrients (ammonia) into the upper mixed layer early in the year. Following a small rise in surface elevation and slight freshening of the mixed layer due to snowmelt runoff, decreased inflow and evaporative concentration led to an inverse chemical gradient with slightly more saline mixolimnetic water overlying the monimolimnion (region beneath the chemocline). Thus, autumn cooling led to holomixis (complete mixing of the lake) in mid-November and the end of an 8-yr period of meromixis (1995-2003).

Algal biomass, as characterized by chlorophyll *a* concentration, was high throughout the winter and spring (50-96 µg chl *a* $l^{-1}$, January through May) and autumn (50-62 µg chl *a* $l^{-1}$, October through November). While *Artemia* grazing and nutrient limitation normally result in low summer algal biomass (~1µg chl *a* $l^{-1}$), values in summer 2003 never fell below 3 µg chl *a* $l^{-1}$ despite near average *Artemia* abundance. Thus, primary production was unusually high. The 2003 estimated annual primary production was 1,645 g C $m^{-2}$ $y^{-1}$, more than twice that observed in 2002 (763 g C $m^{-2}$ $y^{-1}$), and the highest of any year from 1982-2003.

In 2003, the *Artemia* population was characterized by early development of a moderate 1st generation (18 June, 24,600 $m^{-2}$) followed by recruitment balancing mortality through the summer (13 August, 27,300 $m^{-2}$). Mean annual *Artemia* biomass increased 53% from 4.9 g $m^{-2}$ in 2002 to 7.5 g $m^{-2}$ in 2003, although it was still slightly below the long-term (1983-2003) average of 9.2 g $m^{-2}$. Recruitment of ovoviviparous (live-bearing) reproduction into the 2nd generation was low and accounts for below average mean annual biomass. Recent analysis of seasonal *Artemia* dynamics indicates small changes in algal biomass immediately following maturation of the 1st generation dramatically affects recruitment into the summer generation. A detailed cohort analysis of 2003 stage-specific *Artemia* data is being conducted. Total annual cyst production also increased over 2002 and was 4.2 x $10^6$ $m^{-2}$, close to the long-term (1983-2003) mean of 4.5 x $10^6$ $m^{-2}$.

### 2004

The breakdown of an 8-yr period of meromixis in November 2003 mixed nutrient-rich bottom waters throughout the water column. Thus, 2004 began with high ammonia concentrations (10–29 µM) throughout the water column, and a large algal bloom (105 µg chl *a* $\text{liter}^{-1}$) had developed by the February survey. While the upper mixed-layer ammonia concentrations decreased to <1 µM by mid-March, algal biomass remained high (89–95 µg chl *a* $\text{liter}^{-1}$). Dissolved oxygen concentrations in the lake had recovered following low values observed in November 2003 associated with the breakdown of meromixis and hatching of over-wintering *Artemia* cysts began in February as indicated by the presence of abundant (47,324 $m^{-2}$) 1st instar nauplii on 24 February. Record high (68,746 $m^{-2}$) naupliar abundance was observed on the 19 March survey. A large hatch, abundant food, and warmer than average water temperatures led to the largest and earliest 1st generation of adult *Artemia* in Mono Lake observed during the 26-yr period of record (1979-2004). This large 1st generation of adults depleted algal biomass and suppressed fecundity and recruitment into subsequent generations resulting in an early decline in adult abundance.

*Artemia* grazing maintained low phytoplankton abundance throughout the summer and annual primary production was lower (864 g C $m^{-2}$) than the record levels (1645 g C $m^{-2}$) observed in 2003 as meromixis weakened and broke down. However, the mean annual *Artemia* biomass increased 46% from 7.5 g $m^{-2}$ in 2003 to 11.0 g $m^{-2}$ in 2004 and was 18% above the long-term (1983-2004) average of 9.4 g $m^{-2}$. Total annual cyst production decreased to 2.6 x $10^6$ $m^{-2}$ from the 4.2 x $10^6$ $m^{-2}$ observed in 2003. While this was among the lowest estimates of annual cyst production, there is little correlation between cyst production and the subsequent year's population of *Artemia*.

### *Third episode of meromixis (2005-2006)*

#### 2005

On the March 2005 survey, nutrient levels were similar to those observed in 2004, with ammonia concentrations <1 µM in the near-surface mixed layer and 30–40 µM in the hypolimnion. However, the spring algal bloom was somewhat smaller in 2005, with chlorophyll concentrations at 2 and 8 m depth of 57–59 µg chl *a* $liter^{-1}$ compared to 91–105 µg chl *a* $liter^{-1}$ in 2004. The March survey indicated the spring *Artemia* hatch was well underway with abundance across 12 stations ranging from 18,000 to 57,000 $m^{-2}$ with a lakewide mean of 31,800 $m^{-2}$. While not as large as 2004 (75,500 $m^{-2}$), abundant food and above average water temperatures in 2005 led to the third largest 1st generation of adults (45,400 $m^{-2}$) observed during the entire 27-yr period (1979-2005). Although ovoviviparous reproduction was 25 % above the long-term mean, the large 1st generation of adults depleted food availability and reduced recruitment into the second generation resulting in a rapid late summer decline in adults.

Annual primary production was 1,111 g C $m^{-2}$ or twice the long-term mean of 573 g C $m^{-2}$. Average *Artemia* biomass, a measure of secondary production, was 11.8 g $m^{-2}$, 25 % above the long-term mean. Total annual cyst production was 3.8 million $m^{-2}$ or 15 % below the long-term mean of 4.4 million $m^{-2}$. However, secondary productivity is not limited by cyst production and there is little correlation between annual cyst production and the subsequent year's population of *Artemia*.

Snowmelt runoff into the epilimnion of Mono Lake causes seasonal salinity stratification which typically breaks down in November following late summer evaporative concentration, epilimnetic cooling, and declining lake levels. In early 2005, above average snowmelt runoff led to a 1.8 ft seasonal rise in surface elevation. While late summer evaporative concentration and cooling of the upper mixed-layer decreased vertical stratification and almost initiated holomixis, freshwater inputs late in 2005 increased salinity stratification just enough to prevent winter holomixis and initiated a third period of meromixis.

## 2006

Deep (23-24 m) mixing occurred in January-February 2006 resulting in significant upward fluxes of ammonia and the effects of the initiation of meromixis on the 2006 spring plankton dynamics were minimal. On the 13 February 2006 survey, hatching of over-wintering cysts had already begun and increased further during March. Unusually warm conditions in early May and possibly decreased salinity resulted in the 3rd largest 1st generation of adult *Artemia* for the entire 28-yr period of record (1979-2006). A pulse of ovoviviparous reproduction by the 1st generation adults led to a large second generation in early July. There was little further recruitment into the adult population in late summer and the *Artemia* population declined rapidly and by mid-October was virtually gone. While the virtual absence of adult *Artemia* in mid-October has only been observed in one other year (2002), low (<5,000 $m^{-2}$) mid-October abundances were also observed in 1986, 2000, 2003, and 2004.

Integrative measures of primary and secondary productivity in 2006 were within the ranges observed in previous years. In 2006, annual primary production was 1,075 g C $m^{-2}$ or 84 % higher than the long-term mean of 584 g C $m^{-2}$ but much less than the highest estimated productivity of 1,645 g C $m^{-2}$ in 2003. Average *Artemia* biomass in 2006, a measure of secondary production, was 6.8 g $m^{-2}$ or 26 % below the long-term mean. Total annual cyst production was 4.8 million $m^{-2}$ or 10 % higher than the long-term mean of 4.4 million $m^{-2}$.

A second year of above average snowmelt runoff resulted in a net annual rise in surface elevation of 2.2 ft, increased salinity stratification, and strengthening and continuation of the 3rd episode of meromixis. The lake was more strongly stratified through the winter of 2006-2007 compared to the previous winter.

## 2007

On the 15 February 2007 survey, hatching of over-wintering cysts had already begun and increased through April. Growth and survivorship to adults was high resulting in the 5th highest abundance of 1st generation adults in the 27-yr record (1981–2007). While a pulse of ovoviviparous reproduction by 1st generation adults occurred in late May and early June, recruitment of these young into the adult population was low and there was no midsummer July increase in adults. The abundance of adults declined through July and by September was the smallest adult population observed at this time of year for the entire period of records. As observed in 2002 and 2006, adult abundance was very low by mid-October. While the virtual absence of adult *Artemia* in mid-October is unusual, low (<5,000 $m^{-2}$) mid-October abundances were also observed in 1986, 2000, 2003, and 2004.

The estimated 2007 primary production was the highest on record (1,766 g C $m^{-2}$) but similar to that observed in 2003 (1,645 g C $m^{-2}$) when the second episode of meromixis was breaking down. Annual average *Artemia* biomass in 2007, a measure of secondary production, was 7.0 g $m^{-2}$ or 23 % below the long-term mean of 9.1 g $m^{-2}$. Total annual cyst production in 2007 (3.4 million $m^{-2}$) was also 23 % below the long-term mean of 4.4 million $m^{-2}$.

Annually-filtered (365-day running mean) mixed-layer chlorophyll *a* concentration and adult *Artemia* abundance provide two measures of long-term ecological trends. They both highlight the role of year-to-year changes in the annual mixing regime (meromixis/monomixis), the muted response of *Artemia* relative to phytoplankton, and the absence of any marked long-term trend over the period 1982–2007. While neither measure indicates a long-term trend in phytoplankton or *Artemia* abundance, it is clear that abundance of adult *Artemia* has shifted earlier in the year.

**Long-term integrative measures: annual primary productivity, mean annual *Artemia* biomass and egg production**

The availability of dissolved inorganic nitrogen or phosphorus has been shown to limit primary production in a wide array of aquatic ecosystems. Soluble reactive phosphorus concentrations are very high (>400 µM) in Mono Lake and thus will not limit growth. However, inorganic nitrogen varies seasonally, and is often low and potentially limiting to algal growth. A positive response by Mono Lake phytoplankton in ammonium enrichments performed during different periods from 1982 to 1986 indicates inorganic nitrogen limits the standing biomass of algae (Jellison 1992, Jellison and Melack 2001). In Mono Lake, the two major sources of inorganic nitrogen are brine shrimp excretion and vertical mixing of ammonium-rich monimolimnetic water.

Algal photosynthetic activity was measured from 1982 to 1992 (Jellison and Melack, 1988, 1993a; Jellison *et al.* 1994) and clearly showed the importance of variation in vertical mixing of nutrients to annual primary production. Algal biomass during the spring and autumn decreased following the onset of meromixis and annual photosynthetic production was reduced (269–462 g C $m^{-2}$ $yr^{-1}$; 1984 to 1986) compared to non-meromictic conditions (499–641 g C $m^{-2}$ $yr^{-1}$; 1989 and 1990) (Jellison and Melack 1993a). Also, a gradual increase in photosynthetic production occurred even before meromixis was terminated because increased vertical fluxes of ammonium accompanied deeper mixing with ammonium-rich monimolimnetic water. Annual production was greatest in 1988 (1,064 g C $m^{-2}$ $yr^{-1}$) and 2003 (1,645 g C $m^{-2}$ $y^{-1}$) when the weakening of chemical stratification and eventual breakdown of meromixis in November resulted in large fluxes of ammonium into the euphotic zone.

Estimates of annual primary production integrate annual and seasonal changes in photosynthetic rates, algal biomass, temperature, and insolation. Although measurements of photosynthetic rates were discontinued after 1992 (restarted in 2002) most of the variation in photosynthetic rates can be explained by regressions on environmental covariates (i.e. temperature, nutrient, and light regimes) (Jellison and Melack 1993a, Jellison *et al.* 1994). Therefore, estimates of annual primary production using previously derived regressions and current measurements of algal biomass, temperature, and insolation were made during 1993-2001. These estimates of annual primary production indicate a period of declining productivity (1994–1997) associated with the onset of meromixis and increasing chemical stratification, followed by continually increasing estimates of annual primary production through the breakdown of meromixis in 2003 when the second highest estimated annual primary production occurred (1,645 g C $m^{-2}$ $y^{-1}$). Estimated annual productivity declined somewhat in 2004–06 ranging from 864 to 1,111 g C $m^{-2}$ $y^{-1}$ and then increased to1,766 g C $m^{-2}$ $y^{-1}$ as the 2-yr episode of meromixis broke down.

The mean annual biomass of *Artemia* was estimated from instar-specific abundance and length-weight relationships for the period 1983–99 and by direct weighing from 2000 to the present. The mean annual biomass has varied from 5.3 to 17.6 g m$^{-2}$ with a 23-yr (1983-2006) mean of 9.3 g m$^{-2}$. The highest estimated mean annual biomass (17.6 g m$^{-2}$) occurred in 1989 just after the breakdown of meromixis during a period of elevated phytoplankton nutrients (ammonium) and phytoplankton. The lowest annual estimate was in 1997 following two years of meromixis and increasing density stratification. Mean annual biomass was somewhat below the long-term mean during the first 3 years of the 1980s episode of meromixis and then above the mean the next 3 years as meromixis weakened and ended. The years with the lowest annual biomass of *Artemia* were 1997 (5.3 g m$^{-2}$) and 2002 (4.9 g m$^{-2}$), both during the extended period of meromixis, 1995–2003). However, mean annual *Artemia* biomass increased in 2003 as meromixis weakened to 7.5 g m$^{-2}$, and further to 11.0 g m$^{-2}$ in 2004 following the breakdown of meromixis in late 2003. Mean annual *Artemia* biomass during 2005, 2006, and 2007 was 8.8, 6.8, and 5.8 g m$^{-2}$, respectively.

## Peer-reviewed scientific publications

In addition to the long-term limnological monitoring, the City of Los Angeles has partially or wholly funded a number of laboratory experiments, analyses, and analytical modeling studies resulting in a large number of peer-reviewed research publications by University of California, Santa Barbara (UCSB) researchers. In addition to research on mixing dynamics, nutrient cycling, and primary and secondary productivity, data collected as part of the long-term limnological monitoring has also contributed to analyses of other aspects Mono Lake's ecology including bacteria, viruses, and avian populations.

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# CHAPTER 2
# METHODS

## Meteorology

Continuous meteorological data are collected at the Paoha station located on the southern tip of Paoha Island. The station is approximately 30 m from the shoreline of the lake with the base located at 1948 m asl, several meters above the current surface elevation of the lake. Sensor readings are made every second and stored as either ten minute or hourly values. A Campbell Scientific CR10 datalogger records up to 6 weeks of measurements. Data are downloaded to a storage module which is collected monthly during the regular sampling trips to the lake.

Wind speed and direction (RM Young wind monitor) are measured at a height of 3 m above the surface of the island and are averaged over a 10-minute interval. The maximum wind speed during the ten-minute interval is also recorded. The 10-minute wind vector magnitude, wind vector direction, and the standard deviation of the wind vector direction are computed from the measurements of wind speed and wind direction and stored. Hourly measurements of photosynthetically available radiation (PAR, 400 to 700 nm, Li-Cor 192-S), total rainfall (Qualimetrics 601 I-B tipping bucket), and ten minute averages of relative humidity (Vaisalia HMP35C) and air temperature (Vaisalia HNV35C and Omnidata ES-060) are also made and stored.

The Cain Ranch meteorological station is located approximately 7 km southwest of the lake at an elevation of 2088 m. Throughout the 1980s, LADWP measured wind and temperature at this station. Currently UCSB maintains and records hourly averages of incoming shortwave (280 to 2800 nm; Eppley pyranometer), longwave radiation (3000 to 50000 nm; Eppley pyrgeometer) and PAR (400 to 700 nm; Li-Cor 192-S) at this site.

## Sampling Regime

The limnological monitoring program for Mono Lake specifies monthly surveys from February through December. Additional biweekly surveys are necessary during May through July to accurately interpret and monitor *Artemia* biomass and reproduction. Surveys are conducted over one or two days depending on the weather conditions, the number of depths at which productivity is being estimated, and meteorological station maintenance requirements. When conducted over two days, every effort is made to collect the lakewide survey and the station 6 profiles including productivity data on consecutive days.

## Field Procedures

### *In situ profiles*

Water temperature and conductivity were measured at nine buoyed, pelagic stations (2, 3, 4, 5, 6, 7, 8, 10 and 12) (Fig. 1). Prior to 2008 profiles and during February and March 2008 surveys for comparative purposes profiles were taken with a high-precision, conductivity-temperature-depth profiler (CTD) (Seabird Electronics model Seacat 19, on loan from the University of Georgia) equipped with sensors to additionally measure photosynthetically available radiation (PAR) (LiCor 191S), fluorescence (695 nm) (WETLabs WETStar miniature fluorometer), and transmissivity (660 nm) (WETlabs C-Star Transmissometer). During 2008, a newly purchased high-precision CTD (Idronaut, Model 316Plus) was employed. Although the Idronaut CTD was equipped with a polarographic oxygen sensor, slow response times precluded its use in profiling mode and oxygen readings from it were not used. The CTD was deployed by lowering it at a rate of ~0.2 m $s^{-1}$ and recording at 200 ms intervals or approximately 4 cm depth intervals. Pressure readings were converted to depth using the density of Mono Lake water at the in situ temperature and salinity. Conductivity readings at in situ temperatures ($C_t$) were standardized to 25°C ($C_{25}$) using

$$C_{25} = \frac{C_t}{1 + 0.02124(t-25) + 9.16 \times 10^{-5}(t-25)^2}$$

where $t$ is the in situ temperature. Resulting conductivity profiles were visually examined for spiking and smoothed with a 7-pt box car moving average.

To describe the general seasonal pattern of density stratification, the contributions of thermal and chemical stratification to overall density stratification were calculated based on conductivity and temperature differences between 2 and 28 m at station 6 and the following density equation:

$$\begin{aligned}\rho(t, C_{25}) = 1.0034 + 1.335 \times 10^{-5} t - 6.20 \times 10^{-6} t^2 + 4.897 \times 10^{-4} C_{25} \\ + 4.23 \times 10^{-6} C_{25}^2 - 1.35 \times 10^{-6} t C_{25}\end{aligned}.$$

The relationship between total dissolved solids and conductivity for Mono Lake water was given by:

$$TDS\left(g\ kg^{-1}\right) = 3.386 + 0.564 \times C_{25} + 0.00427 \times C_{25}^2.$$

To obtain TDS in grams per liter, the above expression was multiplied by the density at 25°C for a given standardized conductivity given by:

$$\rho_{25}(C) = 0.99986 + 5.2345 \times 10^{-4} C + 4.23 \times 10^{-6} C^2$$

A complete description of the derivation of these relationships is given in Chapter 4 of the 1995 Annual Report.

Dissolved oxygen was measured at one centrally located station (Station 6). Dissolved oxygen concentration was measured with a Yellow Springs Instruments temperature-oxygen meter (YSI, model 58) and probe (YSI, model 5739). The oxygen electrode is calibrated at least once each year against Miller titrations of Mono Lake water (Walker *et al.* 1970).

### *Water samples*

Chlorophyll and nutrient samples were collected from seven to eleven depths at one centrally located station (Station 6). In addition, 9-m integrated samples for chlorophyll *a* determination and nutrient analyses were collected with a 2.5 cm diameter tube at seven stations (Station 1, 2, 5, 6, 7, 8, and 11) (Fig. 1). Samples for nutrient analyses were filtered immediately upon collection through Gelman A/E glass-fiber filters, and kept chilled and dark until returned to the lab. Water samples used for the analysis of chlorophyll *a* were filtered through a 120-µm sieve to remove all stages of *Artemia*, and kept chilled and dark until filtered in the laboratory.

### *Artemia samples*

The *Artemia* population was sampled by one net tow from each of twelve, buoyed stations (Fig. 1). Samples were taken with a plankton net (1 m x 0.30 m diameter, 120 µm Nitex mesh) towed vertically through the water column. Samples were preserved with 5% formalin in lake water. Two additional samples were collected at Stations 1, 6, and 8, to analyze for presence of rotifers, and to archive a representative of the population. When adults were present, an additional net tow is taken from Stations 1, 2, 5, 6, 7, 8 and 11 to collect adult females for brood size and length analysis.

## **Laboratory Procedures**

### *Water samples*

Samples are returned to the laboratory within several hours of collection and immediately processed for ammonium and chlorophyll determinations. Ammonium concentrations were measured immediately, while chlorophyll samples were filtered onto 47 mm Whatman GF/F filters and kept frozen until the pigments were analyzed within two weeks of collection.

Chlorophyll *a* was extracted and homogenized in 90% acetone at room temperature in the dark. Following clarification by centrifugation, absorption was measured at 750 and 663 nm on a spectrophotometer (Milton Roy, model Spectronics 301). The sample was then acidified in the cuvette, and absorption was again determined at the same wavelengths to correct for phaeopigments. Absorptions were converted to phaeophytin-corrected chlorophyll *a* concentrations with the formulae of Golterman (1969). During periods of low phytoplankton concentrations (<5 µg chl *a* $l^{-1}$), the 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.

Ammonium concentrations were measured using the indophenol blue method (Strickland and Parsons 1972). In addition to regular standards, internal standards were analyzed because the molar extinction coefficient is less in Mono Lake water than in distilled water. Oxygen gas was bubbled into Mono Lake water and used for standards and sample dilutions. Oxygenating saline water may help reduce matrix effects that can occur in the spectrophotometer (S. Joye, pers. comm.) When calculating concentration, the proportion of ammonium in the Mono Lake dilution water in diluted (deep) samples was subtracted from the total concentration.

### *Artemia samples*

*Artemia* abundances were counted under a stereo microscope (6x or 12x power). Depending on the density of shrimp, counts were made of the entire sample or of subsamples made with a Folsom plankton splitter. Samples were split so that a count of >100 animals was obtained. Shrimp were classified into adults (instars > 12), juveniles (instars 8–11), and nauplii (instar 1–7) according to Heath's classification (Heath 1924). Adults were sexed and the adult females were divided into ovigerous and non-ovigerous. Ovigerous females included egg-bearing females and females with oocytes. Adult ovigerous females were further classified according to their reproductive mode, ovoviviparous or oviparous. A small percentage of ovigerous females were unclassifiable if eggs were in an early developmental stage. Nauplii at seven stations (Stations 1, 2, 5, 6, 7, 8, and 11) were further classified as to instars 1–7.

Live females were collected for brood size and length analysis are kept cool and in low densities during transport to the laboratory. Immediately on return to the laboratory, females are randomly selected, isolated in individual vials, and preserved. Brood size was determined by counting the number of eggs in the ovisac including those dropped in the vial, and egg type and shape were noted. Female length was measured from the tip of the head to the end of the caudal furca (setae not included).

## **Long-term integrative measures of productivity**

### *Primary Production*

Photosynthetically available radiation (PAR, 400-700 nm) was recorded continuously at Cain Ranch, seven kilometers southwest of the lake, from 1982 to 1994 and on Paoha Island in the center of the lake beginning in 1991 with a cosine-corrected quantum sensor. Attenuation of PAR within the water column was measured at 0.5-m intervals with a submersible quantum sensor. Temperature was measured with a conductivity-temperature-depth profiler (Seabird, SB19) (see Methods, Chapter 2). Phytoplankton samples were filtered onto glass fiber filters and extracted in acetone (see above).

Photosynthetic activity was measured using the radiocarbon method. Carbon uptake rates were measured in laboratory incubations within five hours of sample collection. Samples were kept near lake temperatures and in the dark during transport. Samples were incubated in a "photosynthetron", a temperature-controlled incubator in which 28 20-ml samples are exposed to a range of light intensities from 0 to 1500 $\mu$E m$^{-2}$ s$^{-1}$. After a 4-h incubation, samples were filtered through a Whatman GF/F filter at a pressure not exceeding 125 mm of Hg and rinsed three times with filtered Mono Lake water. Filters were then soaked for 12 h in 1 ml of 2.0 N HCl, after which 10 ml of scintillation cocktail were added and activity measured on a liquid scintillation counter. Chlorophyll-normalized light-limited ($\alpha^B$) and saturated ($P_m^B$) parameters were determined via non-linear least-squared fitting to a hyperbolic tangent equation: $P^B = P_m{}^B \tanh\left(\frac{\alpha^B I}{P_m{}^B}\right)$ where $I$ is the light intensity and $P^B$ is the measured chlorophyll-specific uptake of carbon.

Estimates of daily integral production were made using a numerical interpolative model (Jellison and Melack 1993a). Inputs to the model include the estimated photosynthetic parameters, insolation, the vertical attenuation of photosynthetically available irradiance and vertical water column structure as measured by temperature at 1 m intervals and chlorophyll a from samples collected at 4–6 m intervals. Chlorophyll-specific uptake rates based on temperature were multiplied by ambient chlorophyll a concentrations interpolated to 1-m intervals. The photosynthetically available light field was calculated from hourly-integrated values at Paoha meteorological station, measured water column attenuation, and a calculated albedo. The albedo was calculated based on hourly solar declinations. All parameters, except insolation that was recorded continuously, were linearly interpolated between sampling dates. Daily integral production was calculated by summing hourly rates over the upper 18 m.

### *Artemia biomass and reproduction*

Average daily biomass and annual cyst and naupliar production provide integrative measures of the *Artemia* population allowing comparison among years. Prior to 2000, *Artemia* biomass was estimated from stage specific abundance and adult length data, and weight-length relationship determined in the laboratory simulating in situ conditions of food and temperature (see Jellison and Melack 2000 for details). Beginning in 2000, biomass was determined directly by drying and weighing of *Artemia* collected in vertical net tows.

The resulting biomass estimates are approximate because actual instar-specific weights may vary within the range observed in the laboratory experiments. However, classifying the field samples into one of the three categories will be more accurate than using a single instar-specific weight-length relationship. Because length measurements of adult females are routinely made, they were used to further refine the biomass estimates. The adult female weight was estimated from the mean length on a sample date and one of the three weight-length regressions determined in the laboratory development experiments. As the lengths of adult males are not routinely determined, the average ratio of male to female lengths determined from individual measurements on 15 dates from 1996 and 1999 was used to estimate the average male length of other dates.

Naupliar and cyst production was calculated using a temperature-dependent brood interval, ovigery, ovoviviparity versus oviparity, fecundity, and adult female abundance data from seven stations on each sampling date.

### *Long-term trends in annual algal biomass and adult Artemia abundance*

The seasonality in algal biomass and adult *Artemia* abundance can be removed by calculating yearly moving averages. Because the intervals between sampling dates varied among years, daily values are derived by linearly interpolating between sample dates prior to calculating a 365-day moving average. Thus, each point represents a moving average of 365 days centered on each sample. This seasonally-filtered data can be used to detect long-term trends in algal biomass and adult *Artemia*.

# CHAPTER 3
# RESULTS AND DISCUSSION

## Overview

The multi-year trend beginning in 2004 of above average primary productivity and large spring generations of *Artemia* followed by a smaller than average late summer population of *Artemia* and rapid autumn decline continued in 2008. The episode of meromixis begun in 2005 ended in late 2007 and thus seasonal mixing patterns in 2008 exhibited a "typical" monomictic regime. However, the breakdown of even this short 2-year period of meromixis led to enhanced nutrient availability and a larger phytoplankton biomass in early 2008.

The main factors affecting recruitment of individuals hatching from over-wintering cysts into the first generation of adult shrimp are spring water temperature, salinity, and phytoplankton abundance. In 2008, spring water temperature and phytoplankton abundance were in the middle of the range observed over the past 28 years, but salinity was significantly lower and possibly accounts for the above-average size of the 1st generation.

An inverse correlation between the sizes of spring and summer *Artemia* generations has been observed during many years. Large spring generations of adult *Artemia* reduce phytoplankton to concentrations which become severely limiting to the growth and survival of ovoviviparously produced nauplii of the spring generation. Thus, recruitment into the summer population is reduced. This larval recruitment bottleneck, most apparent in recent years, is the key to understanding and interpreting much of the observed spatial and temporal variation in *Artemia* population dynamics.

Here, we describe the limnological conditions observed during 2008 and calculate several long-term integrative measures of ecosystem productivity.

## Meteorological Data

The Mono Lake limnological monitoring program has included collection of a full suite of meteorological data at a station located on the southern tip of Paoha Island and radiation (shortwave, longwave, and photosynthetically available radiation) at Cain Ranch. Meteorological data is collected at 10-minute intervals at the Paoha Island station except during December-February when hourly data is collected. The weather station was installed in 1990 and during 2007 and 2008 several of the components failed. By late 2007 a number of channels of the CR10 datalogger were no longer functioning and a new CR1000 datalogger was installed in spring 2008. However, several technical difficulties and additional failures were encountered. Further repair was suspended in late May when LADWP personnel informed UCSB researchers the limnological monitoring program was being terminated at the end of June. Although a decision to continue limnological monitoring was made, LADWP informed UCSB researchers that no activities could be funded after 30 June 2008 until a new contract was in place. Thus, further maintenance and repair were deferred until late September when a new contract was awarded. Although the station is now fully operational, 2008 data are incomplete. Here, we supplement existing Paoha data with data recorded at the Simis meteorological station located on the north side of Mono lake.

### *Wind Speed and Direction*

Mean daily wind speed varied from 1.0-10.8 m $s^{-1}$ over the year, with an overall annual mean of 3.0 m $s^{-1}$ (Fig. 2). This annual mean is slightly lower than observed in 2007 (3.3 m $s^{-1}$) and in 2005 and 2006 (3.5 m $s^{-1}$) and only slightly higher than the 3.1 m $s^{-1}$ annual mean observed in 2004 and 3.2 m $s^{-1}$ observed in 2001, 2002, and 2003. The daily maximum 10-min averaged wind speeds recorded on the Island Jan 1-April 21 averaged 3.5 times mean daily wind speeds. The maximum recorded gust (21.07 m $s^{-1}$, 47.1 mph) occurred on the evening of April 20 (Fig. 2). Simis daily maximum 2 second wind gust recorded between 22 April and 31 December was 34.3 m $s^{-1}$, (76.7 mph) on May 20. The mean monthly wind speed varied from 2.16 to 4.17 m $s^{-1}$ (coefficient of variation, 19 %). This was similar to 2007, and 2004 when the mean monthly wind speed varied only from 2.4 to 4.1 and 2.1 to 4.1 m $s^{-1}$ respectively. As observed in the past, winds were predominately from the south (mean, 177 deg).

### *Air Temperature*

Mean daily air temperatures ranged from a minimum of –10.6°C on 29 December to a maximum of 22.9°C on 10 July (Fig. 3). Air temperatures ranged from -0.7°C to 31.1°C during the summer (June through August) with a mean daily range of 9.6°C to 22.9°C and from –16.4°C to 15.3°C during the winter (December through February) with a mean daily range of -10.6°C to 7.3°C

### *Incident Photosynthetically Available Radiation (PAR)*

Photosynthetically available radiation (400-700 nm) exhibits a regular sinusoidal curve dictated by the temperate latitude (38°N) of Mono Lake. Maximum daily values typically range from about ~19 Einsteins $m^{-2}$ $day^{-1}$ at the winter solstice to ~64 Einsteins $m^{-2}$ $day^{-1}$ in mid-June (Fig. 4). Daily values that diverge from the curve indicate overcast or stormy days. During 2008, the annual mean was 38.9 Einsteins $m^{-2}$ $day^{-1}$, with daily values ranging from 1.7 Einsteins $m^{-2}$ $day^{-1}$ on 23 January to 65.1 Einsteins $m^{-2}$ $day^{-1}$ on 18 June. The 2008 annual mean was between those observed in 2002, 2003, 2004, 2005, 2006 and 2007 (39.9, 35.0, 37.5, 39.0, 38.0, 38.7 Einsteins $m^{-2}$ $day^{-1}$) respectively. PAR values presented here were collected at the Cain Ranch station.

### *Relative Humidity and Precipitation*

Mean daily relative humidity values are only available through April 22. They followed the general pattern of high values (mostly 60-80 %) in January, decreasing to lows (mostly 40-70 %) in April. Typically values will be low through October, increasing to 60-80 % through December (Fig. 5). The January - April 22 mean was 62.6%, compared to similar dates during 2003 (54.3 %), 2004 (54 %), 2005 (57.9%) and 2006 (56.4%).

Precipitation data is not available from the Paoha Island station for 2008 and here we present data reported by the Mono Lake Committee from a station in Lee Vining, elevation 6800 ft, lat: 37º 57' 0" N, long: 119º07' 30" W. Average annual precipitation generally declines by half across the lake (LADWP unpub., Vorster 1985). Annual 2008 precipitation measured at Lee Vining was 32.9 cm (source, Mono Lake Committee). One large precipitation event occurred on 4 January delivering 88.4 mm. Two smaller events occurred later the same month, the first on 23 January delivered 23.4 mm and the second on 27 January delivering 32.5 mm (Fig. 6).

## Surface Elevation

The surface elevation of Mono Lake was 6382.7 ft asl on 1 January 2008, rose slightly to 6383.3 ft by April after which it declined to 6382.3 ft in December for a net decline of 0.5 ft (Fig. 7).

## Temperature

The annual pattern of thermal stratification in Mono Lake results from seasonal variations in climatic factors (e.g. air temperature, solar radiation, wind speed, humidity) and their interaction with density stratification arising from the timing and magnitude of freshwater inputs. The annual pattern observed during 1990–94 is typical of large temperate lakes except that in hypersaline Mono Lake the absence of ice cover results in a single long period of winter holomixis. This pattern has been altered by three episodes of meromixis (1983–88, 1995–03, 2005–07) during which vertical salinity gradients prevented winter holomixis (Fig. 7). The recent period of persistent chemical stratification initiated in 2005 weakened during declining lake levels in 2007 and ended with holomixis in late November 2007 and a typical monomictic mixing regime was present during 2008.

In Mono Lake, the annual winter period of holomixis typically extends from late November to early February after which seasonal thermal and salinity stratification are initiated due to warming air temperatures, increased insolation, and increased inflows. January represents a period of low biological activity due to cold water temperatures, low light levels, and absence of *Artemia*. January surveys are only conducted when unusual circumstances warrant it and weather permitting. Monthly surveys are initiated each year in February.

The 1st survey of the year was conducted on 21 February 2008. Due to inclement weather the lakewide survey had to be aborted after sampling just 2 stations (Stations 3 & 4). The vertical temperature and conductivity profiles were almost uniform indicating a well-mixed lake except for slight warming and freshening in the upper 2 m (Table 1, Fig. 8). At the western deep Station 4, water temperature was 1.3-1.5 °C throughout the water column beneath 2 m depth. Some surface warming was present as indicated by 2.9°C water temperature at 1 m depth.

During spring and early summer, multiple weak thermoclines and complex profiles were present due to the interactions among seasonal warming, freshwater inflows, and meteorological events. A strong persistent thermocline was not present until mid-July when mixed-layer water temperatures of 21.4–22.0°C were observed and a pronounced thermocline present at 8–10 m depth. Epilimnetic temperatures increased further to 22.2–22.4°C in mid-August. These are among the highest observed at Mono

Lake. The persistent thermocline lowered throughout late summer to 15-17 m by mid-October and the lake "turned over" prior to the mid-November survey. Water temperatures were near isothermal on 13 November at 9.0–9.6°C and on 18 December at 5.9–6.3°C.

Hypolimnetic water temperatures increased from 1.3°C on 21 February to almost 10°C by mid-October prior to decreasing slightly in November after autumn overturn and further to ~6°C in December under well-mixed winter conditions.

The seasonal pattern and magnitude of water temperatures observed during 2008 were typical of those observed in previous years during monomictic conditions in Mono Lake. Although unusually warm epilimnetic water temperatures (22.2–22.4°C) were observed in August, summer water temperatures above 22°C have been observed during other years.

### Conductivity and Salinity

The episode of meromixis initiated in 2005 ended in late 2007 and little chemical stratification was present in early 2008 (Table 2, Fig. 9). During the February survey conductivities only ranged from 81.0 mS $cm^{-1}$ in the lower half of the water column to 80.9 mS $cm^{-1}$ in the upper half. Slightly lower conductivity (80.4 mS $cm^{-1}$) was observed at 1 m depth indicating some freshwater inputs to the surface layer.

Epilimnetic conductivity decreased only slightly through June as freshwater inputs and lake level rise were minimal. A slight increase throughout the water column to 81.9-82.0 mS $cm^{-1}$ was observed in November and December and reflects concentration of dissolved solids associated with the slightly decreasing lake volume.

Salinity, expressed as total dissolved solids, can be calculated from conductivity measurements corrected to a reference temperature (25 °C, see Methods). Because total dissolved solids are conservative at the current salinities in Mono Lake, salinity fluctuates with volume due to changes in the balance between freshwater inputs (streams and precipitation) and evaporative losses. The observed conductivities of 81 to 82 mS $cm^{-1}$ correspond to salinities of 77.1 to 78.3 g $kg^{-1}$, respectively.

As the Seabird CTD on loan to the Mono Lake project was returned to the University of Georgia, a new Idronaut profiling CTD was purchased by LADWP for use at Mono Lake. The Idronaut probe flooded in March due to a manufacturer defect and was unavailable for the April survey. A new factory replacement was used during the rest of the year. However, end-of-the-year analysis revealed suspect data. Laboratory measurements indicated that while the conductivity measurements compared favorably against seawater standards, the high response thermistor on the new probe was unstable and drifting continually further out of calibration. As conductivity is highly temperature-dependent, accurate in situ temperatures are necessary to interpret raw conductivity data. We attempted to correct the raw conductivity data collected from May through December using in situ temperatures recorded during measurements of dissolved oxygen with a hand-lowered YSI 58. While this was reasonably successful for May-June and November-December surveys, it still resulted in suspect data for the July-August profiles, possibly due to the presence of strong thermal gradients. Therefore, we have not included summer conductivities in this report. The probe was returned to the factory, repaired and subsequently returned.

## Density Stratification: Thermal and Chemical

The large seasonal variation in freshwater inflows associated with a temperate climate and year-to-year climatic variation have led to complex patterns of seasonal density stratification over the last 28 years. Much of the year-to-year variation in the plankton dynamics observed at Mono Lake can be attributed to marked differences in chemical stratification resulting from variation in freshwater inflows and its affect on nutrient cycling. Excess density varied from 64.9 to 71.2 kg $m^{-3}$ over the course of the year (Table 3).

Density stratification was due primarily to seasonal thermal stratification with very little contributed by salinity stratification (Table 4, Fig 10). In mid-June, the difference in salinity between 2 and 32 m only contributed 1.39 kg $m^{-3}$ to overall stratification. Density stratification due to temperature increased 0.05 kg $m^{-3}$ during the near isothermal conditions observed in February to 4.56 kg $m^{-3}$ during mid August.

## Transparency and Light Attenuation

In Mono Lake, variation in transparency is predominately due to changes in algal biomass. Standing algal biomass reflects the balance between all growth and loss processes. Thus, variation in transparency as measured by Secchi depth often reflects the detailed development of the *Artemia* population as much as any changes in nutrient availability and primary productivity.

In 2008, February–April lakewide transparencies during spring as measured by Secchi depth were among the lowest observed ranging from 0.83±0.02 in March to 0.84±0.02 m in mid April (Fig. 11, Table 5). As *Artemia* grazing reduced midsummer phytoplankton, mean lakewide transparency increased to 4.8±0.2 m and 4.9±0.2 m in July and August, respectively. These midsummer transparencies are among the lowest observed. The only other year in which midsummer transparencies were less than 7 m was 2003. While both 2003 and 2008 followed periods of meromixis, low midsummer transparencies were not observed following the breakdown of meromixis in 1988.

Secchi depths decreased to <1.0 during October–December as shrimp population were virtually absent after mid-October and a large autumn phytoplankton bloom occurred.

Secchi depth is an integrative measure of light attenuation within the water column. Because light absorption is exponential with depth, long-term variation in Secchi depth is most appropriately viewed on a logarithmic scale. While the annual pattern of Secchi depths during 2008 was similar to other years, the midsummer values were clearly the lowest observed since 1979 (Fig. 12).

The attenuation of PAR within the water column varies seasonally, primarily as a function of changes in algal biomass. In 2008, the depth of the euphotic zone, operationally defined as the depth at which only 1 % of the surface insolation is present, increased from ~5 m during January and February to 13 m during late summer, and then to 4-5 m late in the year (October–December) (Fig. 13).

## Dissolved Oxygen

Dissolved oxygen concentrations are primarily a function of salinity, temperature, and the balance between photosynthesis and overall community respiration. In the euphotic zone of Mono Lake, dissolved oxygen concentrations are typically highest during the spring algal bloom. As the water temperature and *Artemia* population increase through the spring, dissolved oxygen concentrations decrease. Beneath the euphotic zone, bacterial and chemical processes deplete the oxygen once the lake stratifies. During meromictic periods, the monimolimnion (the region beneath the persistent chemocline) remains anoxic throughout the year.

In 2008, dissolved oxygen concentrations in the upper mixed layer (< 10 m) ranged from 2.6 to 8.7 mg $l^{-1}$ (Table 6, Fig. 14) with the highest concentrations occurring in the upper 5 m during January and February. The lowest epilimnetic values occurred during the October and November surveys when the water column was actively mixing. Although the hypolimnion was well aerated early in the year, it became suboxic in April and anoxic (<0.5 mg $l^{-1}$) shortly thereafter below the mid-depth thermocline through October. The high values throughout the water column in December indicate holomixis.

## Nutrients (ammonia/ammonium)

Nitrogen is the primary limiting macronutrient in Mono Lake as phosphate is in super-abundance (350-450 µM) throughout the year (Jellison *et al.* 1994). External inputs of nitrogen are low relative to recycling fluxes within the lake (Jellison and Melack 1993). Ammonium concentrations in the euphotic zone reflect the dynamic balance between excretion by shrimp, uptake by algae, upward vertical fluxes through thermo- and chemocline(s), release from sediments, ammonium volatilization, and small external inputs. Because a large portion of particulate nitrogen, in the form of algal debris and *Artemia* fecal pellets, sink to the bottom and are remineralized to ammonium in the hypolimnion (or monimolimnion during meromixis), vertical mixing controls much of the annual internal recycling of nitrogen.

Due to a winter period of holomixis, February ammonium concentrations were nearly uniform throughout the water column ranging from 1.2 - 1.9 µM with a slightly lower value (0.6 µM) in the shallow euphotic zone at 2 m depth (Table 7, Fig. 15). Epilimnetic ammonium concentrations remained low throughout the year peaking in June and July (lakewide mean, 2.7 µM) as the spring cohort of *Artemia* matured. July and August ammonium concentrations were generally much higher at the western stations compared to the eastern ones (Table 8, Fig. 16). During July ammonium concentrations were 5 µM at western stations 1 and 2 compared to just 1.2-1.4 µM at the eastern stations 7, 8, and 11. While this seasonal feature of higher concentrations accompanying the peak abundance of *Artemia* is observed during both meromictic and monomictic conditions, it is generally larger during monomictic periods. The causal connection to grazing is highlighted by the variation in the prominence of this feature across the lake which shows an inverse correlation with adult *Artemia* abundance.

Hypolimnetic ammonium concentrations increase through the stratified period. Beneath the chemocline, monimolimnetic ammonium concentrations in 2008 increased from ~5 µM in March to ~78 µM (35 m) in mid-September. As stratification weakened in October, ammonium concentration at 35 m was reduced to 28.5 µM and by November the water column was completely mixed with concentration ranging from 0.3-1.7 µM between 2 m and 35

## Phytoplankton (algal biomass and fluorescence)

The phytoplankton community, as characterized by chlorophyll *a* concentration, shows pronounced seasonal variation. As observed in all years from 1982 to the present, spring and autumn-winter phytoplankton blooms were separated by a period of low phytoplankton biomass during summer due to *Artemia* grazing.

In February 2008, chlorophyll concentrations at Station 4 were well mixed. Chlorophyll was slightly higher at 2 m (110 µg chl $l^{-1}$) decreasing to 94 µg chl $l^{-1}$ at 8 m and ranging from 83-90 µg chl $l^{-1}$ between 12 and 28 m (Table 9, Fig. 17). In March upper 9-m integrated samples at 7 lakewide stations chlorophyll *a* ranged from 36 to 58 µg chl $l^{-1}$ (Table 10, Fig. 18). During the spring algal bloom a sub-surface chlorophyll maxima (8 and 12 m) of 41-43 µg chl $l^{-1}$ was observed in April. By May algal biomass in the upper-9 m, as measured by chlorophyll *a* concentration, was 14.5-26.5 µg chl $l^{-1}$. This is much higher than in 2007 (1.2-2.5 µg chl $l^{-1}$) but similar to that observed in 2006 (11 to 32.6 µg liter$^{-1}$). Lower algal biomass observed in 2007 is due to reduced vertical mixing and internal recycling of nutrients accompanying meromixis.

Epilimnetic chlorophyll concentrations remained low (≤10 µg chl $l^{-1}$) during June through August and only started to increase in September as the mixed-layer deepened and the *Artemia* population declined. By October, epilimnetic chlorophyll had increased to 40 to 58 µg liter$^{-1}$ with a lakewide mean of 48.5 µg liter$^{-1}$. High algal biomass was present during both the November and December surveys as ammonium availability increased during holomixis and *Artemia* were absent. A peak chlorophyll concentration of 91 µg chl $l^{-1}$ was observed at 2 m depth on 13 November 2008.

As observed in all years, chlorophyll *a* concentration in deep samples (24 and 28 m depth) were high throughout the year ranging from 83 to 88 µg chl $l^{-1}$ during February and March, decreasing to 30 to 55 µg chl $l^{-1}$ April through October and increasing in November and December to 87 to 88 µg chl $l^{-1}$.

The large seasonal variation in epilimnetic (upper 9-m integrated) chlorophyll obscures the significant but relatively minor lakewide differences observed during the course of the year. Phytoplankton, as indicated by chlorophyll *a*, are generally less abundant in the eastern portion of the lake compared to western stations early in the year and more abundant during summer. This pattern is inversely related to *Artemia* abundance (Fig. 18).

## *Artemia* Population Dynamics

Zooplankton populations in temperate lakes are highly variable across several spatial and temporal scales. The Mono Lake monitoring program collects samples from 12 stations distributed across the lake and the relative standard errors of lakewide estimates are typically 10-20 %. However, on a given sample date the standard error of a lakewide estimate may be smaller or larger depending on the observed spatial variability occurring on that date. In extreme cases, local convergences of water masses may concentrate shrimp to well above the overall mean. For these reasons, a single level of significant figures in presenting data (e.g. rounding to 10s, 100s, 1000s or even 10,000s) is inappropriate and we include the standard error of each lakewide estimate using the "±" notation. The reader is cautioned to always consider the standard errors when making inferences from the data.

### *Hatching of over-wintering cysts and maturation of the 1st generation*

Hatching of over-wintering cysts is initiated by warming water temperatures and oxic conditions. The peak of hatching usually occurs during March but significant hatching may also occur during February. A small amount of hatching may even occur during January in shallow nearshore regions during periods of above normal air temperatures. The 21 February survey was abandoned after sampling just two western stations (Stations 3 & 4) due to inclement weather and a follow-up survey precluded by continuing poor weather conditions. Samples from these two stations indicated the spring hatch of over-wintering cysts was in progress. Mean abundance of 1st instars was 1097±192 $m^{-2}$ (Table 11a, b). This was slightly higher than observed at these 2 stations in 1997 (765 $m^{-2}$) but lower than the 21 year mean of (8249 $m^{-2}$). As early spring hatching is usually higher in the eastern portions of the lake, this estimate likely underestimates the February lakewide mean population.,

*Artemia* lakewide abundance reached 10,651±1,838 $m^{-2}$ by the mid-March survey as the spring hatch continued. Nauplii consisted almost entirely of 1st instars (99.9%) (Table 12). Naupliar abundance continued to increase with 17 April 2008 abundance ranging from 6,640 to 75,654 $m^{-2}$ across the 12 stations with an overall lakewide mean of 26,663 ±6,926 $m^{-2}$. The population consisted entirely of naupliar instars with instars 1-4 constituting 99.7 % of the total population. No juveniles or adults were present. Naupliar abundance dipped slightly in May to 12,891±651 $m^{-2}$ but increased markedly in June as 1st generation adults reproduced ovoviviparously. Lakewide mean abundance was 83,541±12,971 $m^{-2}$ in June and then declined to 13,551±2,084 $m^{-2}$ in July. On 18 August, naupliar abundance was 6,834±1,116 $m^{-2}$ after which it declined further to 2,269±548 $m^{-2}$ on 9 September and fell below 100 $m^{-2}$ for the remainder of the year (Fig 19).

Adult *Artemia* including fecund females were present on the 30 May survey. At that time adult abundance was 20,054±1,884 $m^{-2}$ and constituted 57.8% of the total population. Adult abundance peaked in June at 27,606±2,015 $m^{-2}$, declining to 20,366±3,373 $m^{-2}$ by 18 July. Adult abundance continued to decline through 18 August (16,777±2,706 $m^{-2}$), 17 September (4,992±1,014 $m^{-2}$), 15 October (89±19 $m^{-2}$) and 13 November (20±12 $m^{-2}$;only stations 1, 2 and 6 sampled). No adults were present at station 4, the only sample collected in December (Fig 19).

Typically, hatching of over-wintering cysts is greater in the eastern sectors of the lake. March nauplii abundance at the eastern station (stations 7-12) was roughly double that observed at the western stations (stations 1-6). However, by 17 April, naupliar abundance in the western sector was almost three times larger than observed in the east. On 30 May all developmental stages were once again slightly more abundant in the east. The eastern sector remained dominant for the naupliar and juvenile stage class from 16 June through 17 September while adult stages were more abundant in the western sector during summer (Table 11a).

The lakewide mean abundance of adults was fairly constant throughout the summer (30 May, 20,054±1,844 $m^{-2}$; 16 June, 27,606±2,015 $m^{-2}$; 18 July, 20,366±3,373 $m^{-2}$; 18 August 16,777±2,706 $m^{-2}$). The 2008 abundance of 1st generation adults (16 June) was average in the 28-yr record (1981-2008) (Fig. 20). However, recruitment of ovoviviparously-produced nauplii into the summer adult population was very low and late summer and early autumn adult abundance (July through October) was among the lowest on record (Fig. 20).

### *Ovoviviparous reproduction and the second generation*

Ovoviviparous reproduction depends on ambient food levels and age of the individual. *Artemia* produce multiple broods and ovoviviparous reproduction in the lake occurs, if at all, almost exclusively with the first brood, rarely occurring in an individual's second and subsequent broods.

On 30 May 9,148±790 adult females comprised 26.4% of the total population, 30.4% were ovigerous with 57.1% reproducing ovoviviparously (naupliar eggs as opposed to encapsulated cysts) (Table 11a, b, c, 13a, b, c, Fig. 21). Ovigery increased to 49 % of 13,467±924 individuals on 16 June with ovoviviparity dropping to 7.2% and remaining below 5% for the remainder of the year. Ovigery increased to 71.9% of 7,334±1,328 females on 18 July, peaked on 18 August with 92.8% of 5,184±803 and decreased again in September and October (82.9% of 1,828±446 and 40% of 8±3 respectively). Cyst production ranged between 92.8% and 100% from mid June through mid October when females stopped reproducing (Table 13a, b, c). Similar to 2007, the May pulse of ovoviviparous reproduction led to a second prominent peak in the June abundance of 1st instar nauplii. The low numbers of later naupliar instars during July–September (Table 12) and the absence of a second peak in adult abundance indicate that relatively few of these individuals survived to adult with recruitment just replacing adult mortality. The lowest number of artemia for the month of September was recorded in 2007 with 3779±479 individuals. 2008 and 2002 show a similar early die off with 4992±1014 and 4961±756, respectively.

Fecundity (eggs per brood) is a function of food availability and adult female size. Lakewide mean fecundity ranged from 68 to 72 eggs $brood^{-1}$ during May and June, dropping substantially to 31 to 38 eggs $brood^{-1}$ in July and August (Table 14). Lakewide mean individual fecundity increased in September (90 eggs $brood^{-1}$) as food became abundant but total reproduction was virtually absent by mid-October as the population declined to near zero..

The mean length of adult females varied from 10.4 to 12.3 mm (Table 14) during the course of the year. These sizes are similar to previous years.

Due to winter conditions and the virtual absence of *Artemia*, only three stations were sampled on the November survey and one station in December. On 13 November 2008 only a single adult male, 2 adult females and 5 naupliar instars were captured in three vertical net tows yielding an areal abundance of 54±50 $m^{-2}$ (Table 11a&b). In December only 3 naupliar instars were captured in a single net tow.

## *Artemia Population Statistics, 1979–2007*

Year to year variation in climate, hydrological conditions, vertical stratification, food availability, and salinity have led to large inter-year differences in *Artemia* dynamics. During years when the first generation was small due to reduced hatching, high mortality, or delayed development, (1981, 1982, and 1989) the second generation peak of adults was 2–3 times the long term average (Table 15, Fig. 22). Seasonal peak abundances were also significantly higher (1.5–2 times the mean) in 1987 and 1988 as the 1980s episode of meromixis weakened and nutrients that had accumulated beneath the chemocline were transported upward and during 2004 following breakdown of the 1990s episode of meromixis. In most years the seasonal peaks of adult abundance were similar (30–40,000 $m^{-2}$) although above average values (42,000–56,000 $m^{-2}$) have occurred in the last three years. The seasonal (1 May to November 30) mean of adult abundance varied less within a range of 14–37,000 $m^{-2}$. The overall mean seasonal abundance of adult *Artemia* from 1979 to 2008 was ~19,600 $m^{-2}$. During this 30-yr record, mean seasonal abundance was lowest in 2000 (~10,500 $m^{-2}$) and 2002 (~11,600 $m^{-2}$) and highest in 1982 (~36,600 $m^{-2}$), 1989 (~36,400 $m^{-2}$), and 2004 (~32,000 $m^{-2}$). During the previous three years (2005, 17,888 $m^{-2}$; 2006, 21,518 $m^{-2}$; 2007, 18,269 $m^{-2}$) seasonal abundance has been close to the long-term mean of 19,584 $m^{-2}$. In 2008, mean seasonal abundance is 11,823 $m^{-2}$ making it the 3rd lowest in the 30 year history.

During most years, the seasonal distribution of adult abundance is roughly normal or lognormal. However, in several years the seasonal abundance was not described well by either of these distributions. Therefore, the abundance-weighted centroid of temporal occurrence was calculated to compare overall seasonal shifts in the timing of adult abundance. The center of the temporal distribution of adults varied from day 180 (28 June) to 252 (9 September) in the 30-yr record from 1979 to 2008 (Table 15, Fig. 23). During five years when there was a small spring hatch (1980–83, and 1989) the overall temporal distribution of adults was much later (24 August – 9 September) and during 2004 the exceptionally large and early 1st generation shifted the seasonal temporal distribution much earlier to 28 June. Although the spring generation was not as big in 2008 as observed in 2007, the timing was similar. Thus the overall temporal occurrence of adults (day 189, 7 July) is early and similar to that observed in 2007.

Over the long-term record there has been a general shift in seasonal adult abundance to earlier in the year. Although there has been significant year-to-year variation among years due to the onset, persistence, and breakdown of three episodes of meromixis during the period 1979 to 2008, a linear regression explains 50 % of the variation in the temporal abundance of adults. The centroid of adult abundance has shifted an average of 1.5 d $yr^{-1}$ over the 30-yr period of variable but generally decreasing salinity. The larger size of the 1st generation and subsequent earlier autumn decline is advantageous to breeding gulls (Wrege et al. 2006) and disadvantageous to migrating grebes (Jellison & Jehl unpublished).

## Long term integrative measures of productivity

### *Planktonic primary production*

Photosynthetic rates were determined by laboratory radiocarbon uptake measurements from 1982-1992 (Jellison and Melack 1988, 1993b) and combined with an interpolative model of chlorophyll, temperature, and in situ photosynthetically-available light (PAR) to estimate annual productivity. While radiocarbon uptake measurements were not conducted from 1993-2001, a significant fraction of the chlorophyll-specific variance in maximum ($P_m^B$) and light-limited uptake rates ($\alpha^B$) is explained by temperature (Jellison and Melack 1988, 1993b) and estimates of primary production in subsequent years were made employing measurements of light, chlorophyll, temperature and estimates of $P_m^B$ and $\alpha^{B.}$ As 1989 and 1990 had elevated ammonium concentrations due to the breakdown of meromixis, regressions were performed on just 1991 and 1992 for use in subsequent years. The exponential equation:

$$P_m^B = 0.237 \times 1.183^T \qquad n=42,\ r^2=0.86$$

where T is temperature (°C) explained 86 % of the overall variation. As found in previous analyses (Jellison and Melack 1993b), there was a strong correlation between light-limited and light-saturated rates. A linear regression on light-saturated rates explained 82 % of the variation in light-limited rates:

$$\alpha^B = 2.69 + (1.47 \times P_m^B) \qquad n=42,\ r^2=0.82$$

Both light-limited and light-saturated carbon uptake rates reported here are within the range reported in other studies (Jellison and Melack 1993b).

In 1995, rising lake levels and greater salinity stratification reduced the vertical flux of nutrients and may have affected the photosynthetic rates, but previous regression analyses (Jellison and Melack 1993b) using an extensive data set collected during periods of different nutrient supply regimes indicated little of the observed variance in photosynthetic rates can be explained by simple estimates of nutrient supply. The differences in annual phytoplankton production throughout the period, 1982–1992, resulted primarily from changes in the amount of standing biomass; year to year changes in photosynthetic parameters during the years they were measured (1983–92) were not correlated with annual production. Thus, we suggested the above regressions might explain most of the variance in photosynthetic rates and provide a reasonable alternative to frequent, costly field and laboratory measurements using radioactive tracers.

In 2001, new “photosynthetrons” (see Methods, Chapter 2) were constructed and direct measurements of carbon uptake were resumed to determine photosynthetic parameters. The new "photosynthetrons" provide more light levels and better control and measurement of the incubator's light and temperature. Thus, more accurate measurements of $P_m^B$ and $\alpha^B$ are possible and carbon uptake experiments are now routinely conducted with a sample from the upper mixed layer (2 m) and a sample from a depth near the bottom of the epilimnion (10-16 m). These measurements enable annual productivity changes associated with varying nutrient regimes or changing phytoplankton composition to be estimated more accurately than during 1993 to 2001 when $P_m^B$ and $\alpha^B$ were estimated from previously derived regressions.

During 2008, nine carbon uptake experiments were conducted with natural phytoplankton assemblages from either the mixed-layer or near the bottom of the epilimnion (Table 16). Chlorophyll-specific maximum carbon uptakes ($P_m^B$) rates and light-limited rates ($\alpha^B$) were determined for each sample by fitting a hyperbolic tangent curve to the data using least-squares nonlinear estimation (Fig 24). Chlorophyll-specific maximum carbon uptakes ($P_m^B$) rates for samples collected at 2 m depth ranged from 0.8 g C g Chl $a^{-1}$ $h^{-1}$ on 21 February to 15.3 g C g Chl $a^{-1}$ $h^{-1}$ on 18 August (Table 16, Fig. 24), while light-limited rates ($\alpha^B$) for these samples ranged from 2.6 to 34 g C g Chl $a^{-1}$ Einst$^{-1}$ m$^2$

Using the interpolative model to integrate the photosynthetic parameters with in situ temperature, chlorophyll, and light resulted in an annual productivity estimate of 1,189 g C m$^{-2}$ during 2008 (Table 17, Figs. 24-26). The maximum uptakes rates are primarily a function of temperature and thus the seasonal pattern and magnitudes were roughly similar during 2002–2007 with the exception of the low rate measured on 30 May 2008 (Fig. 25). The estimated daily production values vary throughout the year and in a complex fashion. Compared to the previous 6 years, the most notable differences are the lack of a prominent peak observed in 2003 and 2007, the low late May value, and somewhat above average August daily values (Fig. 26). Changes in standing algal biomass are a dominant factor in variation in daily and annual primary productivity (Jellison and Melack 1988, 1993b). While the overall seasonal trends were roughly similar during 2002–08, higher algal biomass in late summer during 2008 somewhat compensated for the low specific uptake rates measured in late May. Daily production rates ranged from 0.4 to 5.3, 1.4 to 10.8, 0.1 to 7.7, 0.3 to 5.8, 0.8 to 5.1, 0.9 to 15.4, and 0.5 to 8.0 g C m$^{-2}$ in 2002, 2003, 2004, 2005, 2006, 2007, and 2008, respectively (Fig. 27).

Annual primary production in 2008 was 80% higher than the long-term mean (1982–2008) of 659 g C m$^{-2}$ (Table 17, Fig. 28). Estimates from previous years ranged from 149 g C m$^{-2}$ in 1997 to 1645 g C m$^{-2}$ in 2003. In 1988, a 5-yr episode of meromixis was breaking down and nutrients which had accumulated beneath the thermocline were mixed into the euphotic zone leading to higher algal biomass and estimated annual production of 1064 g C m$^{-2}$. During 2003, an 8-yr period of chemical stratification broke down and significant amounts of ammonium were entrained into the mixed layer. Estimates of planktonic photosynthesis at Mono Lake are generally higher than other hypersaline lakes in the Great Basin: Great Salt Lake (southern basin), 145 g C m$^{-2}$ yr$^{-1}$ (Stephens and Gillespie 1976); Soap Lake, 391 g C m$^{-2}$ yr$^{-1}$ (Walker 1975); and Big Soda, 500 g C m$^{-2}$ yr$^{-1}$ (350 g C m$^{-2}$ yr$^{-1}$ phototrophic production) (Cloern *et al.* 1983).

### *Artemia biomass and egg production*

*Artemia* biomass was estimated from instar-specific population data and previously derived weight-length relationships for the period 1982–99. Variation in weight-length relationships among sampling dates was assessed from 1996–99 and found to lead to errors of up to 20 % in the annual estimates. Thus, in 2000 we implemented direct drying and weighing of vertical net tow samples collected explicitly for biomass determinations.

In 2008, *Artemia* biomass was 0.0 g dry weight m$^{-2}$ on 21 February and increased to the yearly peak of 19.3 g dry weight m$^{-2}$ on 16 July. This was less than peak biomasses observed in 2005 (30.5 g dry weight m$^{-2}$), 2006 (30.7 g dry weight m$^{-2}$), and 2007 (26.5 g dry weight m$^{-2}$). The 2008 mean annual *Artemia* biomass was 5.8 g m$^{-2}$, 36% below the long-term (1983-2008) mean of 9.0 g m$^{-2}$ (Table 17, Fig. 29)

The highest estimated mean annual *Artemia* biomass (17.6 g m$^{-2}$) occurred in 1989 just after the breakdown of meromixis during a period of elevated phytoplankton nutrients (ammonium) and phytoplankton. Mean annual biomass was somewhat below the long-term mean during the first 3 years of the 1980s episode of meromixis and then above the mean during the next 3 years as meromixis weakened and ended. Except for lower values in 1997 and in 2002, *Artemia* biomass has remained relatively constant since 1993 and was only slightly higher during 1990–92. The higher value in 2004 is associated with the largest spring generation observed.

In Mono Lake, oviparous (cyst) reproduction is always much higher than ovoviviparous (live-bearing) reproduction (Fig. 30, Table 17). In 2008, total annual naupliar production (0.34 x 10$^{6}$ m$^{-2}$) was similar to that observed from 2005-2007 (0.29–0.31 x 10$^{6}$ m$^{-2}$) and somewhat higher than the long-term mean of 0.25 x 10$^{6}$ m$^{-2}$. Total annual cyst production in 2008 was 3.1 x 10$^{6}$ m$^{-2}$, slightly lower than the previous three years (3.4–4.8 m$^{-2}$) and 29 % below the long-term mean of 4.3 x 10$^{6}$ m$^{-2}$.

### *Long-term trends in inter-year variation in algal biomass and adult Artemia abundance*

The long-term record of plankton dynamics in Mono Lake show marked seasonal and inter-year variation (Figs. 31-32). Multi-year episodes of meromixis have markedly increased the inter-year variation compared to periods of monomixis in which an annual winter period of holomixis occurs. The large variations caused by changes in mixing regime preclude the possibility of determining the effects of variation in salinity from any small subset of years. Here, we examine the long-term trends in algal biomass in the upper water column (< 10 m) and adult *Artemia* biomass from 1982 through 2007.

The seasonal trend can be removed by calculating a yearly moving average. Because the intervals between sampling dates varied among years, daily values were derived by linearly interpolating between sample dates prior to calculating a 365-day moving average. Thus, each point represents a moving average of 365 days centered about a given day. The seasonally-filtered chlorophyll *a* concentrations (Fig. 31, heavy line) show the marked impact of the three episodes of meromixis, 1983–88, 1995–03, 2005–07). The seasonally-filtered mean chlorophyll ranged from a minimum of 2.8 µg liter$^{-1}$ following the onset of meromixis in 1984 to 50.3 µg liter$^{-1}$ in late 2003 as the second episode of meromixis ended. This represents an 18-fold difference. The seasonally-filtered adult *Artemia* abundance show much less inter-year variation (Fig. 32) with mean abundance ranging from 6,200 $m^{-2}$ in 2000 to 24,000 $m^{-2}$ in 1982 or about a 4-fold difference. Thus, inter-year variation in seasonally-filtered adult *Artemia* abundance is much less than that of algal abundance. While it is clear that any long-term trends in these seasonally-filtered measures either measure are either small or obscured by the inter-year variation due to varying mixing regimes, a significant shift in *Artemia* abundance to earlier in the year has occurred over the last decade.

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Table 1. Temperature (ºC) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.9 | 4.7 | 9.2 | 13.7 | 19.2 | 22.0 | 22.2 | 18.2 | 11.9 | 9.2 | 6.3 |
| 2 | 1.7 | 4.4 | 8.6 | 13.5 | 18.5 | 21.8 | 22.4 | 18.0 | 11.9 | 9.2 | 6.3 |
| 3 | 1.5 | 4.3 | 8.1 | 13.3 | 19.1 | 21.7 | 22.3 | 17.9 | 11.9 | 9.5 | 6.3 |
| 4 | 1.5 | 4.1 | 7.8 | 13.1 | 18.3 | 21.8 | 22.3 | 17.9 | 12.0 | 9.5 | 6.3 |
| 5 | 1.5 | 4.0 | 7.5 | 12.9 | 17.0 | 21.6 | 22.4 | 18.0 | 12.2 | 9.5 | 6.3 |
| 6 | 1.5 | 3.4 | 7.4 | 12.6 | 16.6 | 21.5 | 22.3 | 18.0 | 12.3 | 9.5 | 6.3 |
| 7 | 1.5 | 3.3 | 7.4 | 12.5 | 15.9 | 21.4 | 21.7 | 17.9 | 12.3 | 9.5 | 6.3 |
| 8 | 1.4 | 3.2 | 7.2 | 12.6 | 15.7 | 21.6 | 21.3 | 18.0 | 12.4 | 9.5 | 6.3 |
| 9 | 1.4 | 2.9 | 7.1 | 12.3 | 13.8 | 18.2 | 20.8 | 18.1 | 12.4 | 9.5 | 6.3 |
| 10 | 1.4 | 2.8 | 7.1 | 11.3 | 12.8 | 14.3 | 17.8 | 18.1 | 12.4 | 9.5 | 6.3 |
| 11 | 1.4 | 2.6 | 6.3 | 10.3 | 12.0 | 12.0 | 15.3 | 18.1 | 12.4 | 9.6 | 6.3 |
| 12 | 1.4 | 2.5 | 5.9 | 10.1 | 10.2 | 10.3 | 13.0 | 17.9 | 12.3 | 9.6 | 6.3 |
| 13 | 1.4 | 2.3 | 5.6 | 8.9 | 7.9 | 9.8 | 10.3 | 14.6 | 12.3 | 9.6 | 6.3 |
| 14 | 1.4 | 2.2 | 5.4 | 8.0 | 7.2 | 9.2 | 8.9 | 12.0 | 12.2 | 9.5 | 6.3 |
| 15 | 1.4 | 2.0 | 5.1 | 7.2 | 6.4 | 7.9 | 8.3 | 10.8 | 11.7 | 9.5 | 6.3 |
| 16 | 1.4 | 2.0 | 4.6 | 7.0 | 6.0 | 6.8 | 8.0 | 9.8 | 10.6 | 9.5 | 6.3 |
| 17 | 1.4 | 2.1 | 3.8 | 6.2 | 5.8 | 6.5 | 7.3 | 9.3 | 9.5 | 9.5 | 6.3 |
| 18 | 1.4 | 1.9 | 3.3 | 5.6 | 5.5 | 6.3 | 6.8 | 8.6 | 9.1 | 9.5 | 6.2 |
| 19 | 1.4 | 1.9 | 3.2 | 5.1 | 5.1 | 6.1 | 6.5 | 8.1 | 9.1 | 9.5 | 6.2 |
| 20 | 1.4 | 1.8 | 3.0 | 4.8 | 4.9 | 5.8 | 6.3 | 7.8 | 8.8 | 9.5 | 6.2 |
| 21 | 1.3 | 1.7 | 2.8 | 4.4 | 4.7 | 5.7 | 6.3 | 7.5 | 8.7 | 9.5 | 6.1 |
| 22 | 1.3 | 1.6 | 2.7 | 4.2 | 4.7 | 5.6 | 6.2 | 7.3 | 8.6 | 9.5 | 6.1 |
| 23 | 1.3 | 1.6 | 2.5 | 4.1 | 4.6 | 5.5 | 6.0 | 7.1 | 8.6 | 9.4 | 6.1 |
| 24 | 1.3 | 1.6 | 2.5 | 4.1 | 4.5 | 5.5 | 5.9 | 7.0 | 8.6 | 9.4 | 6.1 |
| 25 | 1.3 | 1.6 | 2.5 | 4.0 | 4.4 | 5.4 | 5.8 | 6.8 | 8.7 | 9.4 | 6.0 |
| 26 | 1.3 | 1.6 | 2.5 | 4.0 | 4.3 | 5.4 | 5.7 | 6.6 | 9.0 | 9.4 | 6.0 |
| 27 | 1.3 | 1.6 | 2.5 | 3.9 | 4.2 | 5.3 | 5.7 | 6.5 | 9.9 | 9.4 | 5.9 |
| 28 | 1.3 | 1.5 | 2.3 | 3.9 | 4.1 | 5.2 | 5.6 | 6.3 | 9.9 | 9.4 | 5.9 |
| 29 | 1.3 | 1.5 | 2.3 | 3.8 | 4.1 | 5.1 | 5.5 | 6.3 | 9.9 | 9.4 | 5.9 |
| 30 | 1.3 | 1.5 | 2.2 | 3.7 | 4.0 | 5.1 | 5.4 | 6.2 | 9.8 | 9.4 | 5.9 |
| 31 | 1.3 | 1.5 | 2.2 | 3.7 | 4.0 | 5.1 | 5.4 | 6.1 | 9.9 | 9.3 | 5.9 |
| 32 | 1.3 | 1.5 | 2.2 | 3.7 | 3.9 | 5.0 | 5.4 | 6.1 | 10.0 | 9.3 | 5.9 |
| 33 | - | 1.5 | 2.0 | 3.6 | 3.8 | 5.0 | 5.3 | 6.1 | 9.4 | 9.3 | 6.3 |
| 34 | - | 1.5 | 2.0 | 3.6 | 3.8 | 4.9 | 5.3 | 6.0 | 9.3 | 9.3 | 6.3 |
| 35 | - | 1.5 | 2.0 | 3.5 | 3.7 | 4.8 | 5.3 | 6.0 | 8.9 | 9.2 | - |
| 36 | - | 1.5 | 1.9 | 3.5 | 3.7 | 4.7 | 5.2 | 6.0 | 9.0 | 9.2 | - |
| 37 | - | 1.5 | 1.9 | 3.5 | 3.7 | 4.7 | 5.1 | 5.9 | 9.0 | 9.1 | - |
| 38 | - | - | 1.9 | 3.4 | 3.7 | 4.6 | 5.1 | 5.9 | 8.1 | 9.0 | - |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

Table 2. Conductivity (mS $cm^{-1}$ at 25ºC) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17** | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 80.4 | 80.4 | | 80.1 | 79.5 | Data unavailable due to unstable temperature probe on high performance Idronaut CTD. | | | 81.6 | 81.4 | 81.8 |
| 2 | 80.9 | 80.5 | | 80.3 | 79.9 | | | | 81.6 | 81.4 | 81.9 |
| 3 | 81.0 | 80.5 | | 80.8 | 79.8 | | | | 81.6 | 81.6 | 81.9 |
| 4 | 80.9 | 80.6 | | 80.9 | 80.6 | | | | 81.7 | 81.7 | 81.9 |
| 5 | 80.9 | 80.6 | | 80.9 | 80.8 | | | | 81.9 | 81.7 | 81.9 |
| 6 | 80.9 | 80.7 | | 81.0 | 80.9 | | | | 81.9 | 81.7 | 81.9 |
| 7 | 80.9 | 80.8 | | 81.0 | 81.0 | | | | 81.9 | 81.7 | 81.9 |
| 8 | 80.9 | 80.7 | | 81.2 | 80.9 | | | | 82.0 | 81.8 | 81.9 |
| 9 | 80.9 | 80.8 | | 81.2 | 81.0 | | | | 82.0 | 81.7 | 81.9 |
| 10 | 81.0 | 80.8 | | 81.1 | 81.1 | | | | 82.1 | 81.8 | 81.9 |
| 11 | 80.9 | 80.8 | | 81.1 | 81.1 | | | | 82.1 | 81.8 | 82.0 |
| 12 | 81.0 | 80.7 | | 81.1 | 81.3 | | | | 82.0 | 81.9 | 82.0 |
| 13 | 81.0 | 80.8 | | 81.1 | 81.4 | | | | 82.0 | 81.9 | 82.0 |
| 14 | 81.0 | 80.8 | | 81.2 | 81.2 | | | | 82.0 | 81.9 | 82.0 |
| 15 | 81.0 | 80.8 | | 81.1 | 81.1 | | | | 81.8 | 81.9 | 82.0 |
| 16 | 81.0 | 80.9 | | 81.1 | 81.1 | | | | 81.4 | 81.9 | 82.0 |
| 17 | 80.9 | 80.9 | | 81.1 | 81.1 | | | | 80.8 | 81.9 | 82.0 |
| 18 | 81.0 | 80.9 | | 81.1 | 81.1 | | | | 80.7 | 81.9 | 82.0 |
| 19 | 81.0 | 80.9 | | 81.1 | 81.1 | | | | 80.6 | 81.9 | 82.0 |
| 20 | 81.0 | 80.9 | | 81.1 | 81.1 | | | | 80.5 | 81.9 | 82.0 |
| 21 | 81.0 | 80.9 | | 81.1 | 81.1 | | | | 80.4 | 81.9 | 82.0 |
| 22 | 81.0 | 80.9 | | 81.0 | 81.0 | | | | 80.4 | 81.9 | 82.0 |
| 23 | 81.0 | 80.9 | | 81.0 | 81.0 | | | | 80.4 | 81.9 | 82.0 |
| 24 | 81.0 | 80.9 | | 81.0 | 81.1 | | | | 80.4 | 81.9 | 82.0 |
| 25 | 81.0 | 80.9 | | 81.0 | 81.0 | | | | 80.4 | 81.9 | 82.0 |
| 26 | 81.0 | 80.9 | | 81.0 | 81.0 | | | | 80.5 | 81.9 | 82.0 |
| 27 | 81.0 | 80.9 | | 81.0 | 81.1 | | | | 81.0 | 81.9 | 81.9 |
| 28 | 81.0 | 81.0 | | 81.0 | 81.0 | | | | 81.0 | 81.9 | 81.9 |
| 29 | 81.0 | 81.0 | | 81.0 | 81.0 | | | | 81.1 | 81.9 | 81.9 |
| 30 | 81.0 | 81.0 | | 81.0 | 81.0 | | | | 81.1 | 81.9 | 81.9 |
| 31 | 81.0 | 81.0 | | 81.0 | 81.1 | | | | 81.1 | 81.9 | 81.9 |
| 32 | 81.0 | 81.0 | | 81.0 | 81.1 | | | | 81.2 | 81.9 | 81.9 |
| 33 | - | 81.0 | | 81.0 | 81.1 | | | | 81.0 | 81.9 | - |
| 34 | - | 81.0 | | 81.0 | 81.0 | | | | 80.9 | 81.9 | - |
| 35 | - | 81.0 | | 81.0 | 81.0 | | | | 80.7 | 81.9 | - |
| 36 | - | 81.0 | | 81.0 | 81.0 | | | | 80.9 | 81.9 | - |
| 37 | - | 81.0 | | 81.0 | 81.0 | | | | 80.9 | 81.9 | - |
| 38 | - | - | | 81.0 | 81.0 | | | | 80.5 | 81.8 | - |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

** Idronaut CTD flooded and sent back to factory.

Table 3. Excess density (kg $m^{-3}$) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17** | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 69.8 | 69.6 | | 67.3 | 64.9 | | | | 69.5 | 69.8 | 70.9 |
| 2 | 70.6 | 69.7 | | 67.6 | 65.7 | | | | 69.5 | 69.9 | 71.0 |
| 3 | 70.6 | 69.7 | | 68.3 | 65.4 | | | | 69.5 | 70.1 | 71.0 |
| 4 | 70.6 | 69.8 | | 68.4 | 66.5 | | | | 69.6 | 70.2 | 71.0 |
| 5 | 70.6 | 69.8 | | 68.4 | 67.2 | | | | 69.7 | 70.2 | 71.0 |
| 6 | 70.6 | 70.1 | | 68.6 | 67.3 | | | | 69.7 | 70.2 | 71.0 |
| 7 | 70.6 | 70.1 | | 68.7 | 67.8 | | | | 69.8 | 70.2 | 71.1 |
| 8 | 70.6 | 70.1 | | 68.8 | 67.7 | | | | 69.8 | 70.2 | 71.1 |
| 9 | 70.6 | 70.2 | | 68.9 | 68.3 | | | | 69.9 | 70.2 | 71.1 |
| 10 | 70.6 | 70.3 | | 69.1 | 68.7 | | | | 69.9 | 70.3 | 71.1 |
| 11 | 70.6 | 70.3 | | 69.3 | 68.9 | | | | 69.9 | 70.3 | 71.1 |
| 12 | 70.6 | 70.2 | | 69.3 | 69.5 | | | | 69.9 | 70.3 | 71.1 |
| 13 | 70.6 | 70.3 | | 69.6 | 70.2 | | | | 69.9 | 70.3 | 71.1 |
| 14 | 70.6 | 70.4 | | 69.8 | 70.1 | | | | 69.9 | 70.3 | 71.1 |
| 15 | 70.6 | 70.4 | | 69.9 | 70.1 | | | | 69.8 | 70.3 | 71.1 |
| 16 | 70.6 | 70.5 | | 69.9 | 70.2 | | | | 69.5 | 70.3 | 71.1 |
| 17 | 70.6 | 70.4 | | 70.1 | 70.2 | | | | 69.1 | 70.3 | 71.1 |
| 18 | 70.6 | 70.5 | | 70.2 | 70.2 | Data unavailable due to unstable temperature probe on high performance Idronaut CTD. | | | 69.1 | 70.3 | 71.1 |
| 19 | 70.6 | 70.5 | | 70.2 | 70.3 | | | | 69.0 | 70.3 | 71.1 |
| 20 | 70.7 | 70.5 | | 70.3 | 70.3 | | | | 68.9 | 70.3 | 71.1 |
| 21 | 70.7 | 70.6 | | 70.4 | 70.4 | | | | 68.9 | 70.4 | 71.1 |
| 22 | 70.7 | 70.6 | | 70.3 | 70.3 | | | | 68.8 | 70.4 | 71.2 |
| 23 | 70.7 | 70.6 | | 70.3 | 70.3 | | | | 68.8 | 70.4 | 71.2 |
| 24 | 70.6 | 70.6 | | 70.4 | 70.3 | | | | 68.8 | 70.4 | 71.2 |
| 25 | 70.7 | 70.6 | | 70.4 | 70.3 | | | | 68.8 | 70.4 | 71.2 |
| 26 | 70.7 | 70.6 | | 70.3 | 70.3 | | | | 68.9 | 70.4 | 71.1 |
| 27 | 70.7 | 70.6 | | 70.3 | 70.4 | | | | 69.3 | 70.4 | 71.1 |
| 28 | 70.7 | 70.6 | | 70.3 | 70.4 | | | | 69.3 | 70.4 | 71.1 |
| 29 | 70.7 | 70.6 | | 70.3 | 70.4 | | | | 69.4 | 70.4 | 71.1 |
| 30 | 70.7 | 70.6 | | 70.4 | 70.4 | | | | 69.4 | 70.4 | 71.1 |
| 31 | 70.7 | 70.6 | | 70.4 | 70.4 | | | | 69.4 | 70.4 | 71.1 |
| 32 | 70.7 | 70.6 | | 70.4 | 70.5 | | | | 69.5 | 70.5 | 71.1 |
| 33 | 69.8 | 70.6 | | 70.4 | 70.4 | | | | 69.4 | 70.5 | - |
| 34 | 70.6 | 70.6 | | 70.4 | 70.4 | | | | 69.3 | 70.5 | - |
| 35 | - | 70.6 | | 70.4 | 70.4 | | | | 69.2 | 70.5 | - |
| 36 | - | 70.6 | | 70.4 | 70.4 | | | | 69.4 | 70.5 | - |
| 37 | - | 70.6 | | 70.4 | 70.4 | | | | 69.3 | 70.5 | - |
| 38 | - | - | | 70.4 | 70.4 | | | | 69.1 | 70.4 | - |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

** Idronaut CTD failed and sent back to factory.

Table 4. Temperature, conductivity, and density stratification (kg $m^{-3}$) at Station 6 (*or Station 4), February – December, 2008.

| Date | Temperature | | Conductivity | | Density Difference due to | | |
|---|---|---|---|---|---|---|---|
| | 2 m | 32 m | 2 m | 32 m | Temperature | Conductivity | Both |
| 2/21 | 1.7 | 1.3 | 80.9 | 81 | 0.05 | 0.12 | 0.16 |
| 3/21 | 4.4 | 1.5 | 80.5 | 81 | 0.38 | 0.58 | 0.97 |
| 4/17 | 8.6 | 2.2 | **80.4 | **81 | 1.04 | 0.70 | 1.74 |
| 5/30 | 13.5 | 3.7 | 80.3 | 81 | 1.98 | 0.81 | 2.79 |
| 6/16 | 18.5 | 3.9 | 79.9 | 81.1 | 3.42 | 1.39 | 4.81 |
| 7/18 | 21.8 | 5 | **80.4 | **81.1 | 4.40 | 0.81 | 5.21 |
| 8/18 | 22.4 | 5.4 | **80.8 | **81.2 | 4.56 | 0.46 | 5.02 |
| 9/17 | 18 | 6.1 | **81.2 | **81.2 | 2.92 | 0.00 | 2.92 |
| 10/15 | 11.9 | 10 | 81.6 | 81.2 | 0.44 | -0.47 | -0.02 |
| 11/13 | 9.2 | 9.3 | 81.4 | 81.9 | -0.02 | 0.58 | 0.56 |
| 12/18 | 6.3 | 5.9 | 81.9 | 81.9 | 0.07 | 0.00 | 0.07 |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

** Values derived by interpolation between measurements during surveys conducted in months before and after

Table 5. Secchi Depths (m), February – December 2008.

| | Dates | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Station | 2/21 | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
| Western Sector | | | | | | | | | | | |
| 1 | | 0.78 | 1.00 | 1.20 | 4.20 | 6.30 | 7.10 | 2.10 | 0.70 | 0.70 | |
| 2 | | 0.78 | 0.80 | 1.20 | 4.10 | 6.10 | 5.70 | 1.50 | 0.70 | 0.65 | |
| 3 | 0.70 | 0.80 | 0.80 | 1.20 | 4.40 | 4.80 | 4.90 | 1.50 | 0.80 | | |
| 4 | 1.00 | 0.90 | 0.80 | 1.50 | 4.50 | 5.20 | 5.00 | 1.40 | 0.80 | | 0.95 |
| 5 | | 0.80 | 0.90 | 1.30 | 4.25 | 5.10 | 5.40 | 1.60 | 0.80 | | |
| 6 | | 0.80 | 0.80 | 1.50 | 3.50 | 5.00 | 4.70 | 1.40 | 0.70 | 0.70 | |
| Avg. | 0.85 | 0.81 | 0.85 | 1.32 | 4.16 | 5.42 | 5.47 | 1.58 | 0.75 | 0.68 | 0.95 |
| S.E. | 0.15 | 0.02 | 0.03 | 0.06 | 0.14 | 0.25 | 0.36 | 0.11 | 0.02 | 0.02 | |
| n | 2 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | 1 |
| Eastern Sector | | | | | | | | | | | |
| 7 | | 0.80 | 0.90 | 1.70 | 3.30 | 4.00 | 4.50 | 1.30 | 0.75 | | |
| 8 | | 0.78 | 0.85 | 1.50 | 3.70 | 4.10 | 4.50 | 1.30 | 0.80 | | |
| 9 | | 1.00 | 0.75 | 1.60 | 3.80 | 4.50 | 4.40 | 1.30 | 0.80 | | |
| 10 | | 0.80 | 0.80 | 1.20 | 3.80 | 3.70 | 4.20 | 1.30 | 0.80 | | |
| 11 | | 0.80 | 0.80 | 1.20 | 4.20 | 4.20 | 4.30 | 1.30 | 0.80 | | |
| 12 | | 0.90 | 0.90 | 1.30 | 3.60 | 4.10 | 4.50 | 1.30 | 0.80 | | |
| Avg. | | 0.85 | 0.83 | 1.42 | 3.73 | 4.10 | 4.40 | 1.30 | 0.79 | | |
| S.E. | | 0.04 | 0.02 | 0.09 | 0.12 | 0.11 | 0.05 | 0.00 | 0.01 | | |
| n | | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | | |
| Total Lakewide | | | | | | | | | | | |
| Avg. | 0.85 | 0.83 | 0.84 | 1.37 | 3.95 | 4.76 | 4.93 | 1.44 | 0.77 | 0.68 | 0.95 |
| S.E. | 0.15 | 0.02 | 0.02 | 0.05 | 0.11 | 0.24 | 0.24 | 0.07 | 0.01 | 0.02 | |
| n | 2 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 3 | 1 |

Table 6: Dissolved Oxygen (mg $l^{-1}$) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.86 | 7.04 | 5.85 | 4.72 | 3.75 | 3.46 | 3.92 | 4.57 | 3.31 | 4.59 | 4.76 |
| 2 | 8.69 | 7.62 | 6.63 | 4.89 | 3.71 | 3.44 | 4.12 | 4.75 | 3.31 | 4.58 | - |
| 3 | 8.27 | 7.85 | 6.79 | 5.00 | 3.76 | 3.41 | 4.23 | 4.89 | 3.23 | 4.62 | 4.41 |
| 4 | 6.67 | 8.04 | 6.72 | 4.88 | 3.89 | 3.41 | 4.23 | 4.90 | 3.18 | 4.36 | - |
| 5 | 6.49 | 8.01 | 6.78 | 4.93 | 4.00 | 3.40 | 4.32 | 4.91 | 3.23 | 3.24 | 4.31 |
| 6 | 6.38 | 7.92 | 6.77 | 4.86 | 4.46 | 3.34 | 4.39 | 4.93 | 3.39 | 3.08 | - |
| 7 | 6.28 | 7.29 | 6.71 | 5.06 | 4.67 | 3.35 | 4.61 | 4.90 | 3.39 | 3.07 | 4.25 |
| 8 | 6.23 | 7.15 | 6.57 | 4.53 | 5.03 | 3.36 | 4.52 | 4.68 | 3.26 | 3.01 | - |
| 9 | 6.00 | 6.91 | 6.57 | 3.78 | 5.04 | 3.49 | 4.41 | 4.74 | 2.89 | 3.06 | 4.29 |
| 10 | 5.99 | 6.26 | 6.61 | 3.91 | 5.23 | 5.58 | 4.35 | 4.85 | 2.63 | 3.03 | - |
| 11 | 5.89 | 5.99 | 6.60 | 3.51 | 4.44 | 6.61 | 4.56 | 4.91 | 2.43 | 1.24 | 4.33 |
| 12 | 5.89 | 5.72 | 5.69 | 3.42 | 4.62 | 5.57 | 4.71 | 4.93 | 2.34 | 2.58 | - |
| 13 | 5.93 | 5.46 | 5.27 | 3.01 | 3.49 | 4.27 | 4.31 | 4.14 | 2.20 | 2.61 | 4.37 |
| 14 | 5.89 | 5.03 | 5.12 | 2.48 | <0.50 | 3.57 | 1.65 | 0.69 | 1.97 | 2.70 | - |
| 15 | 5.80 | 4.86 | 5.00 | 1.90 | <0.50 | 2.16 | <0.50 | <0.50 | 1.82 | 2.82 | 4.39 |
| 16 | 5.79 | 4.78 | 4.61 | 1.58 | <0.50 | <0.50 | <0.50 | <0.50 | 0.76 | 3.12 | - |
| 17 | 5.79 | 4.52 | 4.15 | 1.18 | <0.50 | <0.50 | <0.50 | <0.50 | <0.50 | 3.14 | 4.44 |
| 18 | 5.67 | 4.19 | 3.10 | 0.98 | <0.50 | <0.50 | <0.50 | - | <0.50 | 3.18 | - |
| 19 | 5.68 | 3.88 | 2.93 | 0.60 | <0.50 | - | - | - | - | 3.19 | 4.60 |
| 20 | 5.52 | 3.78 | 2.63 | <0.50 | <0.50 | - | - | - | - | 3.21 | - |
| 21 | 5.52 | 3.84 | 2.37 | <0.50 | <0.50 | - | - | - | - | 3.25 | 4.69 |
| 22 | - | 3.73 | 2.01 | <0.50 | <0.50 | - | - | - | - | 3.29 | - |
| 23 | - | 3.65 | 1.97 | <0.50 | <0.50 | - | - | - | - | 3.29 | 4.83 |
| 24 | - | 3.59 | 1.84 | - | - | - | - | - | - | 3.29 | - |
| 25 | - | 3.52 | 1.76 | - | - | - | - | - | - | 3.40 | 4.91 |
| 26 | - | 3.42 | 1.67 | - | - | - | - | - | - | 3.40 | - |
| 27 | - | 3.37 | 1.54 | - | - | - | - | - | - | 3.41 | 4.95 |
| 28 | - | 3.35 | 1.51 | - | - | - | - | - | - | 3.43 | - |
| 29 | - | 3.29 | 1.48 | - | - | - | - | - | - | 3.45 | 4.96 |
| 30 | - | 3.16 | 1.06 | - | - | - | - | - | - | 3.45 | - |
| 31 | - | 3.12 | 0.97 | - | - | - | - | - | - | 3.25 | 4.95 |
| 32 | - | 3.10 | 0.90 | - | - | - | - | - | - | 3.23 | - |
| 33 | - | 2.88 | 0.81 | - | - | - | - | - | - | 2.35 | 4.98 |
| 34 | - | 2.69 | 0.73 | - | - | - | - | - | - | 2.34 | - |
| 35 | - | 2.54 | 0.69 | - | - | - | - | - | - | 2.77 | - |
| 36 | - | 2.47 | 0.52 | - | - | - | - | - | - | 1.67 | - |
| 37 | - | 2.42 | 0.50 | - | - | - | - | - | - | 2.91 | - |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

Table 7. Ammonium (µM) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - | - | - | - |
| 2 | 0.61 | 1.1 | 0.27 | 1.4 | 3.25 | 2.82 | 0.99 | 0.9 | 0.75 | 0.41 | 0.53 |
| 3 | - | - | - | - | - | - | - | - | - | - | - |
| 4 | - | - | - | - | - | - | - | - | - | - | - |
| 5 | - | - | - | - | - | - | - | - | - | - | - |
| 6 | - | - | - | - | - | - | - | - | - | - | - |
| 7 | - | - | - | - | - | - | - | - | - | - | - |
| 8 | 1.44 | 0.84 | 0.09 | 0.93 | 2.81 | 2.62 | 0.99 | 0.8 | 0.54 | 0.41 | 0.53 |
| 9 | - | - | - | - | - | - | - | - | - | - | - |
| 10 | - | - | - | - | - | - | - | - | - | - | - |
| 11 | - | - | - | - | - | - | - | - | - | - | - |
| 12 | 1.21 | 1.62 | 0.81 | 1.51 | 2.61 | 1.39 | 1.32 | 0.75 | 1.89 | 1.66 | 0.43 |
| 13 | - | - | - | - | - | - | - | - | - | - | - |
| 14 | - | - | - | - | - | - | - | - | - | - | - |
| 15 | - | - | - | - | - | - | - | - | - | - | - |
| 16 | 1.86 | 1.3 | 0.57 | 5.17 | 14.61 | 11.6 | 16.71 | 31.4 | 13.55 | 0.36 | 0.38 |
| 17 | - | - | - | - | - | - | - | - | - | - | - |
| 18 | - | - | - | - | - | - | - | - | - | - | - |
| 19 | - | - | - | - | - | - | - | - | - | - | - |
| 20 | 1.17 | 1.15 | 5.89 | 12.49 | 19.91 | 35.16 | 46.22 | 50.43 | 34.74 | 0.31 | 0.43 |
| 21 | - | - | - | - | - | - | - | - | - | - | - |
| 22 | - | - | - | - | - | - | - | - | - | - | - |
| 23 | - | - | - | - | - | - | - | - | - | - | - |
| 24 | 1.44 | 1.67 | 10.13 | 16.47 | 28.83 | 40.29 | 52.95 | 56.91 | 40.96 | 0.26 | 0.33 |
| 25 | - | - | - | - | - | - | - | - | - | - | - |
| 26 | - | - | - | - | - | - | - | - | - | - | - |
| 27 | - | - | - | - | - | - | - | - | - | - | - |
| 28 | 1.54 | 1.98 | 10.97 | 22.94 | 19.91 | 43.37 | 60.64 | 62.88 | 22.82 | 0.46 | 0.43 |
| 29 | - | - | - | - | - | - | - | - | - | - | - |
| 30 | - | - | - | - | - | - | - | - | - | - | - |
| 31 | - | - | - | - | - | - | - | - | - | - | - |
| 32 | - | - | - | - | - | - | - | - | - | - | 0.43 |
| 33 | - | - | - | - | - | - | - | - | - | - | - |
| 34 | - | - | - | - | - | - | - | - | - | - | - |
| 35 | 1.21 | 5.1 | 13.64 | 31 | 37.26 | 47.99 | 67.37 | 77.83 | 28.52 | 0.41 | - |
| 36 | - | - | - | - | - | - | - | - | - | - | - |
| 37 | - | - | - | - | - | - | - | - | - | - | - |

* The February and December surveys sampled Station 4 instead of Station 6 due to inclement weather and equipment failure.

Table 8. Ammonium (µM) at 7 stations in upper 9 m of water column, February – December, 2008.

| Station | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.94 | 0.39 | 0.77 | 2.86 | 5.03 | 2.43 | 2.75 | 1.01 | 0.50 |
| 2 | 0.94 | 0.81 | 1.09 | 3.65 | 4.93 | 1.42 | 0.90 | 0.80 | 0.89 |
| 5 | 0.94 | 1.05 | 0.98 | 2.31 | 2.21 | 1.76 | 1.50 | 0.65 | |
| 6 | 1.25 | 0.15 | 1.40 | 2.31 | 2.82 | 1.28 | 0.80 | 0.70 | 0.31 |
| 7 | 1.04 | 0.39 | 0.93 | 2.66 | 1.28 | 0.99 | 1.00 | 1.32 | |
| 8 | 0.89 | 0.09 | 0.77 | 2.41 | 1.18 | 0.99 | 1.65 | 0.70 | |
| 11 | 1.30 | 0.81 | 1.09 | 3.06 | 1.44 | 0.99 | 0.95 | 0.80 | |
| Mean | 1.04 | 0.53 | 1.00 | 2.75 | 2.70 | 1.41 | 1.36 | 0.85 | 0.57 |
| SE | 0.06 | 0.14 | 0.08 | 0.18 | 0.63 | 0.20 | 0.26 | 0.09 | 0.17 |

Table 9. Chlorophyll *a* (µg l$^{-3}$) at Station 6 (*or Station 4), February – November, 2008.

| Depth (m) | 2/21 | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 | 12/18 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | - | - | - | - | - | - | - | - | - | - | - |
| 2 | 110.17 | 51.23 | 33.22 | 9.21 | 2.17 | 3.25 | 2.69 | 15.12 | 51.61 | 91.08 | 89.80 |
| 3 | - | - | - | - | - | - | - | - | - | - | - |
| 4 | - | - | - | - | - | - | - | - | - | - | - |
| 5 | - | - | - | - | - | - | - | - | - | - | - |
| 6 | - | - | - | - | - | - | - | - | - | - | - |
| 7 | - | - | - | - | - | - | - | - | - | - | - |
| 8 | 93.78 | 62.36 | 40.91 | 8.78 | 5.77 | 3.10 | 5.69 | 18.76 | 46.68 | 93.00 | 94.15 |
| 9 | - | - | - | - | - | - | - | - | - | - | - |
| 10 | - | - | - | - | - | - | - | - | - | - | - |
| 11 | - | - | - | - | - | - | - | - | - | - | - |
| 12 | 83.48 | 80.02 | 43.13 | 50.98 | 29.35 | 18.38 | 20.62 | 16.73 | 45.97 | 77.18 | 88.05 |
| 13 | - | - | - | - | - | - | - | - | - | - | - |
| 14 | - | - | - | - | - | - | - | - | - | - | - |
| 15 | - | - | - | - | - | - | - | - | - | - | - |
| 16 | 82.66 | 86.66 | 46.72 | 49.44 | 49.97 | 67.38 | 56.24 | 34.00 | 45.00 | 72.26 | 92.24 |
| 17 | - | - | - | - | - | - | - | - | - | - | - |
| 18 | - | - | - | - | - | - | - | - | - | - | - |
| 19 | - | - | - | - | - | - | - | - | - | - | - |
| 20 | 89.79 | 89.82 | 55.72 | 42.53 | 46.56 | 35.89 | 51.81 | 38.05 | 44.21 | 90.13 | 93.69 |
| 21 | - | - | - | - | - | - | - | - | - | - | - |
| 22 | - | - | - | - | - | - | - | - | - | - | - |
| 23 | - | - | - | - | - | - | - | - | - | - | - |
| 24 | 85.92 | 87.73 | 53.61 | 39.16 | 43.72 | 29.69 | 48.75 | 45.93 | 47.94 | 87.01 | 87.77 |
| 25 | - | - | - | - | - | - | - | - | - | - | - |
| 26 | - | - | - | - | - | - | - | - | - | - | - |
| 27 | - | - | - | - | - | - | - | - | - | - | - |
| 28 | 82.84 | 88.08 | 54.58 | 38.51 | 40.41 | 39.22 | 47.74 | 41.11 | 44.46 | 88.31 | 88.10 |
| 29 | - | - | - | - | - | - | - | - | - | - | - |
| 30 | - | - | - | - | - | - | - | - | - | - | - |
| 31 | - | - | - | - | - | - | - | - | - | - | - |
| 32 | - | - | - | - | - | - | - | - | - | - | - |
| 33 | - | - | - | - | - | - | - | - | - | - | - |
| 34 | - | - | - | - | - | - | - | - | - | - | - |
| 35 | - | - | - | - | - | - | - | - | - | - | - |
| 36 | - | - | - | - | - | - | - | - | - | - | - |
| 37 | - | - | - | - | - | - | - | - | - | - | - |

Table 10. Chlorophyll *a* (µg $l^{-3}$) at 7 stations in upper 9 m of water column, February – December 2008.

| Station | 3/21 | 4/17 | 5/30 | 6/16 | 7/18 | 8/18 | 9/17 | 10/15 | 11/13 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 50.28 | 36.35 | 25.22 | 5.65 | 2.13 | 1.66 | 11.68 | 47.90 | 94.20 |
| 2 | 53.99 | 43.52 | 26.54 | 6.28 | 2.62 | 2.47 | 16.58 | 57.66 | 87.56 |
| 5 | 58.20 | 41.18 | 21.17 | 4.16 | 4.20 | 3.92 | 25.19 | 49.25 | |
| 6 | 56.46 | 41.41 | 18.52 | 8.50 | 3.47 | 3.80 | 15.82 | 47.66 | 92.71 |
| 7 | 48.12 | 41.59 | 18.70 | 8.19 | 4.93 | 4.51 | 18.10 | 43.70 | |
| 8 | 41.24 | 42.59 | 15.85 | 9.42 | 4.11 | 2.99 | 20.47 | 52.67 | |
| 11 | 35.60 | 36.61 | 14.53 | 5.42 | 3.41 | 3.24 | 15.81 | 40.44 | |
| Mean | 49.13 | 40.46 | 20.08 | 6.80 | 3.55 | 3.23 | 17.66 | 48.47 | 91.49 |
| SE | 3.11 | 1.07 | 1.71 | 0.73 | 0.36 | 0.36 | 1.61 | 2.13 | 2.01 |

Table 11a. *Artemia* lake and sector means, 2008.

| | Instars 1-7 | Instars 8-11 | adult male | adult fem ? | adult fem e | adult fem c | adult fem n | adult fem tot | adult total | total |
|---|---|---|---|---|---|---|---|---|---|---|
| Lakewide Mean: | | | | | | | | | | |
| 2/21 | 1,097 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,097 |
| 3/21 | 10,651 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10,651 |
| 4/17 | 26,663 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 26,663 |
| 5/30 | 12,891 | 1,771 | 10,905 | 1,744 | 6,372 | 443 | 590 | 9,148 | 20,054 | 34,715 |
| 6/16 | 83,541 | 832 | 14,138 | 1,046 | 6,868 | 5,151 | 402 | 13,467 | 27,606 | 111,980 |
| 7/18 | 13,551 | 44 | 13,032 | 577 | 2,059 | 4,604 | 94 | 7,334 | 20,366 | 33,960 |
| 8/18 | 6,834 | 80 | 11,593 | 309 | 372 | 4,326 | 178 | 5,184 | 16,777 | 23,692 |
| 9/17 | 2,269 | 114 | 3,164 | 77 | 312 | 1,383 | 55 | 1,828 | 4,992 | 7,374 |
| 10/15 | 193 | 5 | 80 | 2 | 5 | 2 | 0 | 8 | 89 | 287 |
| 11/13 | 34 | 0 | 7 | 0 | 13 | 0 | 0 | 13 | 20 | 54 |
| 12/18 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Western Sector Mean: | | | | | | | | | | |
| 2/21 | 1,097 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,097 |
| 3/21 | 6,747 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6,747 |
| 4/17 | 39,457 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 39,457 |
| 5/30 | 11,831 | 1,127 | 8,156 | 1,583 | 5,661 | 429 | 563 | 8,236 | 16,392 | 29,349 |
| 6/16 | 61,704 | 751 | 16,633 | 1,234 | 7,244 | 6,170 | 429 | 15,077 | 31,710 | 94,165 |
| 7/18 | 12,314 | 0 | 19,021 | 778 | 3,032 | 6,358 | 134 | 10,302 | 29,323 | 41,636 |
| 8/18 | 5,956 | 107 | 15,614 | 429 | 429 | 5,124 | 107 | 6,090 | 21,704 | 27,767 |
| 9/17 | 3,514 | 141 | 4,534 | 121 | 396 | 2,153 | 80 | 2,750 | 7,284 | 10,939 |
| 10/15 | 198 | 0 | 107 | 3 | 3 | 0 | 0 | 7 | 114 | 312 |
| 11/13 | 34 | 0 | 7 | 0 | 13 | 0 | 0 | 13 | 20 | 54 |
| 12/18 | 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 60 |
| Eastern Sector Mean: | | | | | | | | | | |
| 2/21 | | | | | | | | | | |
| 3/21 | 14,554 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14,554 |
| 4/17 | 13,870 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13,870 |
| 5/30 | 13,950 | 2,414 | 13,655 | 1,905 | 7,083 | 456 | 617 | 10,060 | 23,716 | 40,080 |
| 6/16 | 105,379 | 912 | 11,643 | 858 | 6,492 | 4,131 | 376 | 11,858 | 23,501 | 129,792 |
| 7/18 | 14,789 | 87 | 7,042 | 376 | 1,087 | 2,850 | 54 | 4,366 | 11,408 | 26,284 |
| 8/18 | 7,713 | 54 | 7,572 | 188 | 315 | 3,528 | 248 | 4,279 | 11,851 | 19,618 |
| 9/17 | 1,023 | 87 | 1,794 | 34 | 228 | 614 | 30 | 905 | 2,700 | 3,810 |
| 10/15 | 188 | 10 | 54 | 0 | 7 | 3 | 0 | 10 | 64 | 262 |
| 11/13 | | | | | | | | | | |
| 12/18 | | | | | | | | | | |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Table 11b. Standard errors of *Artemia* sector means (Table 11a), 2008.

| | Instars | | adult | adult | adult | adult | adult | adult | adult | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1-7 | 8-11 | male | fem ? | fem e | fem c | fem n | fem tot | total | total |
| SE of Lakewide Mean: | | | | | | | | | | |
| 2/21 | 192 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 192 |
| 3/21 | 1,838 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,838 |
| 4/17 | 6,926 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6,926 |
| 5/30 | 651 | 249 | 1,185 | 281 | 567 | 105 | 127 | 790 | 1,884 | 2,209 |
| 6/16 | 12,971 | 179 | 1,181 | 206 | 616 | 520 | 113 | 924 | 2,015 | 13,161 |
| 7/18 | 2,084 | 29 | 2,153 | 118 | 452 | 829 | 37 | 1,328 | 3,373 | 4,065 |
| 8/18 | 1,116 | 37 | 2,014 | 90 | 92 | 709 | 53 | 803 | 2,706 | 2,686 |
| 9/17 | 548 | 32 | 604 | 36 | 60 | 350 | 26 | 446 | 1,014 | 1,530 |
| 10/15 | 37 | 3 | 18 | 2 | 3 | 2 | 0 | 3 | 19 | 50 |
| 11/13 | 24 | 0 | 7 | 0 | 7 | 0 | 0 | 7 | 12 | 24 |
| 12/18 | | | | | | | | | | |
| SE of Western Sector Mean: | | | | | | | | | | |
| 2/21 | 192 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 192 |
| 3/21 | 1,742 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,742 |
| 4/17 | 11,995 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11,995 |
| 5/30 | 767 | 195 | 897 | 292 | 667 | 115 | 108 | 856 | 1,730 | 2,318 |
| 6/16 | 13,276 | 198 | 1,235 | 316 | 796 | 825 | 215 | 1,046 | 2,015 | 14,215 |
| 7/18 | 1,850 | 0 | 2,140 | 188 | 636 | 1,181 | 65 | 1,783 | 3,693 | 3,891 |
| 8/18 | 1,460 | 54 | 3,149 | 154 | 129 | 1,124 | 80 | 1,272 | 4,285 | 3,874 |
| 9/17 | 802 | 62 | 872 | 68 | 93 | 508 | 50 | 676 | 1,466 | 2,162 |
| 10/15 | 61 | 0 | 32 | 3 | 3 | 0 | 0 | 4 | 35 | 87 |
| 11/13 | 24 | 0 | 7 | 0 | 7 | 0 | 0 | 7 | 12 | 24 |
| 12/18 | | | | | | | | | | |
| SE of Eastern Sector Mean: | | | | | | | | | | |
| 2/21 | | | | | | | | | | |
| 3/21 | 2,394 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2,394 |
| 4/17 | 1,296 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,296 |
| 5/30 | 909 | 263 | 1,534 | 503 | 877 | 188 | 244 | 1,296 | 2,696 | 2,140 |
| 6/16 | 19,321 | 316 | 1,457 | 271 | 988 | 304 | 99 | 1,275 | 2,657 | 20,812 |
| 7/18 | 3,883 | 53 | 1,207 | 99 | 337 | 628 | 34 | 1,027 | 2,082 | 5,830 |
| 8/18 | 1,744 | 54 | 1,211 | 77 | 140 | 832 | 64 | 944 | 2,037 | 3,178 |
| 9/17 | 241 | 16 | 311 | 13 | 65 | 208 | 12 | 280 | 522 | 734 |
| 10/15 | 48 | 4 | 10 | 0 | 4 | 3 | 0 | 4 | 10 | 54 |
| 11/13 | | | | | | | | | | |
| 12/18 | | | | | | | | | | |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Table 11c. Percentage in different classes for *Artemia* sector means (Table 11a), 2008.

| | Instars 1-7 | 8-11 | adult male | adult fem ? | adult fem e | adult fem c | adult fem n | adult fem tot | adult total | total |
|---|---|---|---|---|---|---|---|---|---|---|
| Lakewide (%): | | | | | | | | | | |
| 2/21 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 3/21 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 4/17 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 5/30 | 37.1 | 5.1 | 31.4 | 19.1 | 69.6 | 4.8 | 6.5 | 26.4 | 57.8 | 100 |
| 6/16 | 74.6 | 0.7 | 12.6 | 7.8 | 51.0 | 38.2 | 3.0 | 12.0 | 24.7 | 100 |
| 7/18 | 39.9 | 0.1 | 38.4 | 7.9 | 28.1 | 62.8 | 1.3 | 21.6 | 60.0 | 100 |
| 8/18 | 28.8 | 0.3 | 48.9 | 6.0 | 7.2 | 83.4 | 3.4 | 21.9 | 70.8 | 100 |
| 9/17 | 30.8 | 1.5 | 42.9 | 4.2 | 17.1 | 75.7 | 3.0 | 24.8 | 67.7 | 100 |
| 10/15 | 67.3 | 1.8 | 28.1 | 20.0 | 60.0 | 20.0 | 0.0 | 2.9 | 31.0 | 100 |
| 11/13 | 62.5 | 0.0 | 12.5 | 0.0 | 100.0 | 0.0 | 0.0 | 25.0 | 37.5 | 100 |
| 12/18 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| Western Sector (%): | | | | | | | | | | |
| 2/21 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 3/21 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 4/17 | 100.0 | 0.0 | 0.0 | 19.2 | 0.0 | 5.2 | 6.8 | 0.0 | 0.0 | 100 |
| 5/30 | 40.3 | 3.8 | 27.8 | 8.2 | 68.7 | 40.9 | 2.8 | 28.1 | 55.9 | 100 |
| 6/16 | 65.5 | 0.8 | 17.7 | 7.6 | 48.0 | 61.7 | 1.3 | 16.0 | 33.7 | 100 |
| 7/18 | 29.6 | 0.0 | 45.7 | 7.0 | 29.4 | 84.1 | 1.8 | 24.7 | 70.4 | 100 |
| 8/18 | 21.4 | 0.4 | 56.2 | 4.4 | 7.0 | 78.3 | 2.9 | 21.9 | 78.2 | 100 |
| 9/17 | 32.1 | 1.3 | 41.4 | 50.0 | 14.4 | 0.0 | 0.0 | 25.1 | 66.6 | 100 |
| 10/15 | 63.4 | 0.0 | 34.4 | 0.0 | 50.0 | 0.0 | 0.0 | 2.2 | 36.6 | 100 |
| 11/13 | 62.5 | 0.0 | 12.5 | 0.0 | 100.0 | 0.0 | 0.0 | 25.0 | 37.5 | 100 |
| 12/18 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| Eastern Sector (%): | | | | | | | | | | |
| 2/21 | | | | | | | | | | |
| 3/21 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 4/17 | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 5/30 | 34.8 | 6.0 | 34.1 | 18.9 | 70.4 | 4.5 | 6.1 | 25.1 | 59.2 | 100 |
| 6/16 | 81.2 | 0.7 | 9.0 | 7.2 | 54.8 | 34.8 | 3.2 | 9.1 | 18.1 | 100 |
| 7/18 | 56.3 | 0.3 | 26.8 | 8.6 | 24.9 | 65.3 | 1.2 | 16.6 | 43.4 | 100 |
| 8/18 | 39.3 | 0.3 | 38.6 | 4.4 | 7.4 | 82.4 | 5.8 | 21.8 | 60.4 | 100 |
| 9/17 | 26.8 | 2.3 | 47.1 | 3.7 | 25.2 | 67.8 | 3.3 | 23.8 | 70.9 | 100 |
| 10/15 | 71.8 | 3.8 | 20.5 | 0.0 | 66.7 | 33.3 | 0.0 | 3.8 | 24.4 | 100 |
| 11/13 | | | | | | | | | | |
| 12/18 | | | | | | | | | | |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Table 12. Lakewide *Artemia* instar analysis, 2008.

| | Instars | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8-11 | adults | total |
| Mean: | | | | | | | | | | |
| 3/21 | 9,810 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,825 |
| 4/17 | 8,600 | 10,704 | 5,007 | 1,615 | 75 | 0 | 0 | 0 | 0 | 26,002 |
| 5/30 | 1,656 | 621 | 1,748 | 3,311 | 2,644 | 1,909 | 1,196 | 1,886 | 10,003 | 34,148 |
| 6/16 | 37,390 | 29,158 | 92 | 1,104 | 920 | 690 | 460 | 690 | 14,165 | 98,557 |
| 7/18 | 3,593 | 6,358 | 1,719 | 132 | 23 | 0 | 0 | 6 | 12,843 | 31,199 |
| 8/18 | 730 | 1,851 | 1,495 | 1,794 | 460 | 23 | 29 | 115 | 13,228 | 25,001 |
| 9/17 | 132 | 707 | 595 | 609 | 184 | 69 | 26 | 69 | 3,110 | 7,105 |
| 10/15 | 17 | 43 | 26 | 69 | 52 | 14 | 9 | 6 | 95 | 342 |
| 11/13 | 0 | 7 | 13 | 13 | 0 | 0 | 0 | 0 | 7 | 54 |
| Standard error of the mean: | | | | | | | | | | |
| 3/21 | 1,527 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,527 |
| 4/17 | 2,947 | 4,416 | 1,645 | 872 | 47 | 0 | 0 | 0 | 0 | 8,907 |
| 5/30 | 490 | 108 | 268 | 375 | 250 | 355 | 265 | 368 | 850 | 2,288 |
| 6/16 | 9,122 | 11,103 | 92 | 384 | 375 | 204 | 96 | 204 | 1,128 | 20,103 |
| 7/18 | 910 | 2,429 | 652 | 42 | 23 | 0 | 0 | 6 | 3,051 | 6,019 |
| 8/18 | 170 | 627 | 581 | 530 | 124 | 23 | 23 | 58 | 3,401 | 4,582 |
| 9/17 | 61 | 351 | 234 | 216 | 51 | 11 | 23 | 19 | 917 | 2,258 |
| 10/15 | 7 | 12 | 11 | 18 | 19 | 6 | 6 | 4 | 27 | 71 |
| 11/13 | 0 | 7 | 13 | 13 | 0 | 0 | 0 | 0 | 7 | 24 |
| Percentage in different age classes: | | | | | | | | | | |
| 3/21 | 99.9 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 4/17 | 37.5 | 36.9 | 18.8 | 6.4 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 100 |
| 5/30 | 11.8 | 4.8 | 13.9 | 26.3 | 20.1 | 14.3 | 8.8 | 5.5 | 29.1 | 100 |
| 6/16 | 56.6 | 37.4 | 0.2 | 1.5 | 2.0 | 1.4 | 1.0 | 0.8 | 16.8 | 100 |
| 7/18 | 39.1 | 44.8 | 13.0 | 2.8 | 0.2 | 0.0 | 0.0 | 0.2 | 40.8 | 100 |
| 8/18 | 16.7 | 26.6 | 20.5 | 24.0 | 10.9 | 0.2 | 1.0 | 1.2 | 49.8 | 100 |
| 9/17 | 6.4 | 21.2 | 25.1 | 29.1 | 10.7 | 6.4 | 1.0 | 1.7 | 46.2 | 100 |
| 10/15 | 12.8 | 25.2 | 8.4 | 29.9 | 16.2 | 5.3 | 2.3 | 2.8 | 29.7 | 100 |
| 11/13 | 0.0 | 0.2 | 0.4 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 16.7 | 100 |

All data in this table are from stations 1, 2, 5, 6, 7, 8, and 11 only.

Table 13a. *Artemia* reproductive summary, lake and sector means, 2008.

| | Adult Females | | | | | |
|---|---|---|---|---|---|---|
| | Total | Ovigery | e | ? | c | n |
| Lakewide Mean: | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 9,148 | 2,777 | 6,372 | 1,744 | 443 | 590 |
| 6/16 | 13,467 | 6,600 | 6,868 | 1,046 | 5,151 | 402 |
| 7/18 | 7,334 | 5,275 | 2,059 | 577 | 4,604 | 94 |
| 8/18 | 5,184 | 4,812 | 372 | 309 | 4,326 | 178 |
| 9/17 | 1,828 | 1,516 | 312 | 77 | 1,383 | 55 |
| 10/15 | 8 | 3 | 5 | 2 | 2 | 0 |
| 11/13 | 13 | 0 | 13 | 0 | 0 | 0 |
| 12/18 | 0 | 0 | 0 | 0 | 0 | 0 |
| Western Sector Mean: | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 8,236 | 2,575 | 5,661 | 1,583 | 429 | 563 |
| 6/16 | 15,077 | 7,834 | 7,243 | 1,234 | 6,170 | 429 |
| 7/18 | 10,302 | 7,270 | 3,032 | 778 | 6,358 | 134 |
| 8/18 | 6,090 | 5,661 | 429 | 429 | 5,124 | 107 |
| 9/17 | 2,750 | 2,354 | 396 | 121 | 2,153 | 80 |
| 10/15 | 7 | 3 | 3 | 3 | 0 | 0 |
| 11/13 | 13 | 0 | 13 | 0 | 0 | 0 |
| 12/18 | 0 | 0 | 0 | 0 | 0 | 0 |
| Eastern Sector Mean: | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 10,060 | 2,978 | 7,082 | 1,905 | 456 | 617 |
| 6/16 | 11,858 | 5,366 | 6,492 | 858 | 4,131 | 376 |
| 7/18 | 4,366 | 3,280 | 1,087 | 376 | 2,850 | 54 |
| 8/18 | 4,279 | 3,964 | 315 | 188 | 3,528 | 248 |
| 9/17 | 905 | 677 | 228 | 34 | 614 | 30 |
| 10/15 | 10 | 3 | 7 | 0 | 3 | 0 |
| 11/13 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12/18 | 0 | 0 | 0 | 0 | 0 | 0 |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Table 13b. Standard errors of *Artemia* reproductive summary (Table 13a), 2008.

| | | Adult Females | | | | |
|---|---|---|---|---|---|---|
| | Total | Ovigery | e | ? | c | n |
| Standard Error of Lakewide Mean: | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 790 | 335 | 567 | 281 | 105 | 127 |
| 6/16 | 924 | 686 | 616 | 206 | 520 | 113 |
| 7/18 | 1,328 | 922 | 452 | 118 | 829 | 37 |
| 8/18 | 803 | 765 | 92 | 90 | 709 | 53 |
| 9/17 | 446 | 395 | 60 | 36 | 350 | 26 |
| 10/15 | 3 | 2 | 3 | 2 | 2 | 0 |
| 11/13 | 7 | 0 | 7 | 0 | 0 | 0 |
| 12/18 | 0 | 0 | 0 | 0 | 0 | 0 |
| Standard Error of Western Sector Mean: | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 856 | 444 | 667 | 292 | 115 | 108 |
| 6/16 | 1046 | 1083 | 796 | 316 | 825 | 215 |
| 7/18 | 1783 | 1281 | 636 | 188 | 1181 | 65 |
| 8/18 | 1272 | 1206 | 129 | 154 | 1124 | 80 |
| 9/17 | 676 | 598 | 93 | 68 | 508 | 50 |
| 10/15 | 4 | 3 | 3 | 3 | 0 | 0 |
| 11/13 | 7 | 0 | 7 | 0 | 0 | 0 |
| 12/18 | 0 | 0 | 0 | 0 | 0 | 0 |
| Standard Error of Eastern Sector Mean: | | | | | | |
| 2/21 | | | | | | |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 1296 | 529 | 877 | 503 | 188 | 244 |
| 6/16 | 1275 | 537 | 988 | 271 | 304 | 99 |
| 7/18 | 1027 | 711 | 337 | 99 | 628 | 34 |
| 8/18 | 944 | 912 | 140 | 77 | 832 | 64 |
| 9/17 | 280 | 217 | 65 | 13 | 208 | 12 |
| 10/15 | 4 | 3 | 4 | 0 | 3 | 0 |
| 11/13 | | | | | | |
| 12/18 | | | | | | |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Table 13c. *Artemia* percentages in different reproductive categories (Table 13a), 2008.

| | Adult Females | | | | | |
|---|---|---|---|---|---|---|
| | Total | Ovigery | e | ? | c | n |
| Lakewide Mean (%): | | | | | | |
| 2/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3/21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4/17 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5/30 | 100 | 30.4 | 69.6 | 62.8 | 42.9 | 57.1 |
| 6/16 | 100 | 49.0 | 51.0 | 15.9 | 92.8 | 7.2 |
| 7/18 | 100 | 71.9 | 28.1 | 10.9 | 98.0 | 2.0 |
| 8/18 | 100 | 92.8 | 7.2 | 6.4 | 96.1 | 3.9 |
| 9/17 | 100 | 82.9 | 17.1 | 5.1 | 96.2 | 3.8 |
| 10/15 | 100 | 40.0 | 60.0 | 50.0 | 100 | 0.0 |
| 11/13 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12/18 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Western Sector Mean (%): | | | | | | |
| 2/21 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3/21 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4/17 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5/30 | 100 | 31.3 | 68.7 | 61.5 | 43.2 | 56.8 |
| 6/16 | 100 | 52.0 | 48.0 | 15.8 | 93.5 | 6.5 |
| 7/18 | 100 | 70.6 | 29.4 | 10.7 | 97.9 | 2.1 |
| 8/18 | 100 | 93.0 | 7.0 | 7.6 | 97.9 | 2.1 |
| 9/17 | 100 | 85.6 | 14.4 | 5.1 | 96.4 | 3.6 |
| 10/15 | 100 | 50.0 | 50.0 | 100.0 | 0.0 | 0.0 |
| 11/13 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12/18 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Eastern Sector Mean (%): | | | | | | |
| 2/21 | | | | | | |
| 3/21 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4/17 | 0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5/30 | 100 | 29.6 | 70.4 | 64.0 | 42.5 | 57.5 |
| 6/16 | 100 | 45.2 | 54.8 | 16.0 | 91.7 | 8.3 |
| 7/18 | 100 | 75.1 | 24.9 | 11.5 | 98.2 | 1.8 |
| 8/18 | 100 | 92.6 | 7.4 | 4.7 | 93.4 | 6.6 |
| 9/17 | 100 | 74.8 | 25.2 | 5.0 | 95.3 | 4.7 |
| 10/15 | 100 | 33.3 | 66.7 | 0.0 | 100 | 0.0 |
| 11/13 | | | | | | |
| 12/18 | | | | | | |

(?): undifferentiated egg mass(e): empty ovisac (c): cysts (n): nauplii

Total, ovigery, and e given as percentages of total number of females.

? given as percentage of ovigerous females.

Cyst and naup given as percentages of individuals with differentiated egg masses.

Table 14. *Artemia* fecundity summary, 2008.

| | #eggs/brood | | | | female length | | |
|---|---|---|---|---|---|---|---|
| | mean | SE | %cyst | %intended | mean | SE | n |
| Lakewide Mean: | | | | | | | |
| 5/30 | 71.7 | 1.3 | 0.6 | 0.1 | 11.2 | 0.0 | 6 |
| 6/16 | 68.0 | 3.0 | 0.9 | 0.5 | 11.0 | 0.1 | 7 |
| 7/18 | 30.9 | 1.2 | 0.9 | 0.5 | 10.4 | 0.2 | 7 |
| 8/18 | 38.3 | 2.3 | 1.0 | 0.6 | 10.7 | 0.1 | 6 |
| 9/17 | 90.0 | 6.5 | 1.0 | 0.5 | 12.3 | 0.1 | 7 |
| Western Sector Mean: | | | | | | | |
| 5/30 | 71.9 | 1.6 | 0.6 | 0.1 | 11.2 | 0.1 | 4 |
| 6/16 | 71.3 | 4.0 | 0.9 | 0.5 | 11.2 | 0.2 | 4 |
| 7/18 | 30.4 | 2.1 | 1.0 | 0.6 | 10.3 | 0.2 | 4 |
| 8/18 | 35.3 | 1.8 | 1.0 | 0.6 | 10.6 | 0.1 | 3 |
| 9/17 | 82.2 | 9.2 | 1.0 | 0.6 | 12.2 | 0.0 | 4 |
| Eastern Sector Mean: | | | | | | | |
| 5/30 | 71.3 | 3.0 | 0.7 | 0.1 | 11.1 | 0.0 | 2 |
| 6/16 | 63.5 | 3.4 | 0.9 | 0.5 | 10.7 | 0.0 | 3 |
| 7/18 | 31.7 | 1.0 | 0.9 | 0.3 | 10.5 | 0.3 | 3 |
| 8/18 | 41.4 | 3.8 | 0.9 | 0.5 | 10.7 | 0.2 | 3 |
| 9/17 | 100.5 | 5.1 | 1.0 | 0.4 | 12.5 | 0.3 | 3 |

‘n’ in last column refers to number of stations averaged.
Ten females were collected and measured from each station.

Table 15. Summary Statistics of Adult *Artemia* Abundance from 1 May through 30 November, 1979–2008.

| **Year** | **Mean** | **Median** | **Peak** | **Centroid***|
|---|---|---|---|---|
| 1979 | 14,118 | 12,286 | 31,700 | 216 |
| 1980 | 14,643 | 10,202 | 40,420 | 236 |
| 1981 | 32,010 | 21,103 | 101,670 | 238 |
| 1982 | 36,643 | 31,457 | 105,245 | 252 |
| 1983 | 17,812 | 16,314 | 39,917 | 247 |
| 1984 | 17,001 | 19,261 | 40,204 | 212 |
| 1985 | 18,514 | 20,231 | 33,089 | 218 |
| 1986 | 14,667 | 17,305 | 32,977 | 190 |
| 1987 | 23,952 | 22,621 | 54,278 | 226 |
| 1988 | 27,639 | 25,505 | 71,630 | 207 |
| 1989 | 36,359 | 28,962 | 92,491 | 249 |
| 1990 | 20,005 | 16,775 | 34,930 | 230 |
| 1991 | 18,129 | 19,319 | 34,565 | 226 |
| 1992 | 19,019 | 19,595 | 34,648 | 215 |
| 1993 | 15,025 | 16,684 | 26,906 | 217 |
| 1994 | 16,602 | 18,816 | 29,408 | 212 |
| 1995 | 15,584 | 17,215 | 24,402 | 210 |
| 1996 | 17,734 | 17,842 | 34,616 | 216 |
| 1997 | 14,389 | 16,372 | 27,312 | 204 |
| 1998 | 19,429 | 21,235 | 33,968 | 226 |
| 1999 | 20,221 | 21,547 | 38,439 | 225 |
| 2000 | 10,550 | 9,080 | 22,384 | 210 |
| 2001 | 20,031 | 20,037 | 38,035 | 209 |
| 2002 | 11,569 | 9,955 | 25,533 | 200 |
| 2003 | 13,778 | 12,313 | 29,142 | 203 |
| 2004 | 32,044 | 36,909 | 75,466 | 180 |
| 2005 | 17,888 | 15,824 | 45,419 | 192 |
| 2006 | 21,518 | 20,316 | 55,748 | 186 |
| 2007 | 18,826 | 17,652 | 41,751 | 186 |
| 2008 | 11,823 | 12,524 | 27,606 | 189 |
| **Mean** | **19,584** | **18,842** | **44,130** | **214** |

*Centroid calculated as the abundance-weighted mean day of occurrence.

Table 16. Photosynthetic parameters, 2008.

| Date | Depth (m) | Temperature (C) | $\alpha^B$ (g C g Chl a$^{-1}$ h$^{-1}$) | $P_m^B$ (g C g Chl $a^{-1}$ Einst$^{-1}$ m$^2$) |
|---:|---:|---:|---:|---:|
| 2/21 | 2 | 1.6 | 2.6 | 0.8 |
| 3/21 | 2 | 4.5 | 4.6 | 1.2 |
| 4/17 | 2 | 8.0 | 5.8 | 2.1 |
| 5/30 | 2 | 13.3 | 2.8 | 1.0 |
| 6/16 | 2 | 18.4 | 29.5 | 10.2 |
| 8/18 | 2 | 22.2 | 34.0 | 15.3 |
| 10/15 | 2 | 11.5 | 9.9 | 2.6 |
| 11/13 | 2 | 9.5 | 7.1 | 1.6 |
| 12/18 | 2 | 5.8 | 7.7 | 1.6 |

$P_m^B$: Chlorophyll-specific maximum carbon uptakes rates (g C g Chl a$^{-1}$ h$^{-1}$)

$\alpha^B$: Chlorophyll-specific light-limited uptake rates (g C g Chl $a^{-1}$ Einst$^{-1}$ m$^2$)

Table 17. Long term Integrative Measures of Productivity: Annual Primary Production, *Artemia* biomass and egg production (see Chapter 2 for methods), 1982-2008.

| **Year** | **Planktonic Primary Production** ($g\ C\ m^{-2}\ y^{-1}$) | ***Artemia*** **Biomass** ($g$ dry weight $m^{-2}$) | **Naupliar Production** ($10^6\ m^{-2}$) | **Cyst Production** ($10^6\ m^{-2}$) |
|---|---|---|---|---|
| 1982 | 1,107 | - | - | - |
| 1983 | 523 | 9.3 | 0.15 | 4.8 |
| 1984 | 269 | 7.8 | 0.08 | 3.7 |
| 1985 | 399 | 7.8 | 0.22 | 4.6 |
| 1986 | 462 | 7.7 | 0.44 | 3.0 |
| 1987 | 371 | 12.5 | 0.23 | 6.4 |
| 1988 | 1,064 | 15.2 | 0.21 | 4.7 |
| 1989 | 499 | 17.6 | 0.11 | 6.7 |
| 1990 | 641 | 11.0 | 1.02 | 6.1 |
| 1991 | 418 | 9.7 | 0.69 | 5.5 |
| 1992 | 435 | 10.2 | 0.26 | 5.8 |
| 1993 | 602 | 8.9 | 0.35 | 6.3 |
| 1994 | 446 | 8.7 | 0.16 | 5.6 |
| 1995 | 227 | 8.4 | 0.40 | 4.9 |
| 1996 | 221 | 8.2 | 0.05 | 3.6 |
| 1997 | 149 | 5.3 | 0.01 | 2.5 |
| 1998 | 228 | 8.0 | 0.01 | 2.8 |
| 1999 | 297 | 8.9 | 0.03 | 4.2 |
| 2000 | 484 | 8.2 | 0.08 | 4.0 |
| 2001 | 532 | 8.8 | 0.10 | 3.0 |
| 2002 | 763 | 4.9 | 0.10 | 2.5 |
| 2003 | 1,645 | 7.5 | 0.60 | 4.2 |
| 2004 | 864 | 11.0 | 0.04 | 2.6 |
| 2005 | 1,111 | 8.8 | 0.31 | 3.8 |
| 2006 | 1,075 | 6.8 | 0.32 | 4.8 |
| 2007 | 1,766 | 7.0 | 0.29 | 3.4 |
| 2008 | 1,189 | 5.8 | 0.34 | 3.1 |
| **Mean** | **659** | **9.0** | **0.25** | **4.3** |

*Carbon uptake measurements not conducted during 1982, 1993-2001. Estimates in these years are based on temperature, chlorophyll, light, and regressions of photosynthetic rates ($P_m^B$) and ($\alpha^B$) versus temperature (see methods).

# FIGURE CAPTIONS

Fig. 1. UCSB sampling stations at Mono Lake. Solid circles represent permanently moored buoys.

Fig. 2. Wind speed; daily mean and 10-min. maximum, 2008.

Fig. 3. Daily air temperature; mean, maximum, and minimum, 2008.

Fig. 4. Daily photosynthetically available radiation, 2008.

Fig. 5. Mean daily relative humidity, 2008.

Fig. 6. Daily precipitation, 2008.

Fig. 7. Mono Lake surface elevation (ft asl), 1979–08, USGS datum.

Fig. 8. Temperature (°C) at station 6, 2008.

Fig. 9. Conductivity (mS $cm^{-1}$ corrected to 25°C) at station 6, 2008.

Fig.10. Density difference (kg $m^{-3}$) between 2 and 32 m at station 6 due to temperature and chemical stratification from 1991–2008.

Fig. 11. Transparency as measured by mean lakewide Secchi depth (m), 1994–08. Error bars show standard errors of the lakewide estimate based on 12-20 stations.

Fig. 12. Mean lakewide Secchi depth ($\log_{10}$ m) 1979–08.

Fig. 13. Light attenuation (% of surface) at station 6, 2008.

Fig. 14. Dissolved oxygen (mg $O_2$ $l^{-1}$) at station 6, 2008. Dots denote the dates and depths of samples.

Fig. 15. Ammonium (µM) at station 6, 2008. Dots denote the dates and depths of samples.

Fig. 16. Ammonium (µM) in upper 9 m of the water column at 7 stations, 2008.

Fig. 17. Chlorophyll *a* (µg chl *a* $l^{-1}$) at station 6, 2008. Dots denote the dates and depths of samples.

Fig. 18. Chlorophyll *a* (µg chl *a* $l^{-1}$) in upper 9 m of the water column at 7 stations, 2008.

Fig. 19. Lakewide *Artemia* abundance during 2008: nauplii (instars 1-7), juveniles (instars 8-11), and adults (instars 12+).

Fig. 20. Lakewide estimates of adult *Artemia* based on 3-20 stations, 1982–08 (see Methods). The mean relative error of the lakewide estimates is 20-25%.

Fig. 21. Reproductive characteristics of *Artemia* during 2008: lakewide mean abundance of total females and ovigerous females (top), percent of females ovoviviparous and ovigerous (middle), and brood size (bottom). Vertical lines are the standard error of the estimate.

Fig. 22. Summary statistics of the seasonal (1 May through 30 November) lakewide abundance of adult *Artemia*, 1979–08. Values are based on interpolated daily abundances.

Fig. 23. Temporal center of abundance-weighted centroid of the seasonal (1 May through 30 November) distribution of adult *Artemia*, 1979–08. Centroid is based on interpolated daily abundances of adult *Artemia*.

Fig. 24. Chlorophyll-specific uptake rates during March, August, and December 2008 for samples collected from the surface mixed layer and the deep chlorophyll maximum.

Fig. 25. Chlorophyll-specific light saturated carbon uptake rate (g C g $Chl^{-1}$ $h^{1}$), algal biomass (mg $m^{-3}$), and daily primary production (g C $m^{-2}$), 2008.

Fig. 26. Comparison of 2002–08 photosynthetic rates and algal biomass. A) Chlorophyll-specific specific light saturated carbon uptake rate (g C g $Chl^{-1}$ $h^{1}$) B) Mixed-layer (2 m depth) chlorophyll *a* concentrations µg Chl $l^{-1}$.

Fig. 27. Comparison of 2002–08 daily primary production (g C $m^{-2}$ $y^{-1}$) calculated with a numerical interpolative model of chlorophyll, temperature, insolation, attenuation, and photosynthetic parameters.

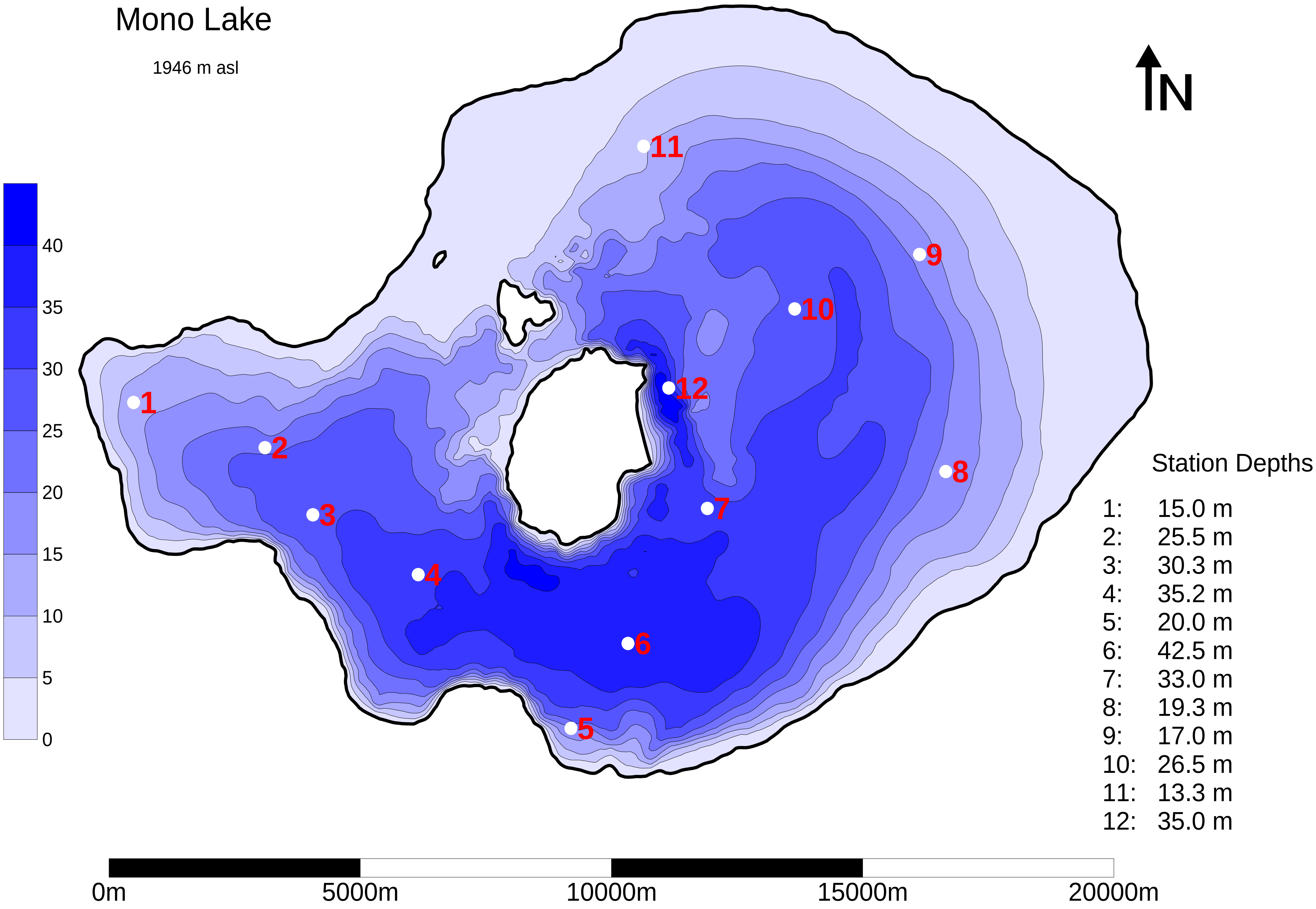
Fig. 28. Annual phytoplankton production estimates (g C $m^{-2}$), 1982–08.

Fig. 29. Mean annual *Artemia* biomass, 1983–08. Data for the period 1982–99 estimated from instar-specific population data and previously derived weight-length relationships. In 2000–08, *Artemia* biomass was measured directly by determining dry weights of plankton tows.

Fig. 30. Annual *Artemia* reproduction, ovoviviparous (live-bearing) and oviparous (cyst-bearing), 1983–08.

Fig. 31. Lakewide mean of mixolimnetic (<10 m) chlorophyll *a*, 1982–08. Heavy line shows seasonally filtered data formed by linearly interpolating between sampling dates to daily values and then calculating a 365-day running mean.

Fig. 32. Lakewide mean of adult *Artemia* abundance, 1982–08. Heavy line shows seasonally filtered data formed by linearly interpolating between sampling dates to daily values and then calculating a 365-day running mean.



Station Depths

| | |
|---|---|
| 1: | 15.0 m |
| 2: | 25.5 m |
| 3: | 30.3 m |
| 4: | 35.2 m |
| 5: | 20.0 m |
| 6: | 42.5 m |
| 7: | 33.0 m |
| 8: | 19.3 m |
| 9: | 17.0 m |
| 10: | 26.5 m |
| 11: | 13.3 m |
| 12: | 35.0 m |

**Figure 1**

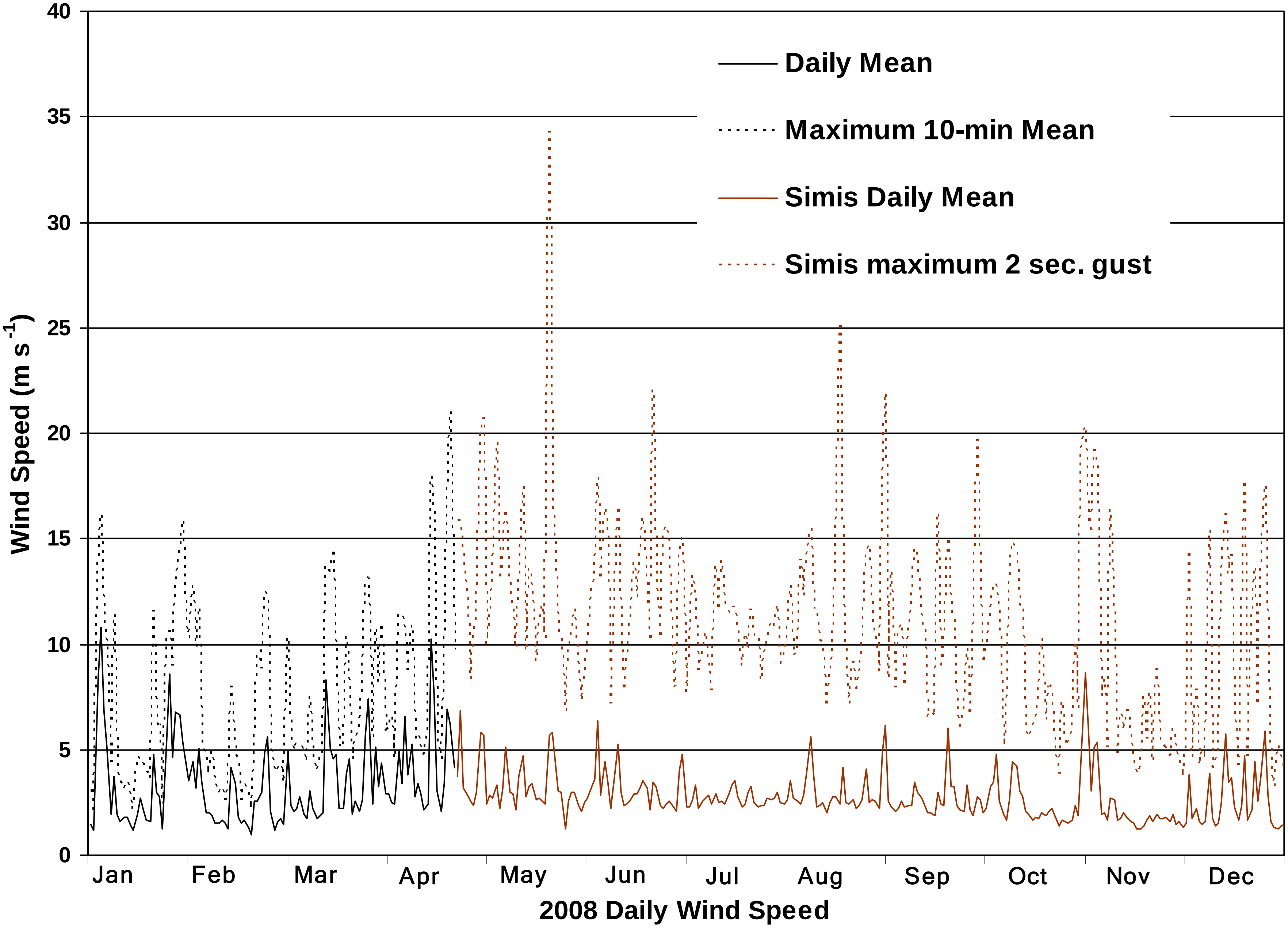

Daily Mean
Maximum 10-min Mean
Simis Daily Mean
Simis maximum 2 sec. gust
Wind Speed (m s$^{-1}$)
0
5
10
15
20
25
30
35
40
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2008 Daily Wind Speed

Figure 2

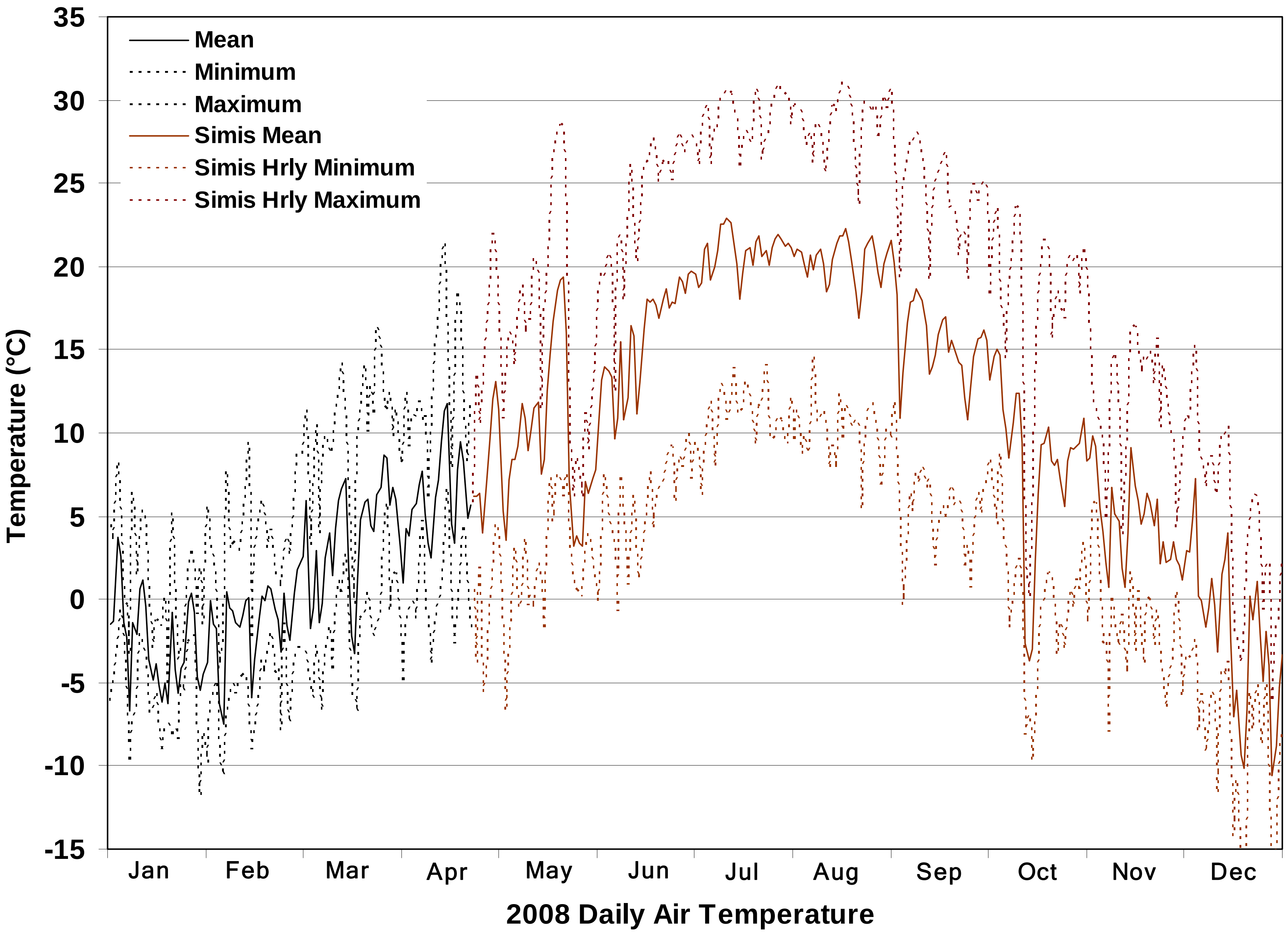

Mean
Minimum
Maximum
Simis Mean
Simis Hrly Minimum
Simis Hrly Maximum
35
30
25
20
15
10
5
0
-5
-10
-15
Temperature (°C)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2008 Daily Air Temperature

Figure 3

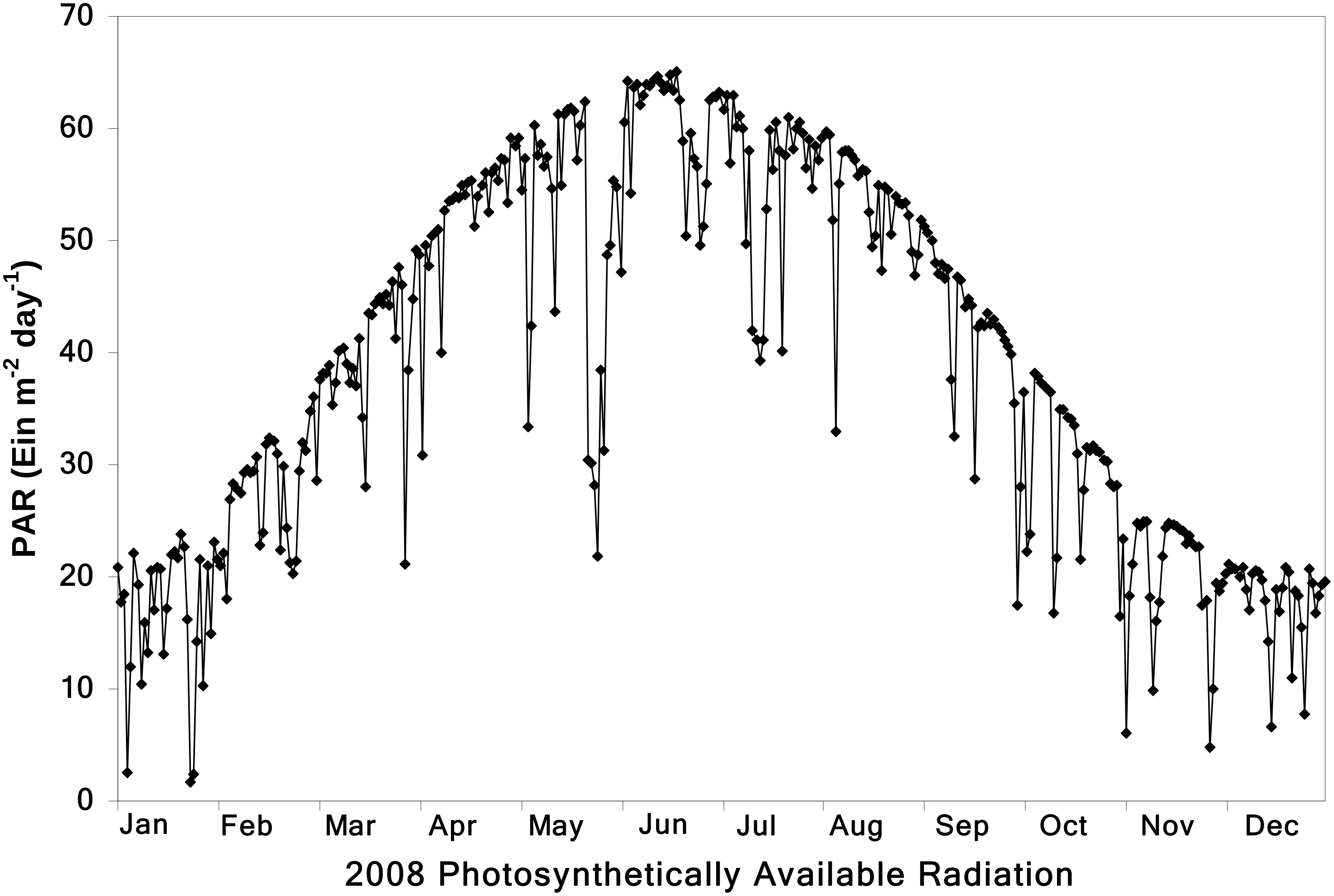
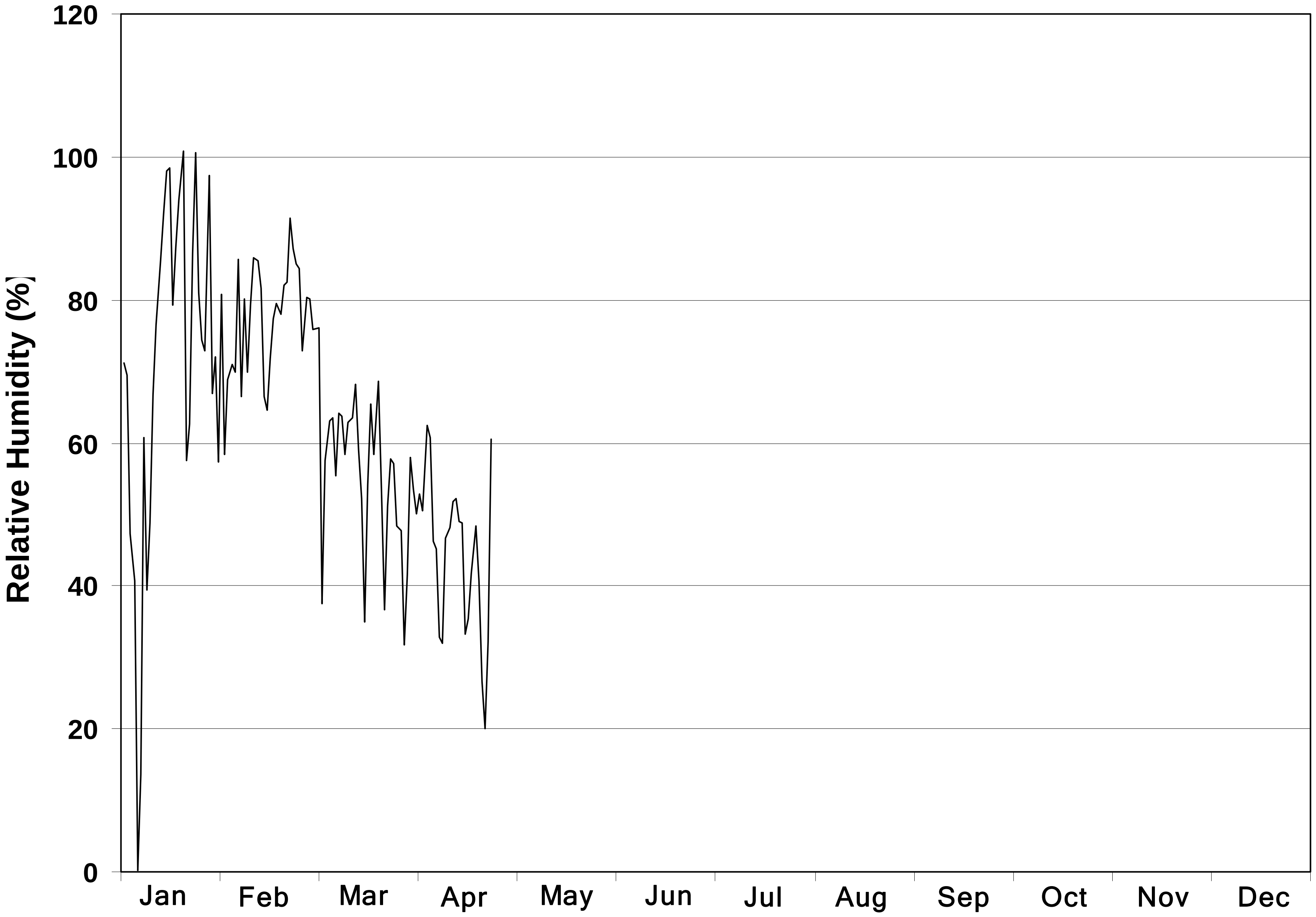
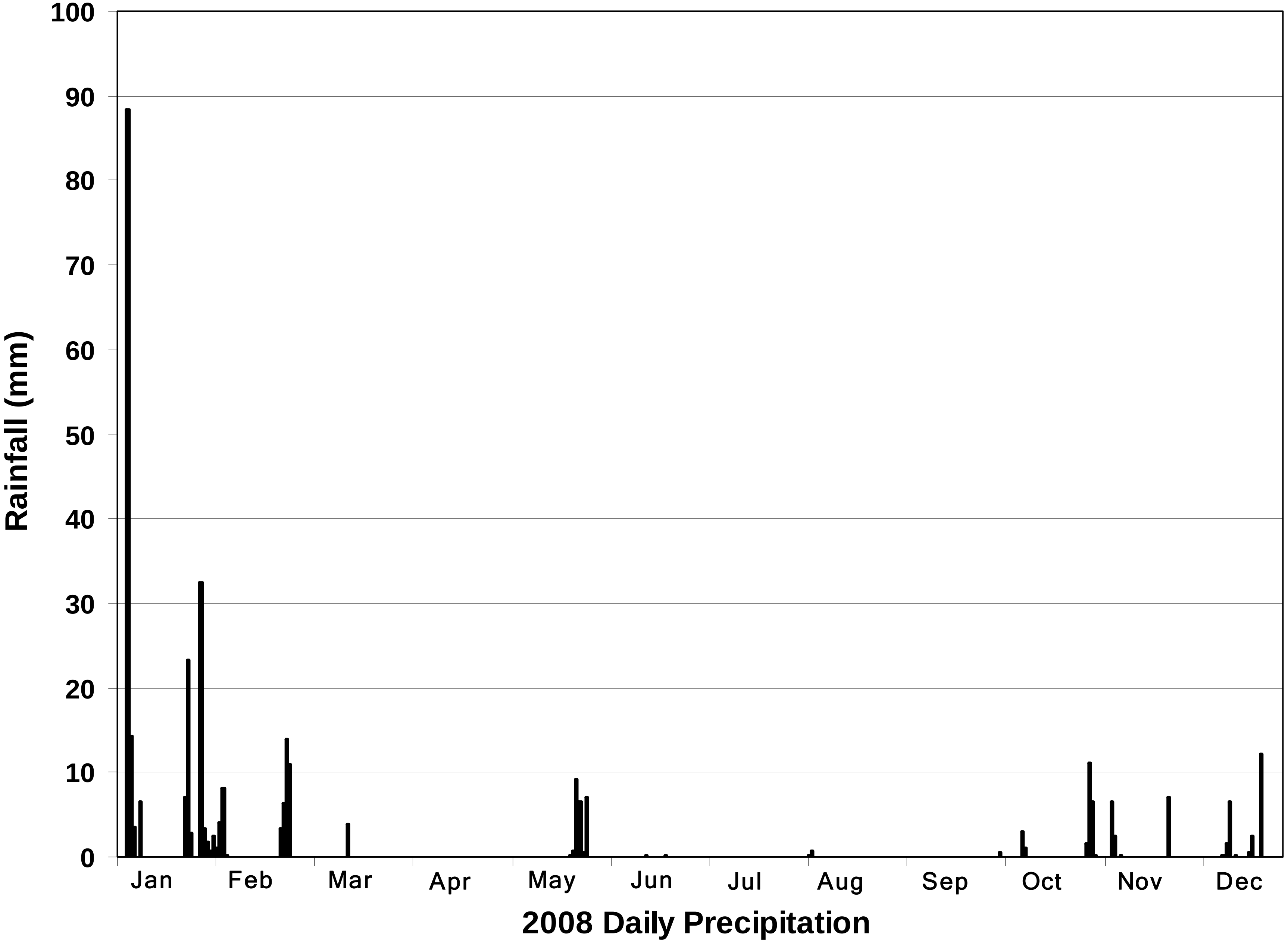

PAR (Ein m-2 day-1)
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2008 Photosynthetically Available Radiation

**Figure 4**



2008 Mean Daily Relative Humidity

Figure 5



Rainfall (mm)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2008 Daily Precipitation

Figure 6

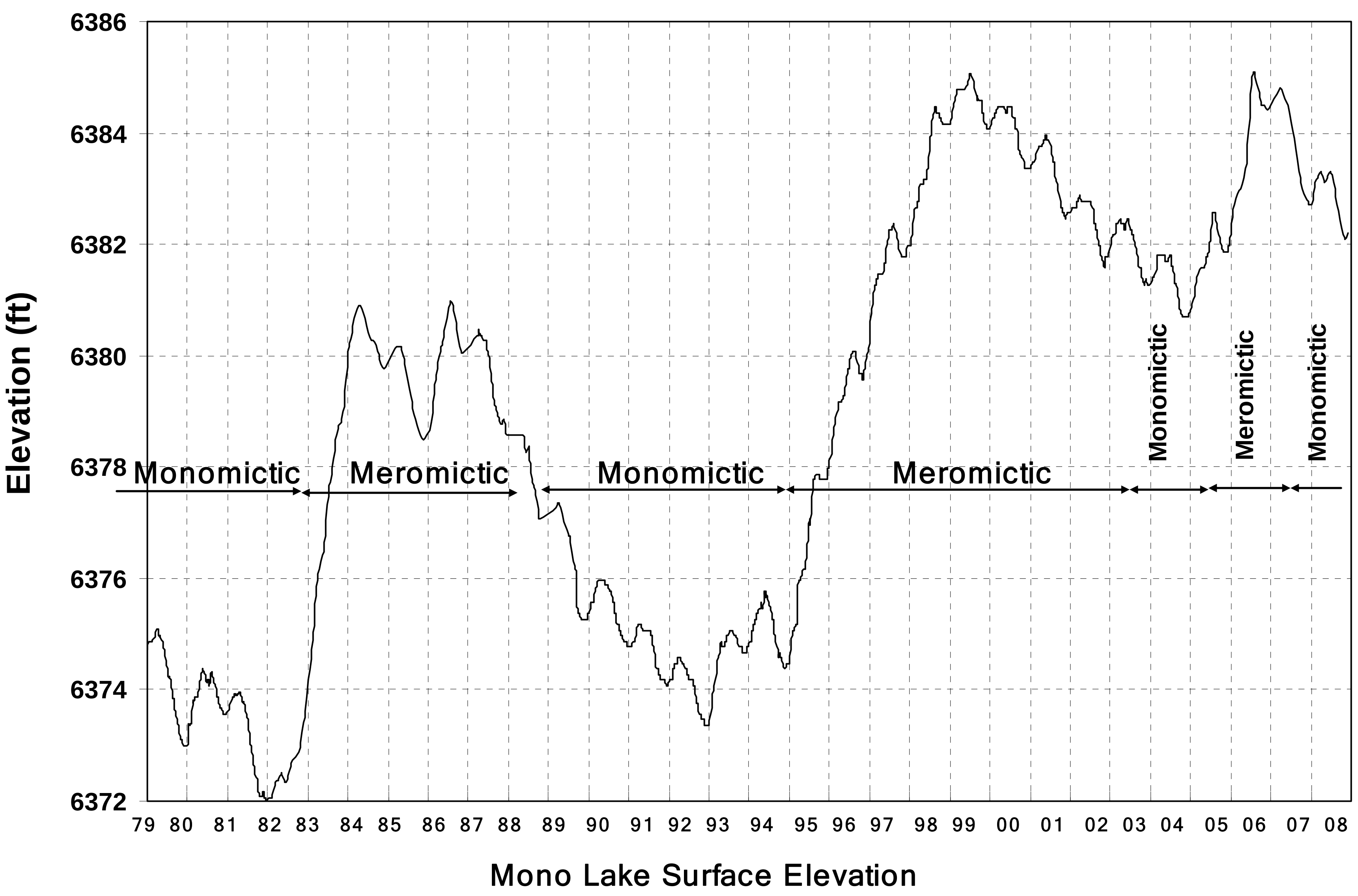
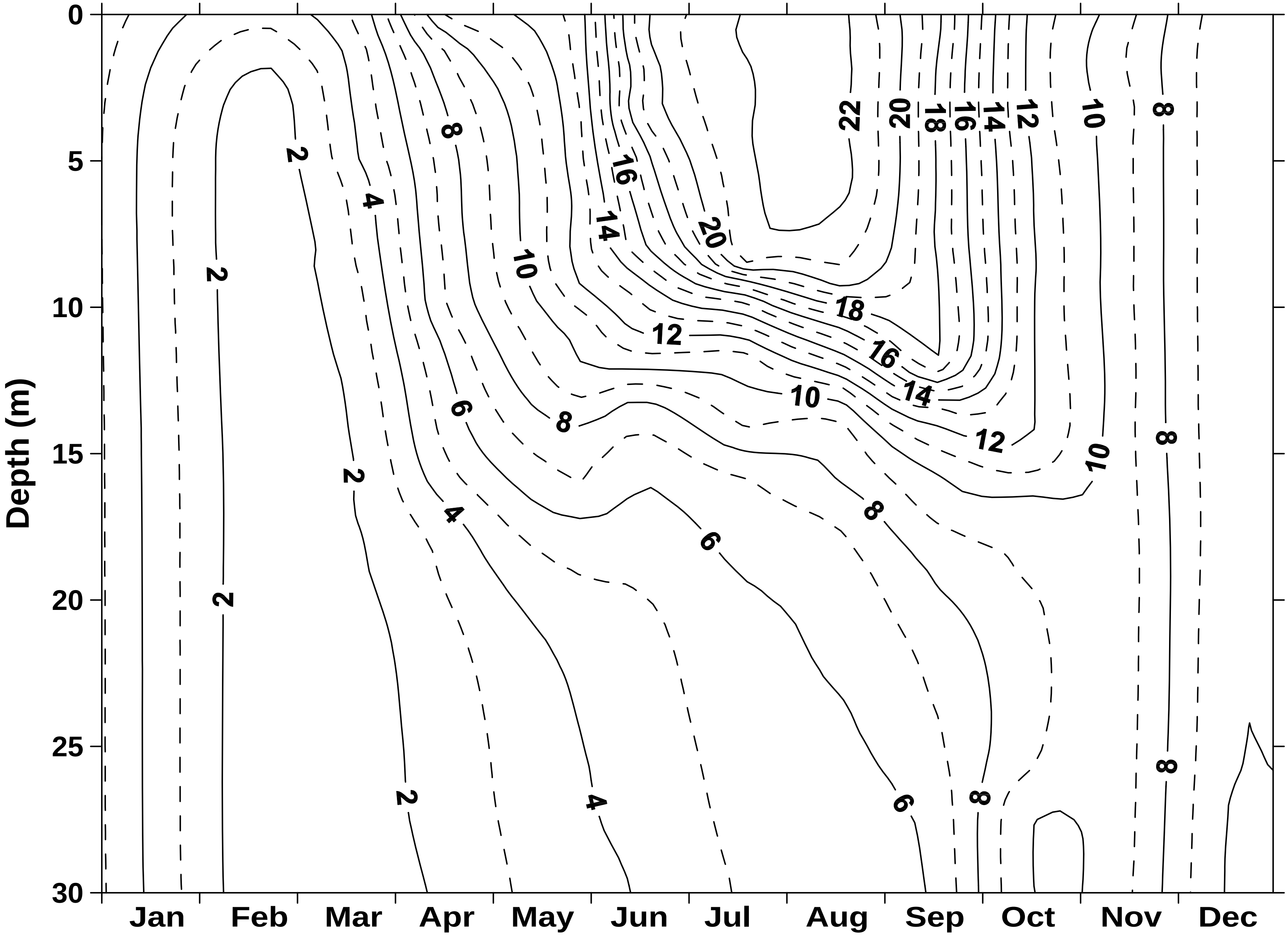

Elevation (ft)
6386
6384
6382
6380
6378
6376
6374
6372
79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08
Monomictic
Meromictic
Monomictic
Meromictic
Monomictic
Meromictic
Monomictic
Mono Lake Surface Elevation

Figure 7



Temperature (°C) at Station 6, 2008

Figure 8

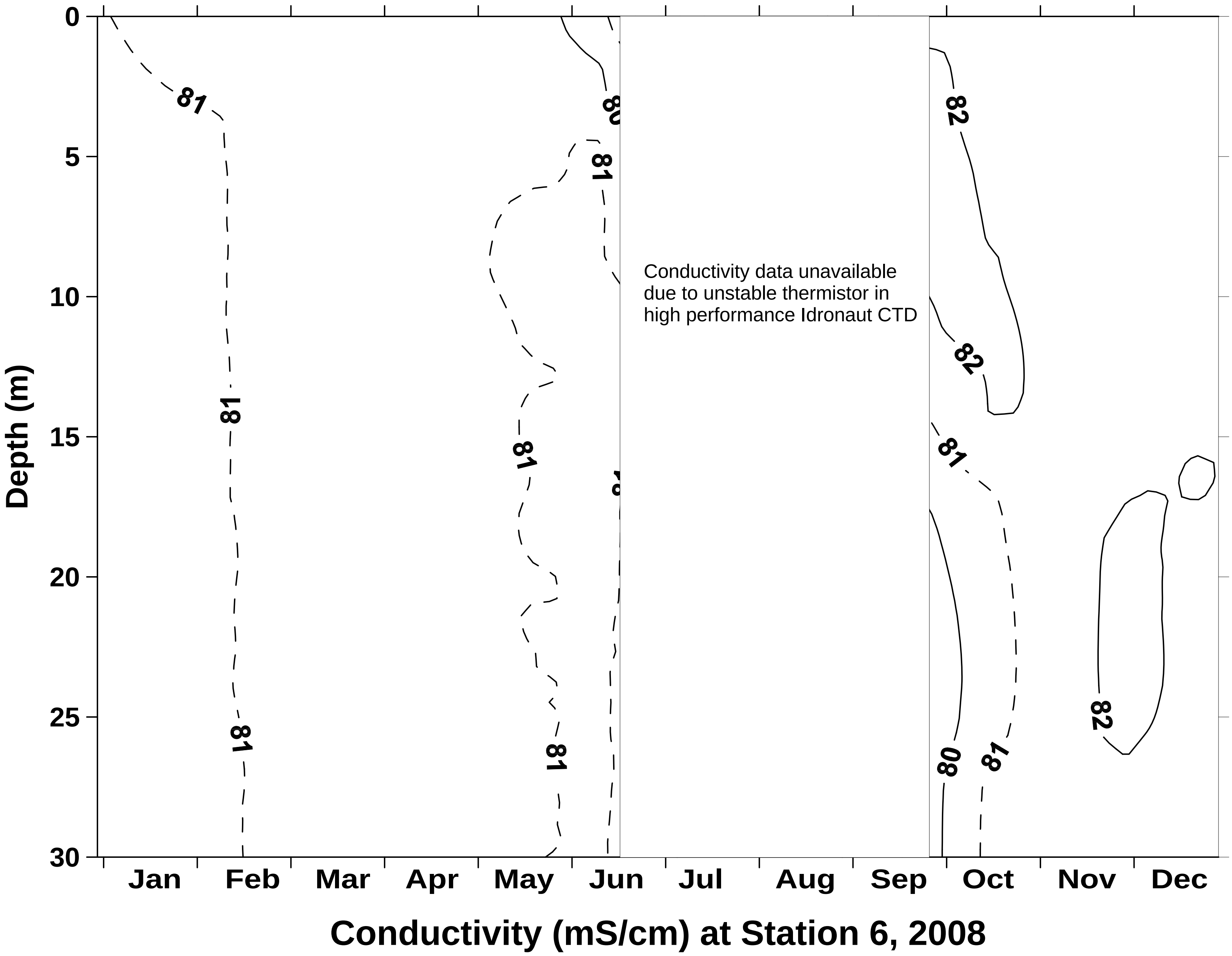

Depth (m)
0
5
10
15
20
25
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
81
81
81
80
81
81
81
81
82
82
81
82
80
81
Conductivity data unavailable due to unstable thermistor in high performance Idronaut CTD
Conductivity (mS/cm) at Station 6, 2008

Figure 9

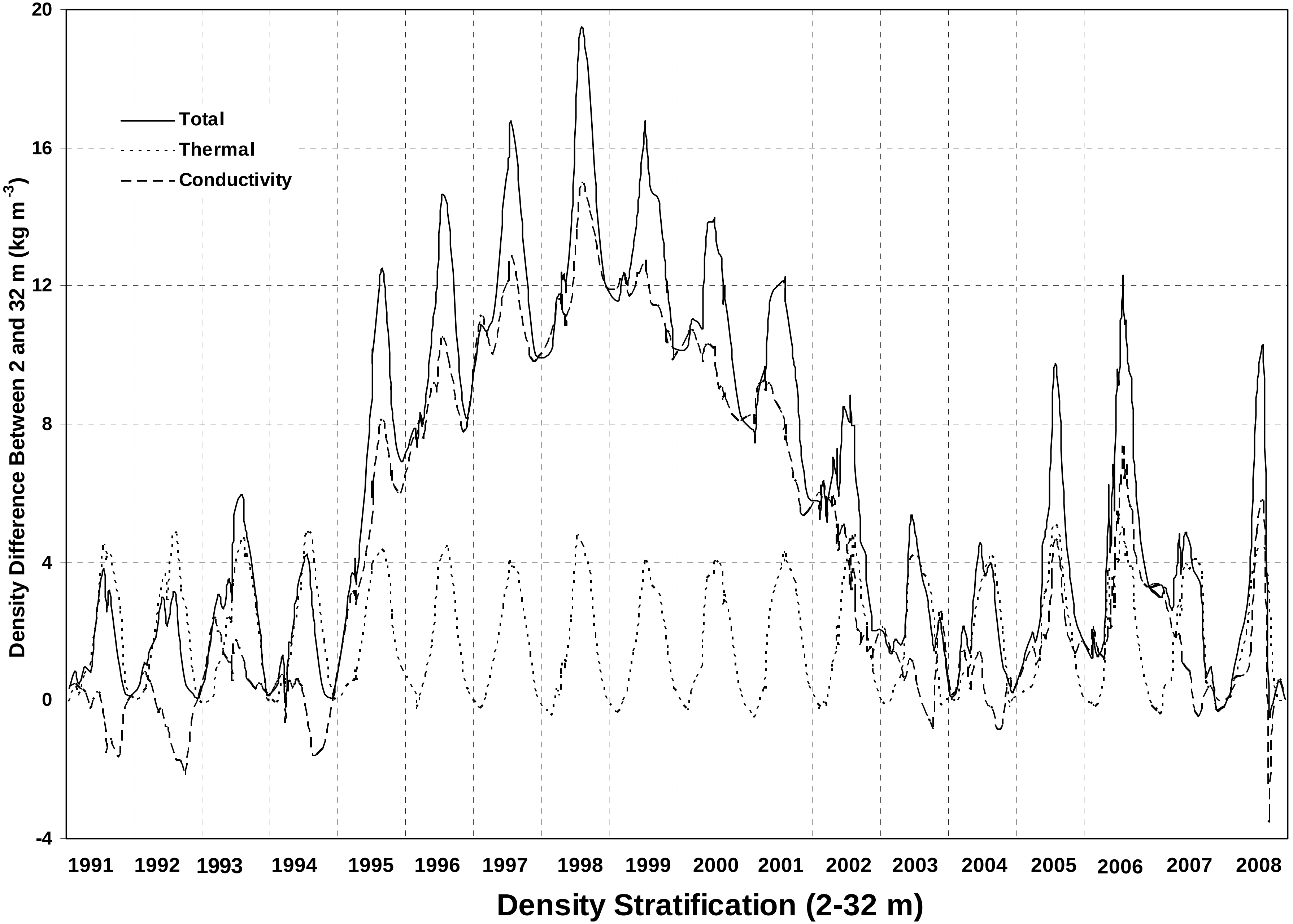
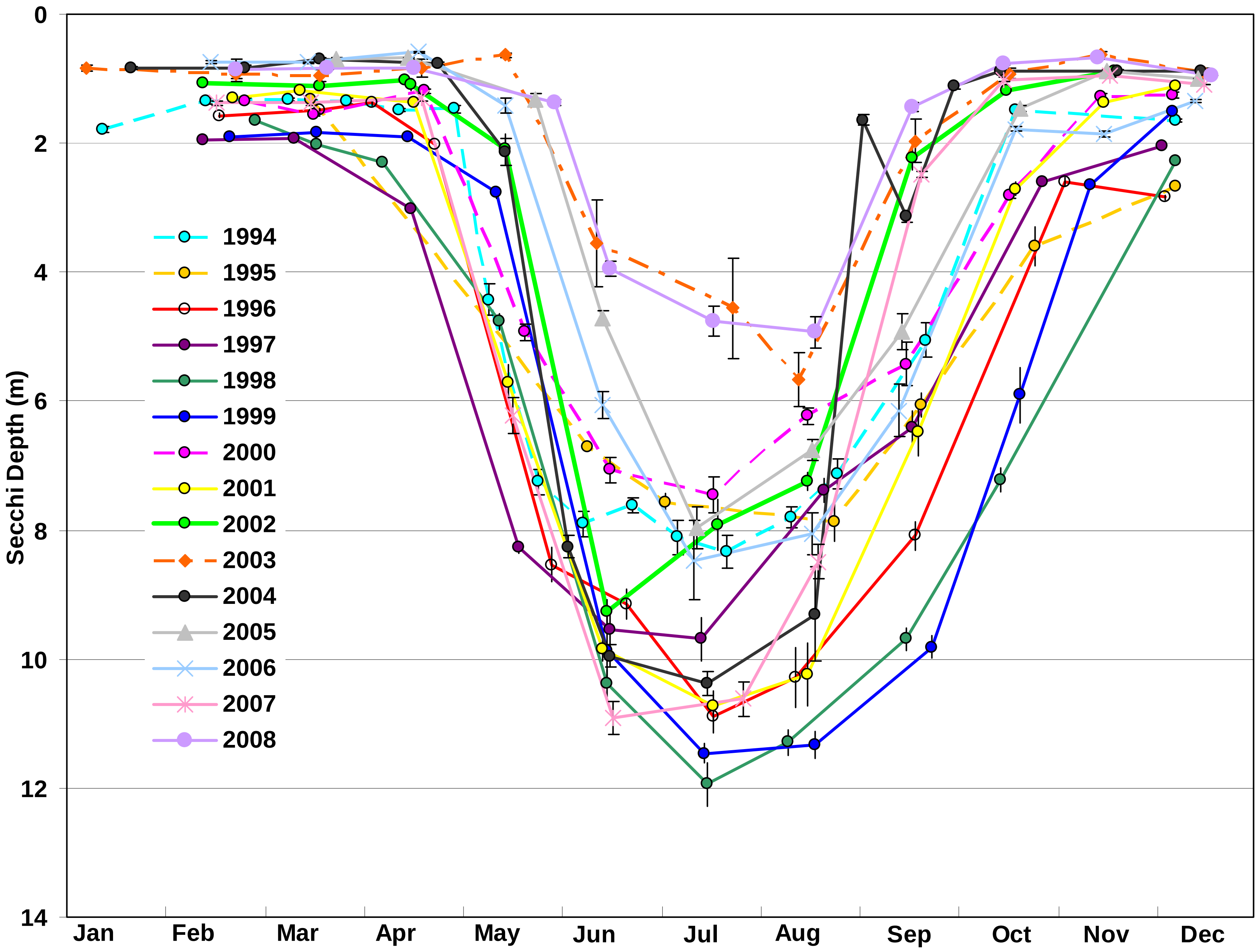
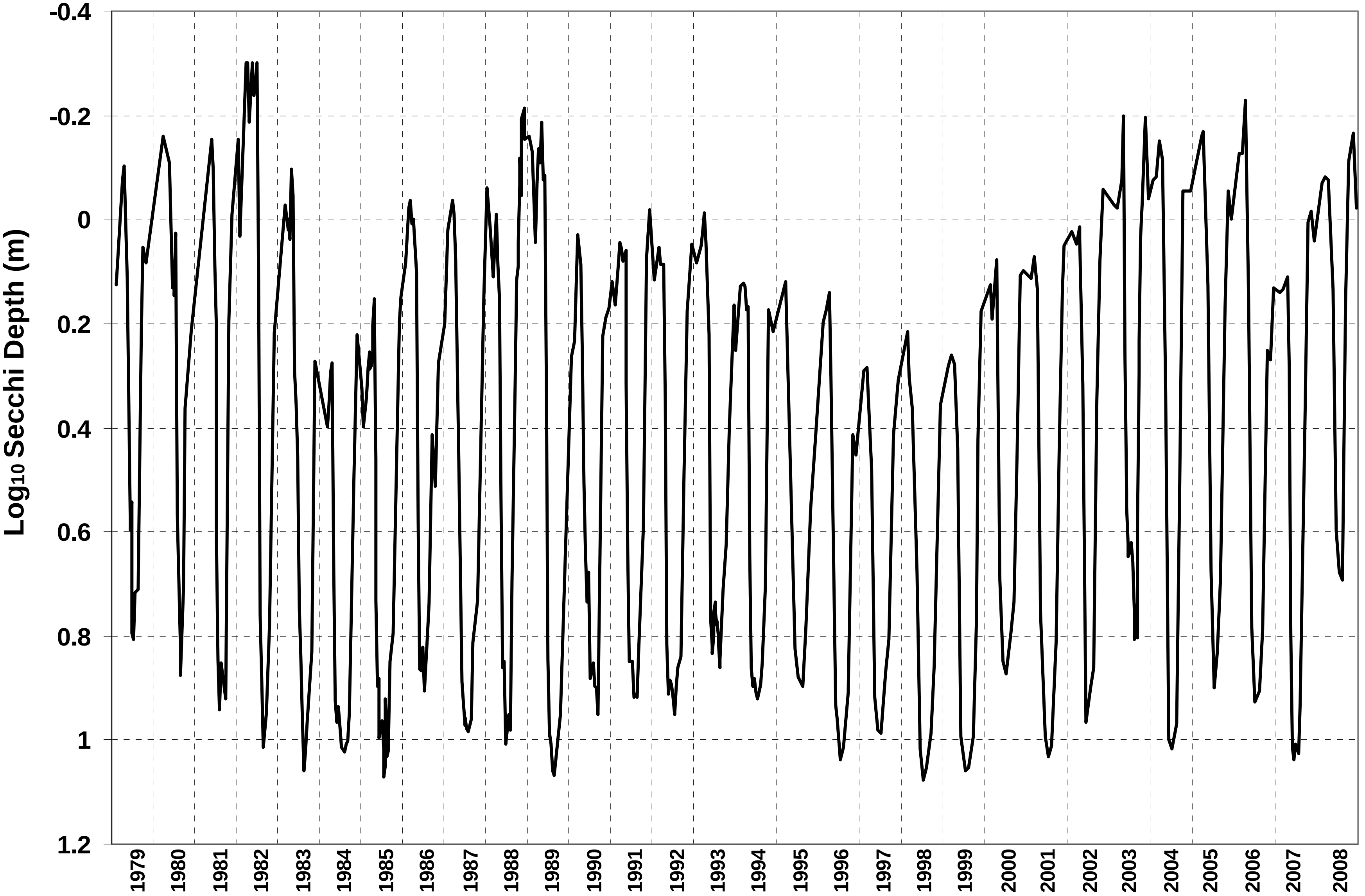

Total
Thermal
Conductivity
Density Difference Between 2 and 32 m (kg m$^{-3}$)
20
16
12
8
4
0
-4
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Density Stratification (2-32 m)

Figure 10



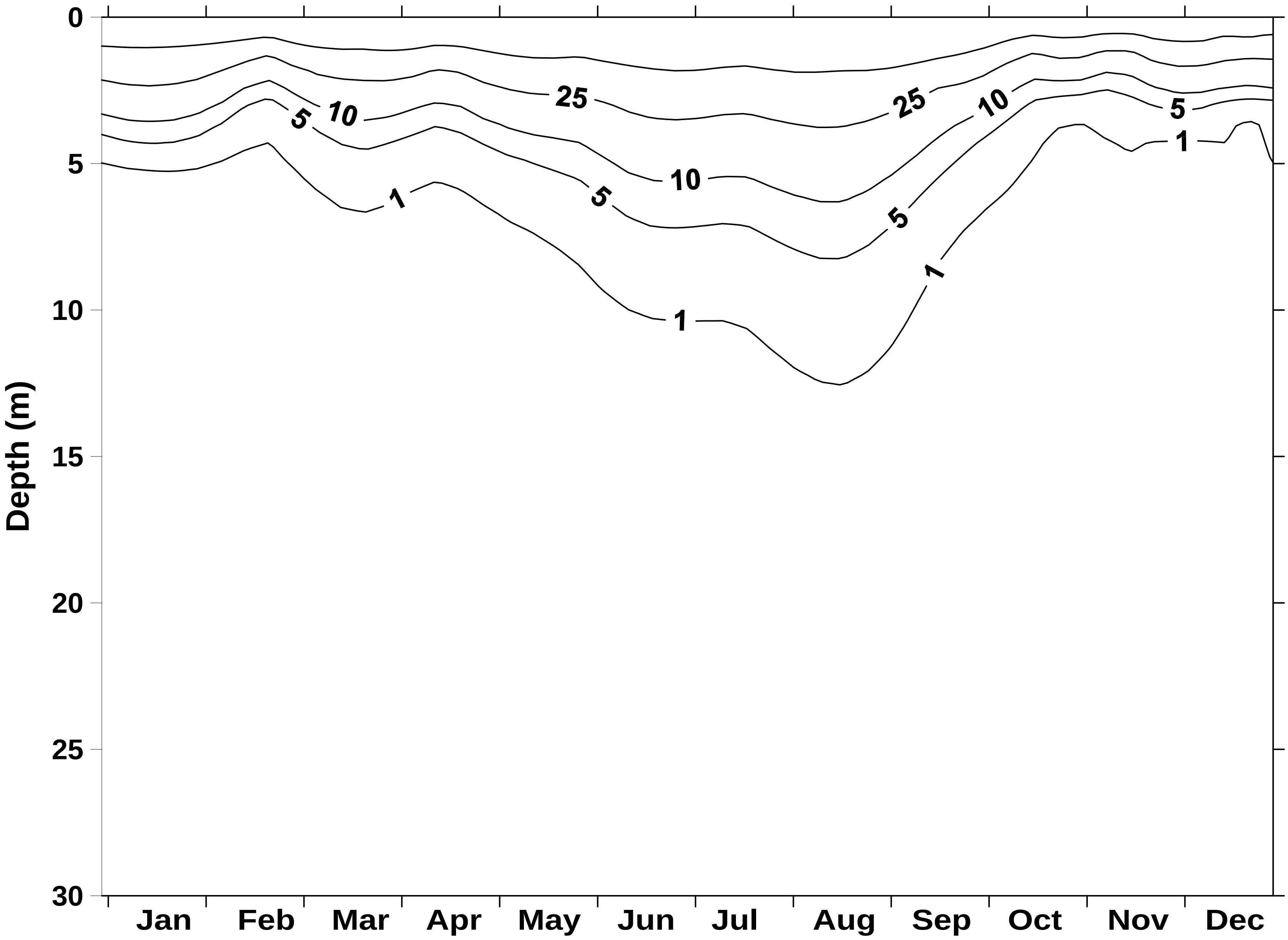
Mono Lake Transparency

Figure 11



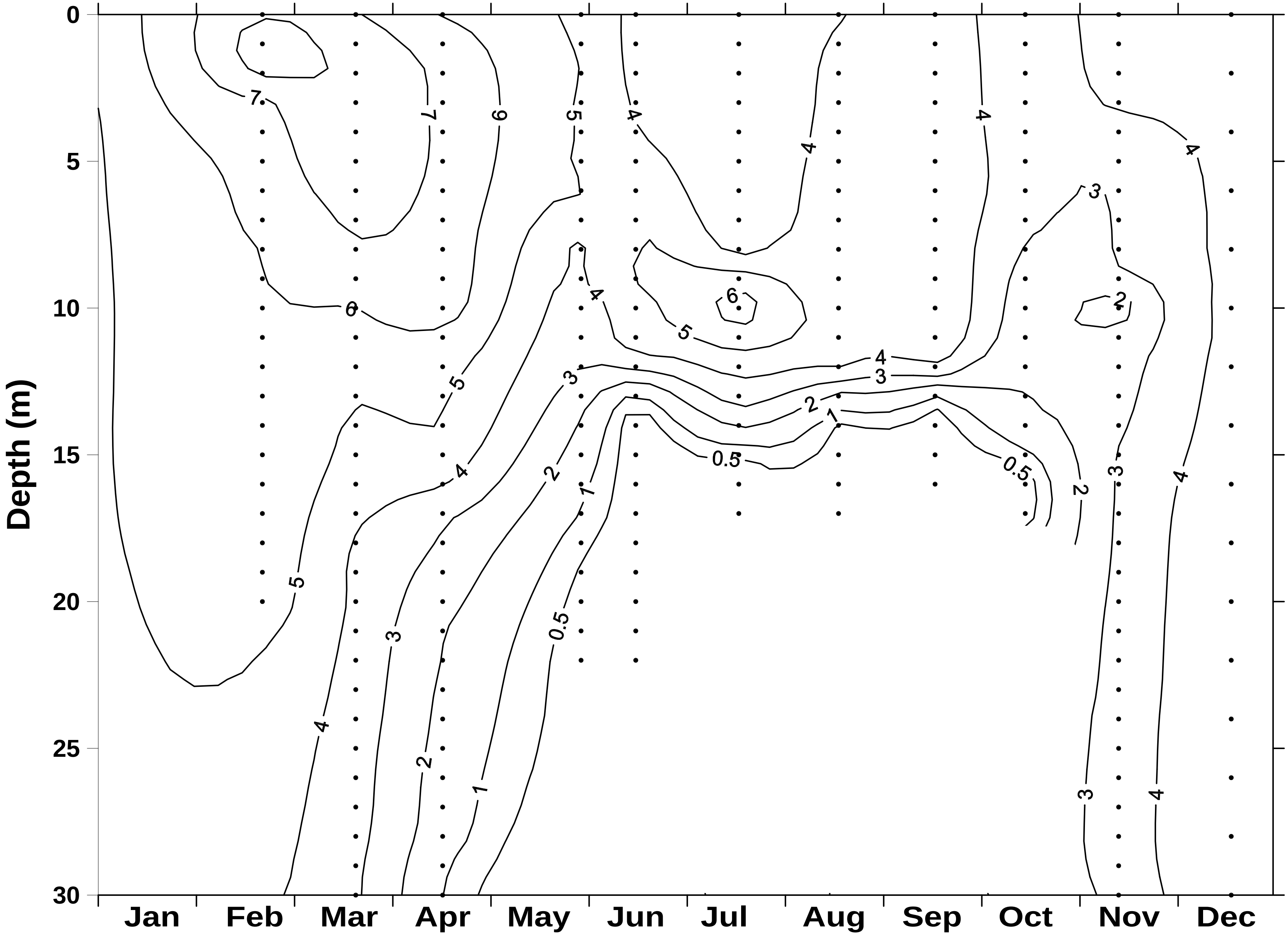
Water Transparency in Mono Lake

Figure 12



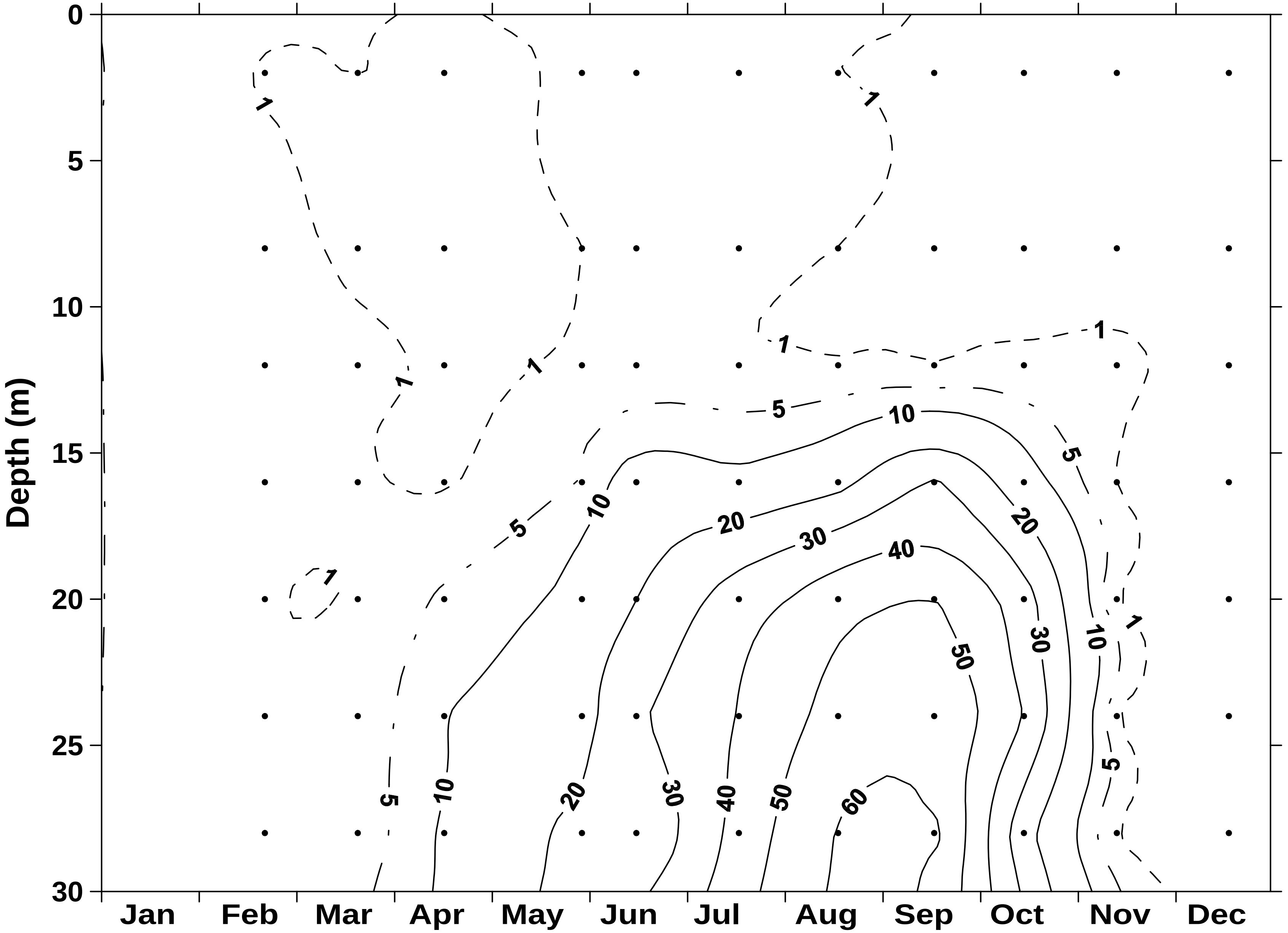
Light Attenuation (% of surface) at Station 6, 2008

Figure 13



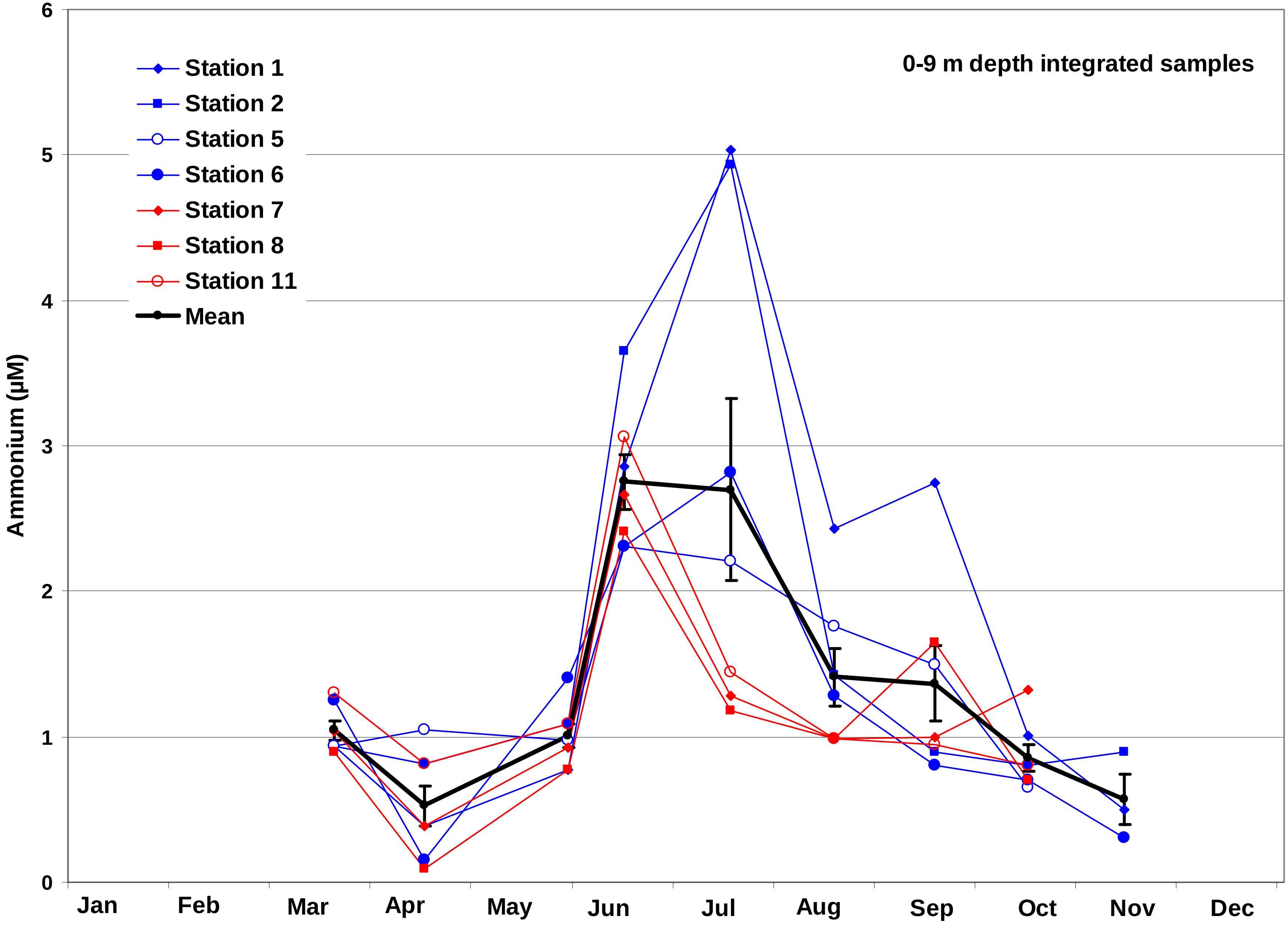
Dissolved oxygen (mg/l) at Station 6, 2008

Figure 14



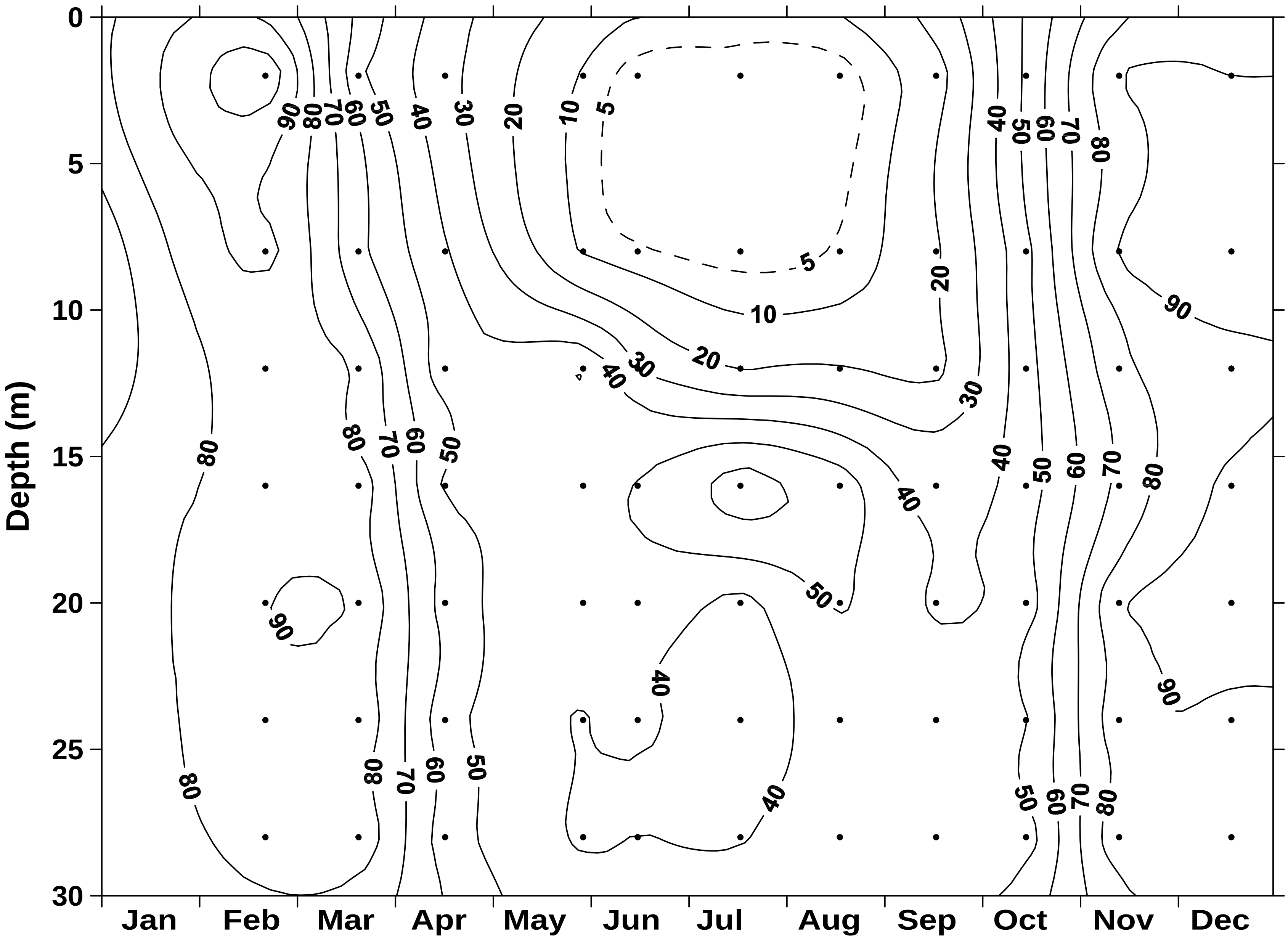
Ammonia (µM) at Station 6, 2008

Figure 15



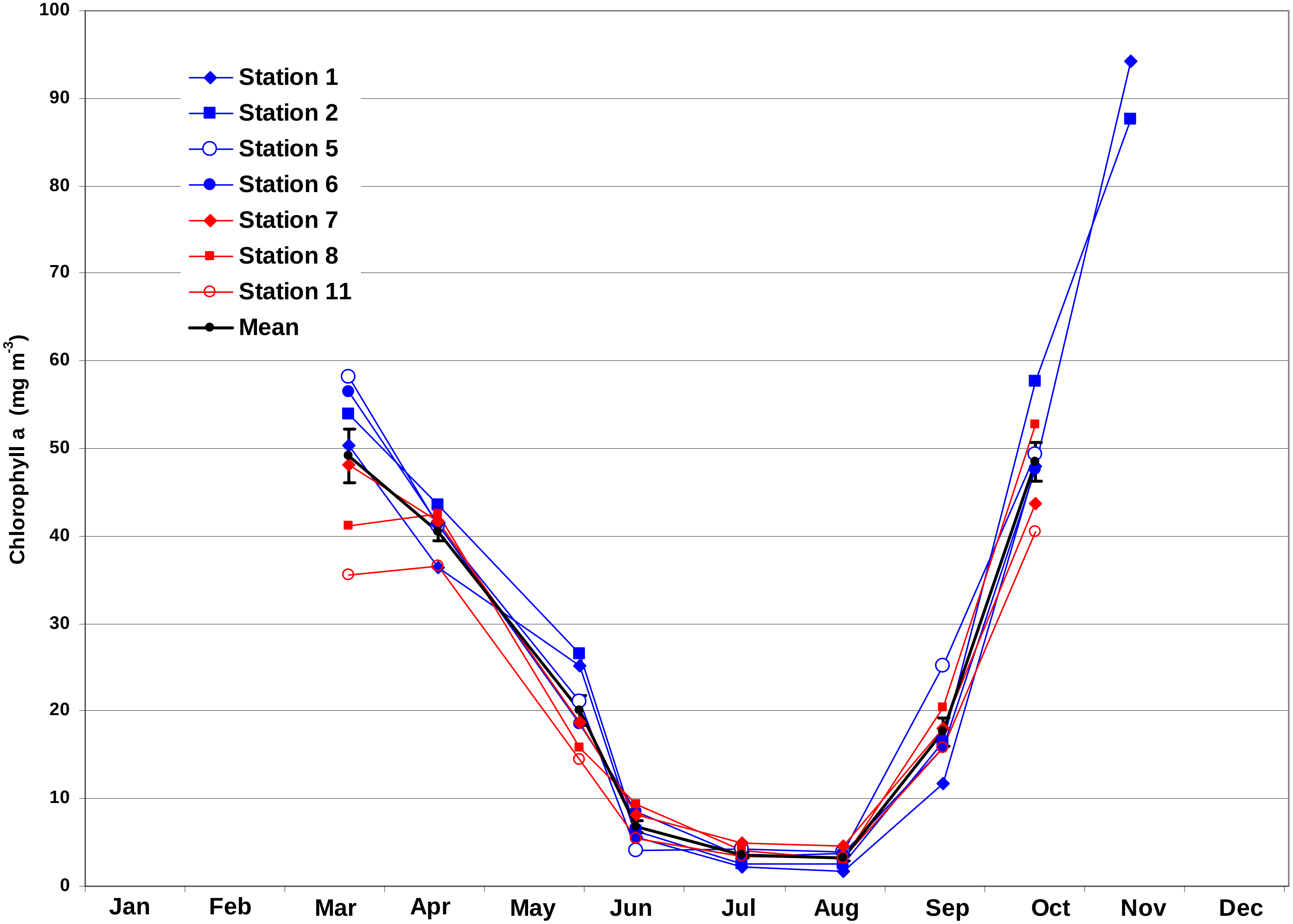
Ammonium Spatial Variability, 2008

Figure 16



Chlorophyll a (μg/l) at Station 6, 2008

Figure 17



Chlorophyll Spatial Variability, 2008

Figure 18

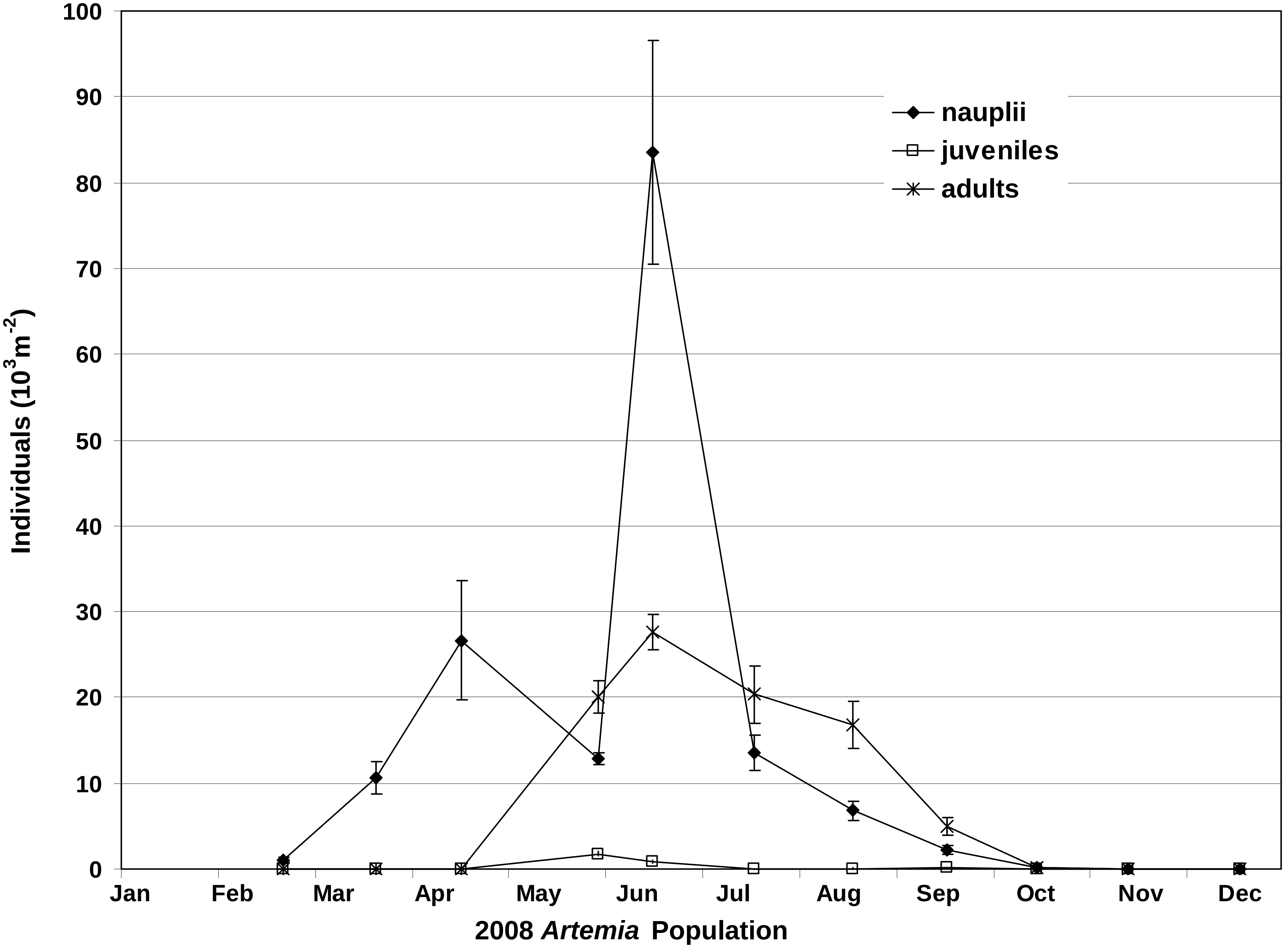

Individuals ($10^3 m^{-2}$)
100
90
80
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2008 *Artemia* Population
nauplii
juveniles
adults

Figure 19

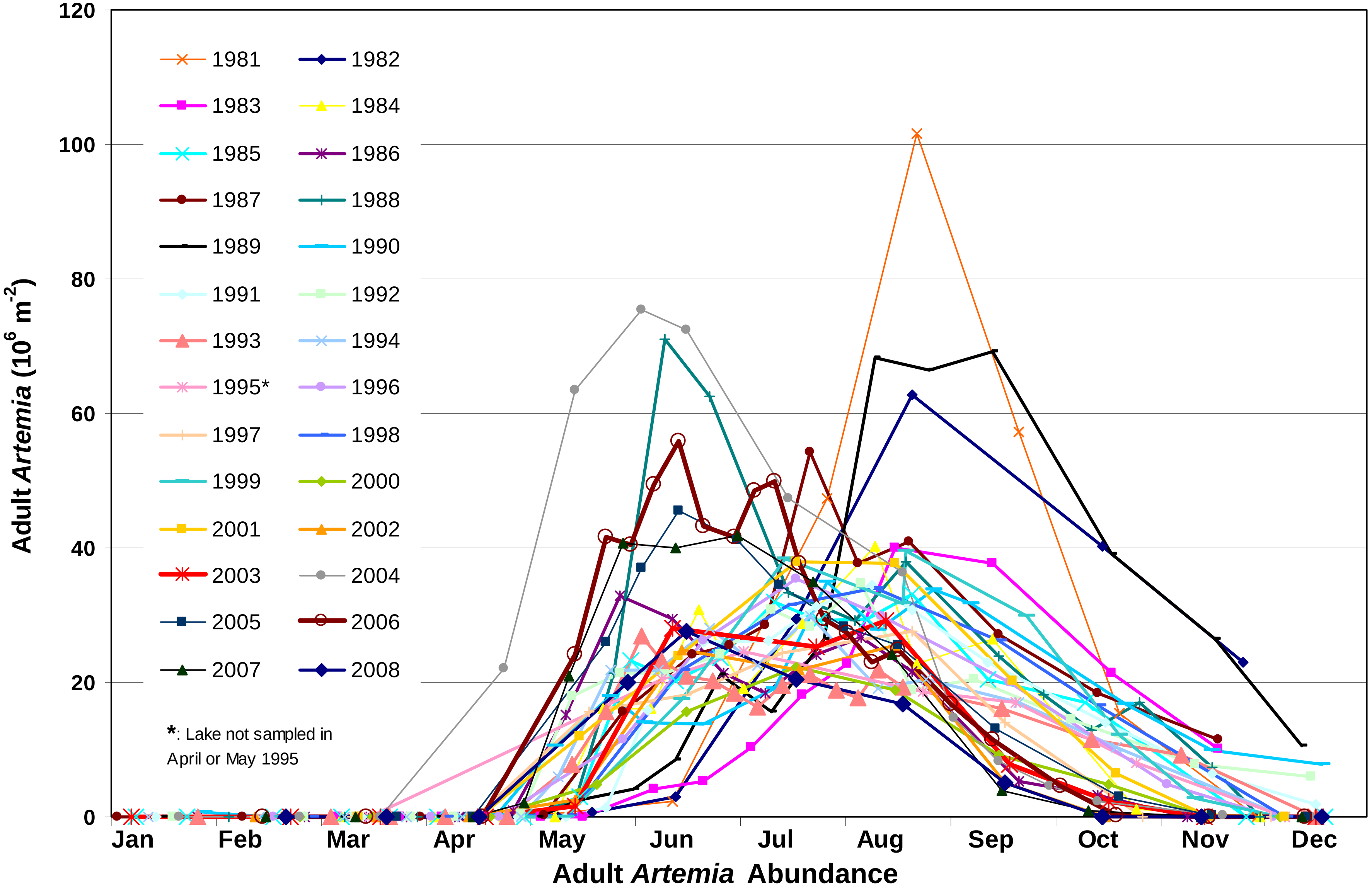
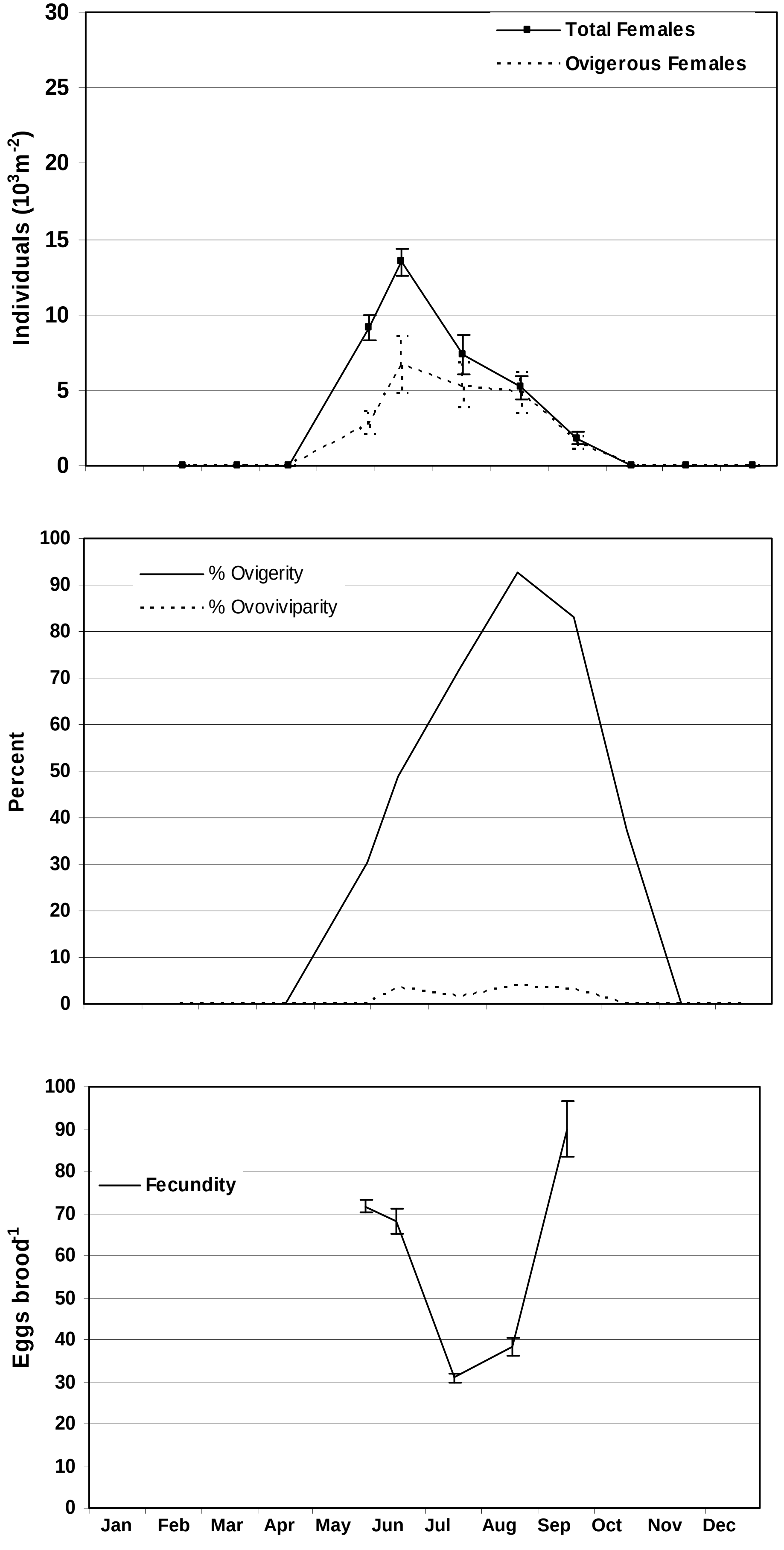

120
100
80
60
40
20
0
Adult *Artemia* ($10^6$ m$^{-2}$)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Adult *Artemia* Abundance
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995*
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
*: Lake not sampled in
April or May 1995

**Figure 20**

**Figure 21**



***Artemia* Reproductive Parameters**

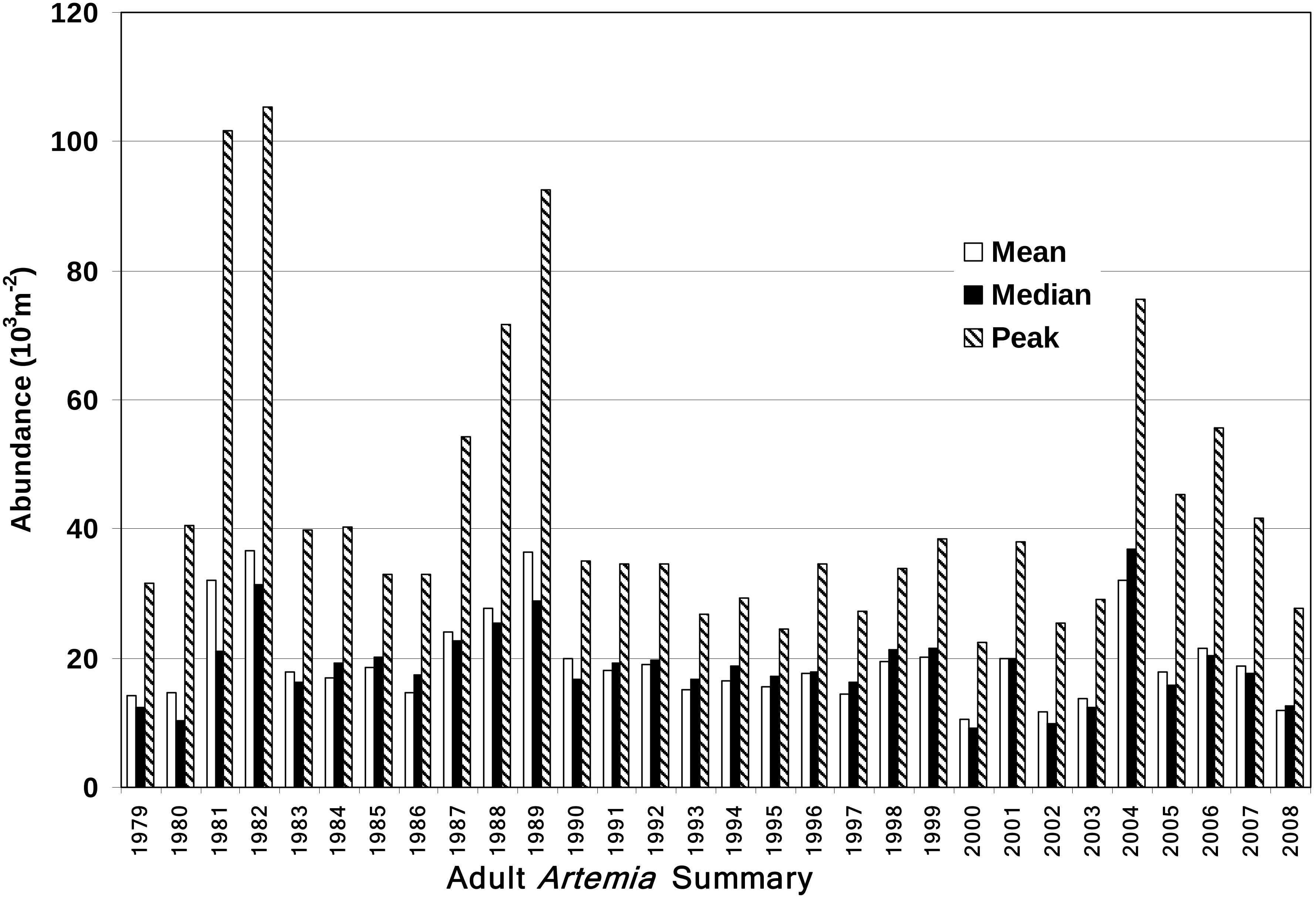
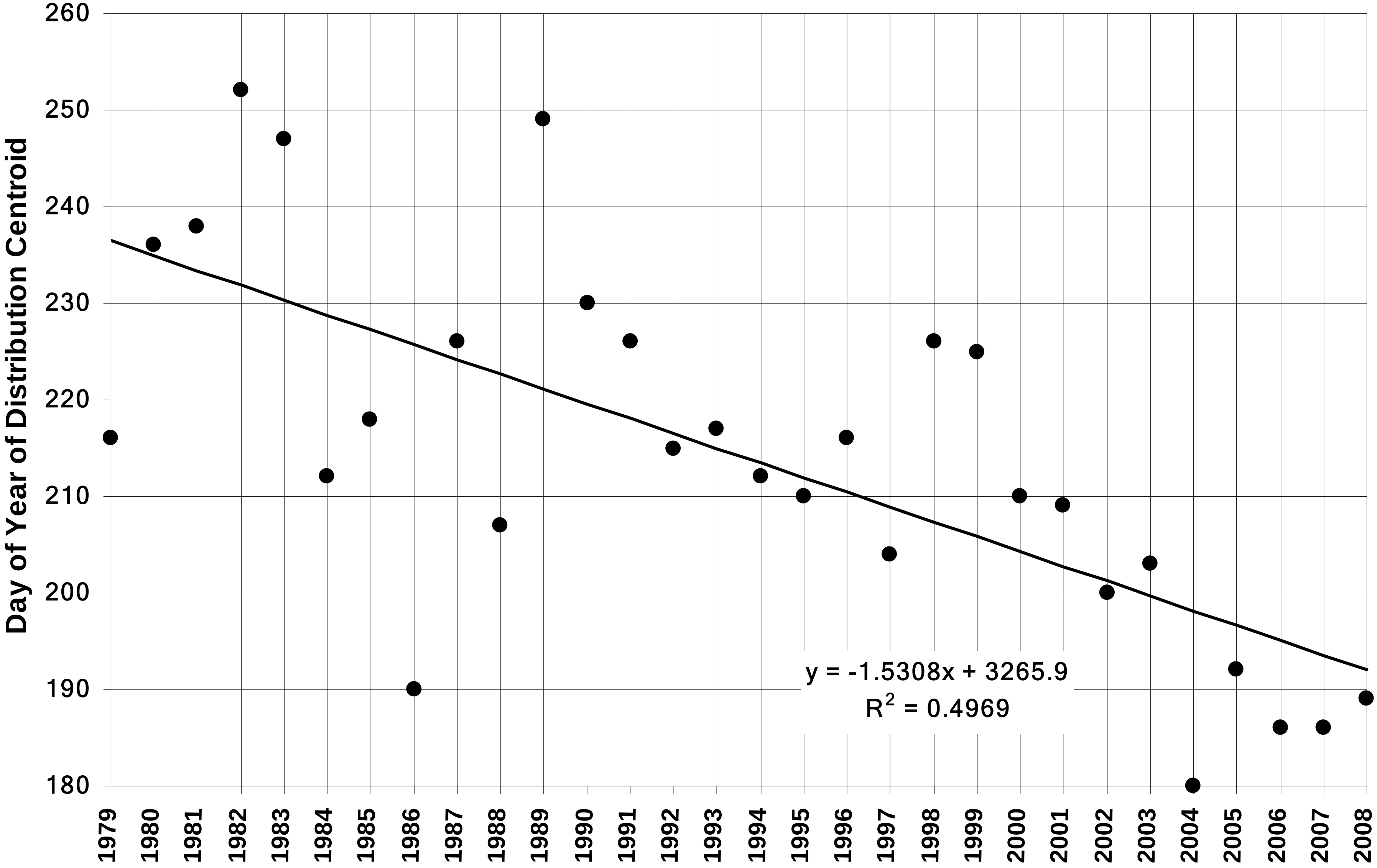

120
100
80
60
40
20
0
Abundance ($10^3 m^{-2}$)
Mean
Median
Peak
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Adult *Artemia* Summary

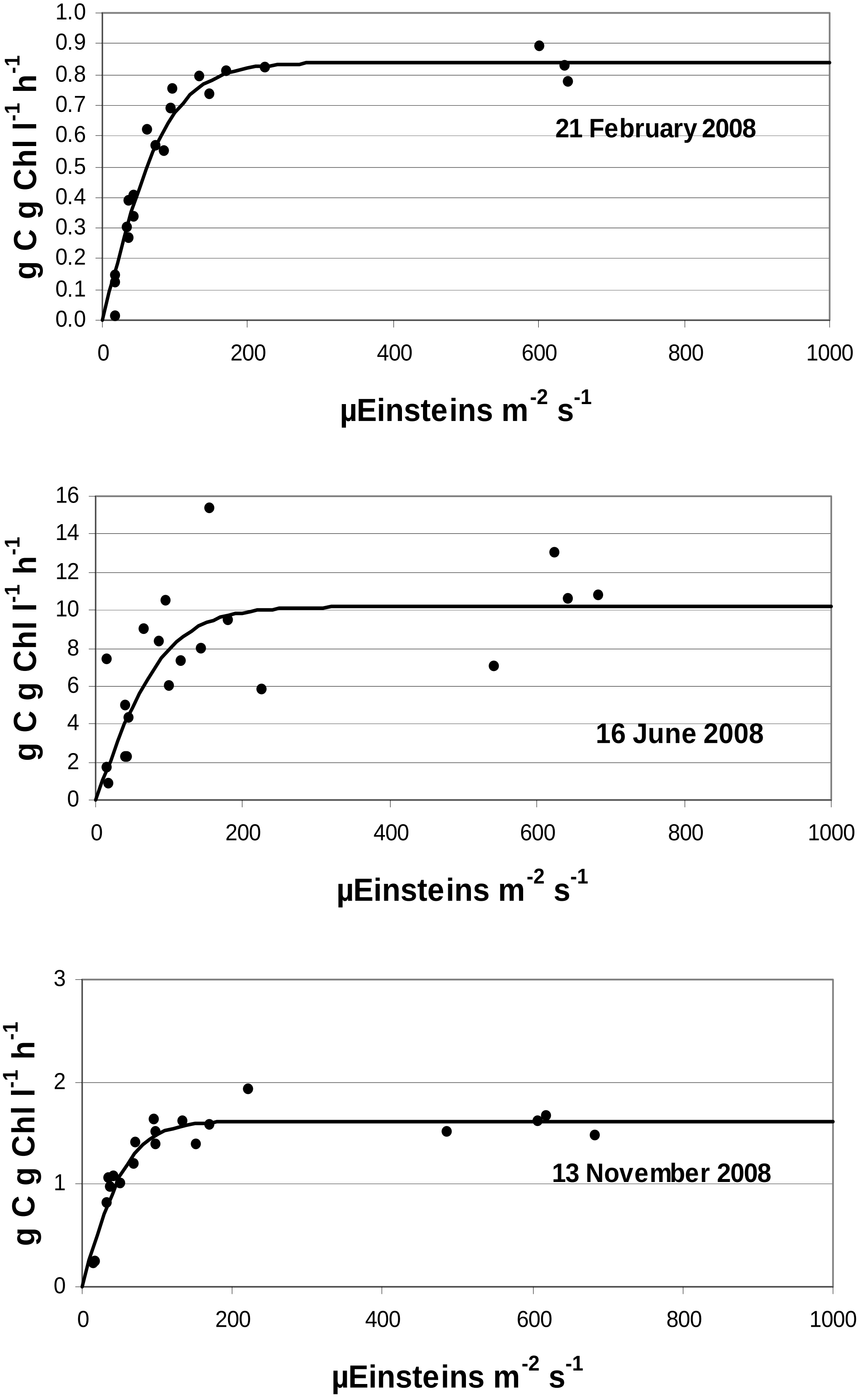
Figure 22



Adult *Artemia* Temporal Distribution

Figure 23

Figure 24



Photosynthetic Rates

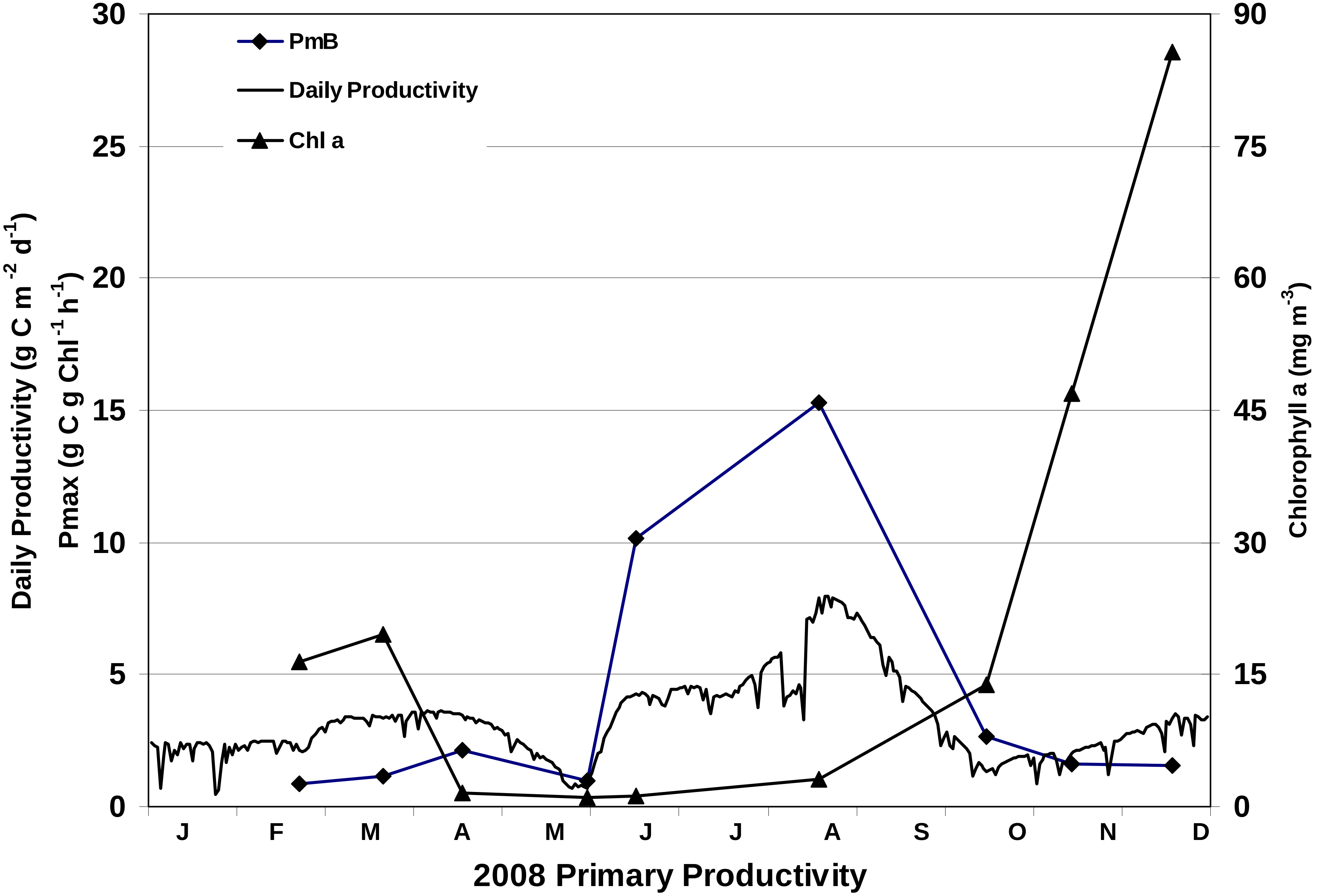
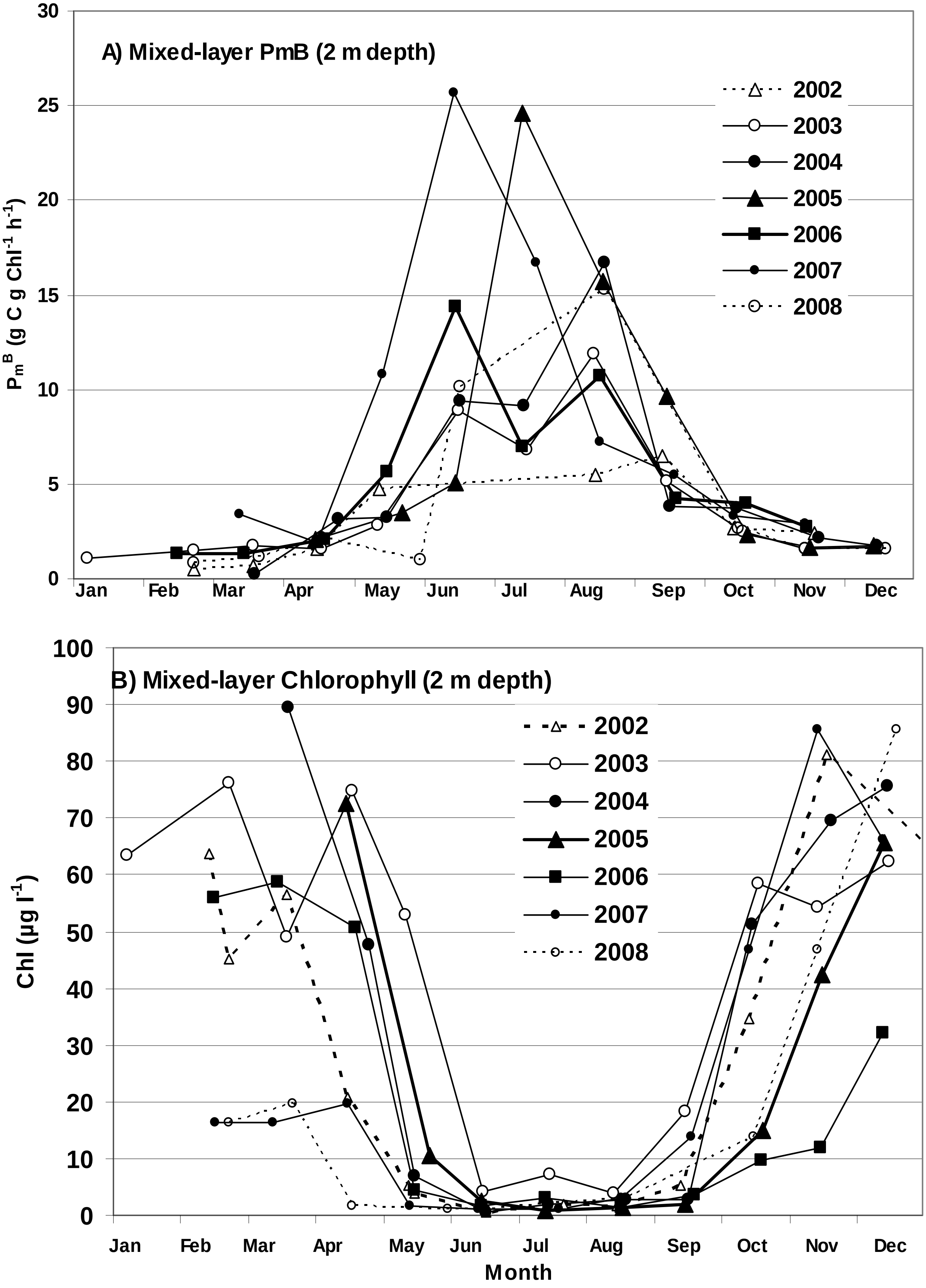

PmB
Daily Productivity
Chl a
Daily Productivity (g C m $^{-2}$ d$^{-1}$)
Pmax (g C g Chl$^{-1}$ h$^{-1}$)
Chlorophyll a (mg m$^{-3}$)
0
5
10
15
20
25
30
0
15
30
45
60
75
90
J
F
M
A
M
J
J
A
S
O
N
D
2008 Primary Productivity

Figure 25

**Figure 26**



A) Mixed-layer PmB (2 m depth)
$P_m^B$ (g C g Chl$^{-1}$ h$^{-1}$)
0
5
10
15
20
25
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002
2003
2004
2005
2006
2007
2008
B) Mixed-layer Chlorophyll (2 m depth)
Chl (µg l$^{-1}$)
0
10
20
30
40
50
60
70
80
90
100
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2002
2003
2004
2005
2006
2007
2008

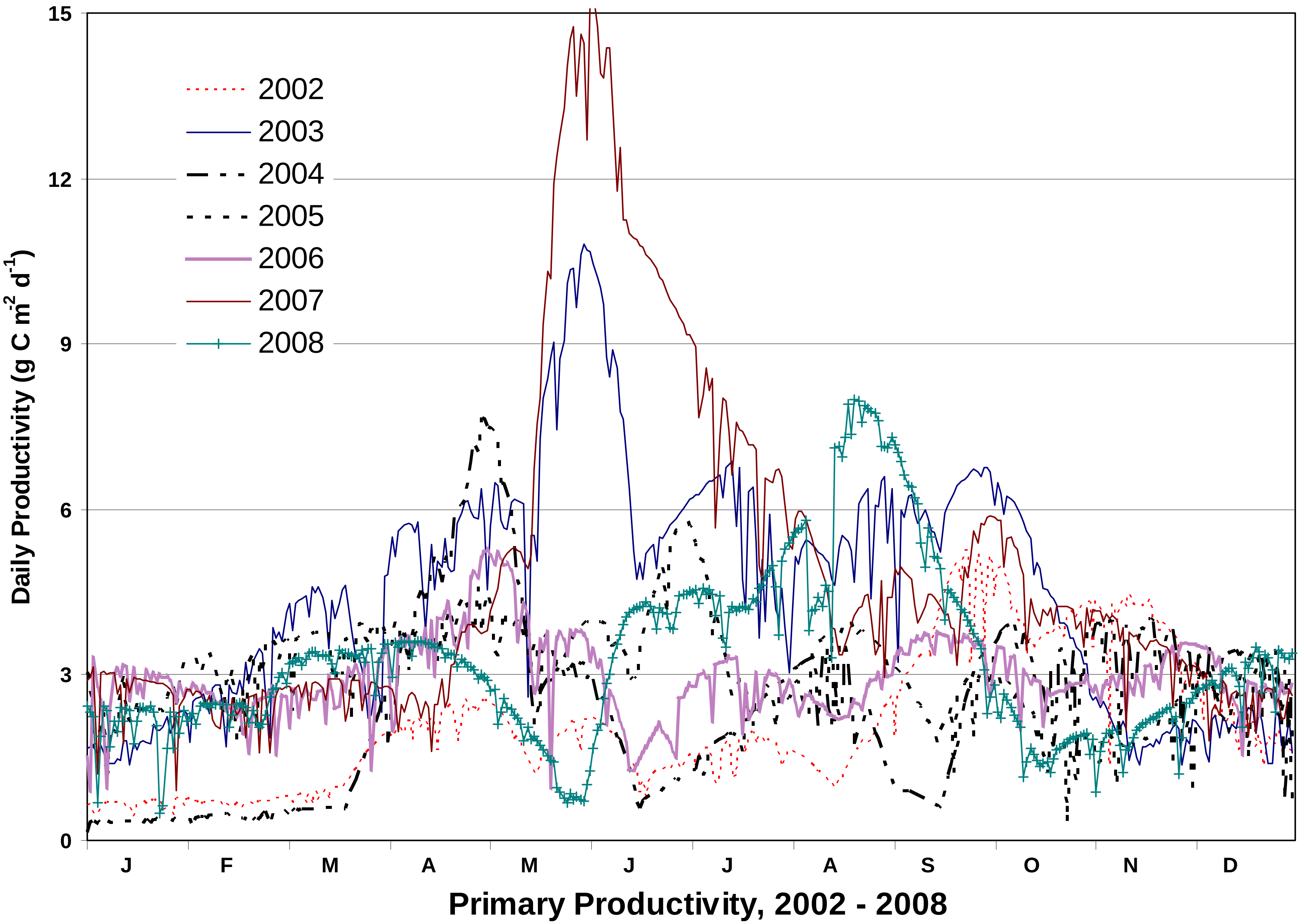

15
12
9
6
3
0
Daily Productivity (g C m$^{-2}$ d$^{-1}$)
2002
2003
2004
2005
2006
2007
2008
J
F
M
A
M
J
J
A
S
O
N
D
Primary Productivity, 2002 - 2008

Figure 27

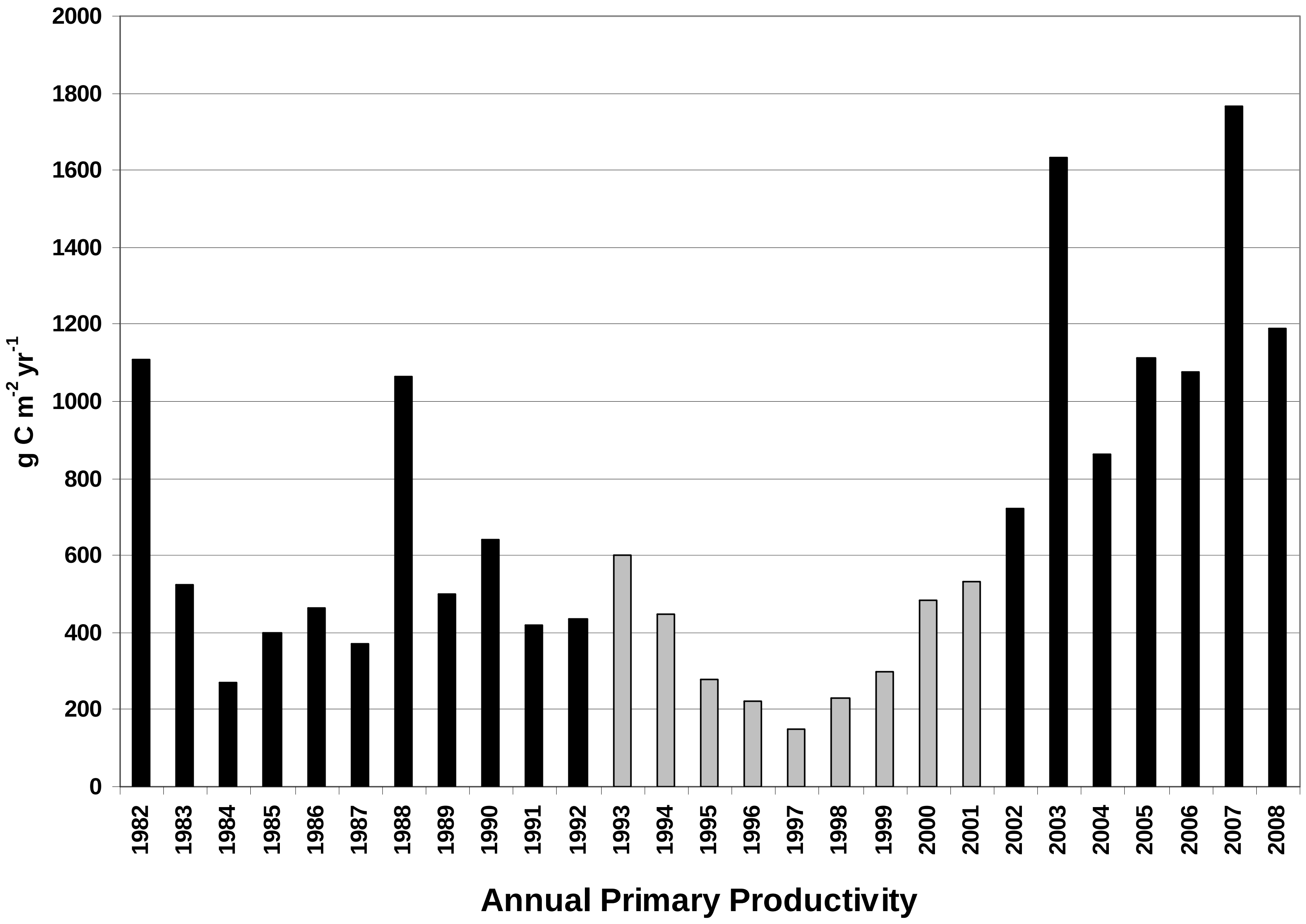

g C m^-2 yr^-1
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Annual Primary Productivity

Figure 28

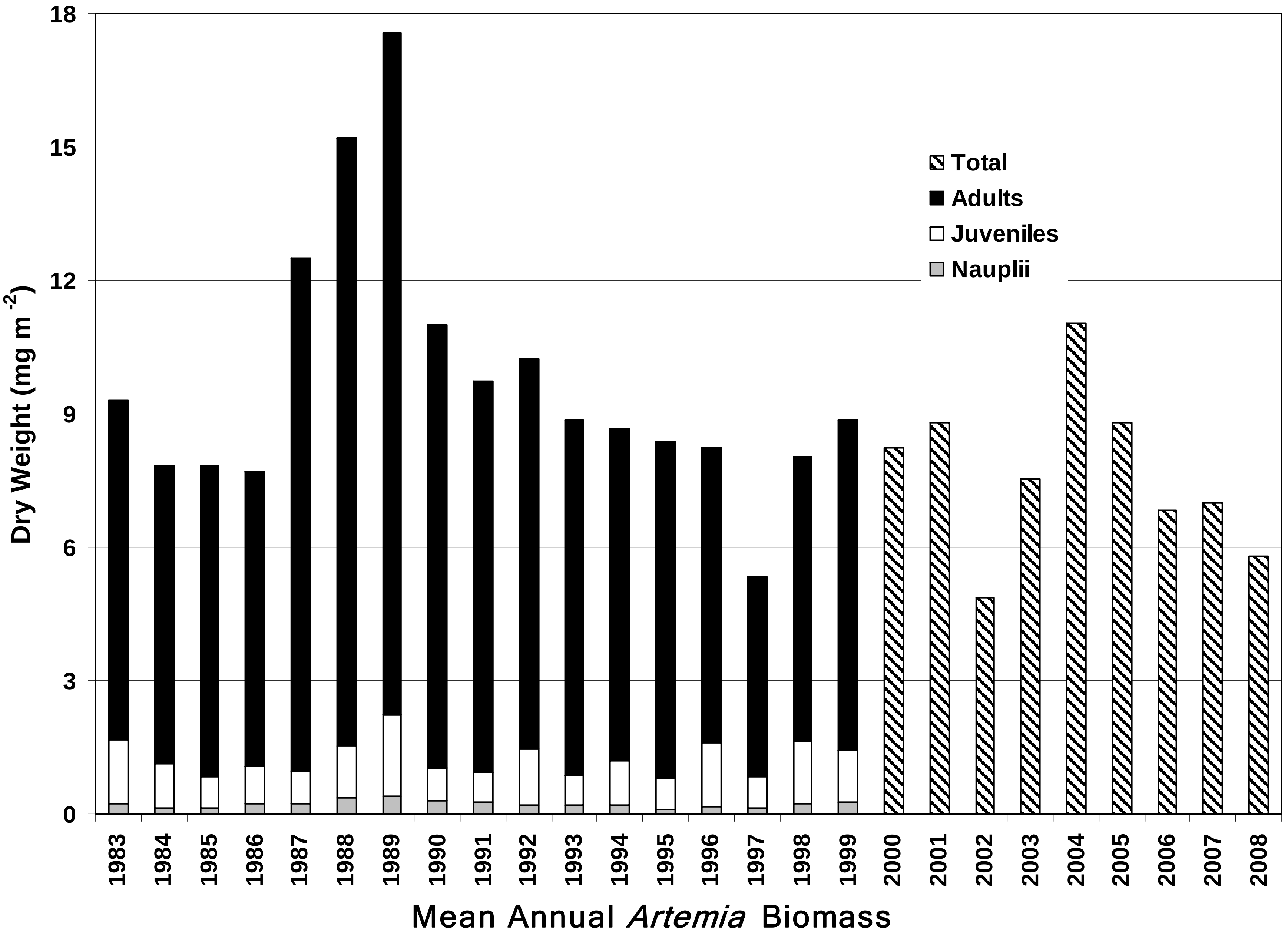

18
15
12
9
6
3
0
Dry Weight (mg m $^{-2}$)
▨ Total
■ Adults
☐ Juveniles
▩ Nauplii
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Mean Annual *Artemia* Biomass

**Figure 29**

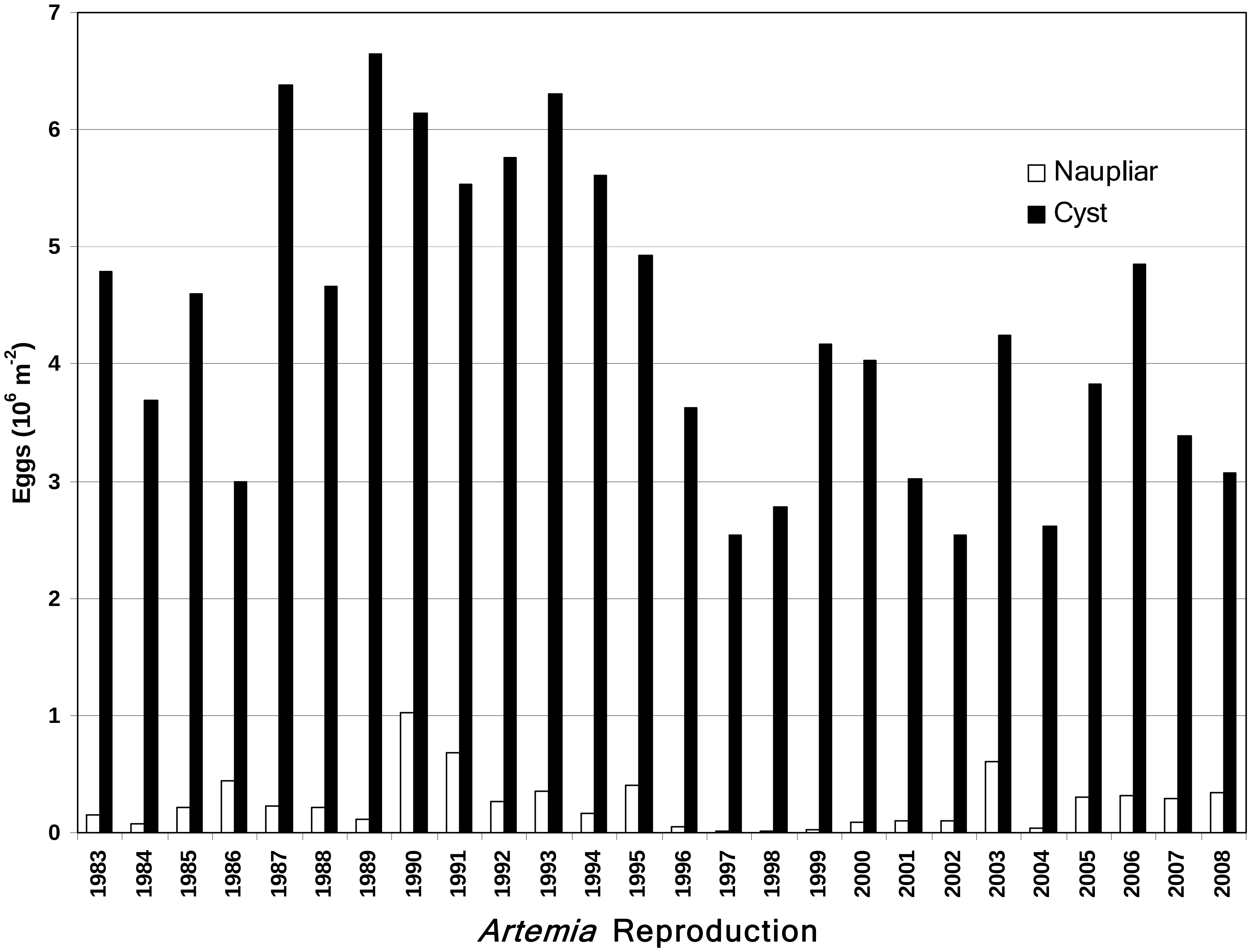

7
6
5
4
3
2
1
0
Eggs (10$^6$ m$^{-2}$)
Naupliar
Cyst
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
*Artemia* Reproduction

Figure 30

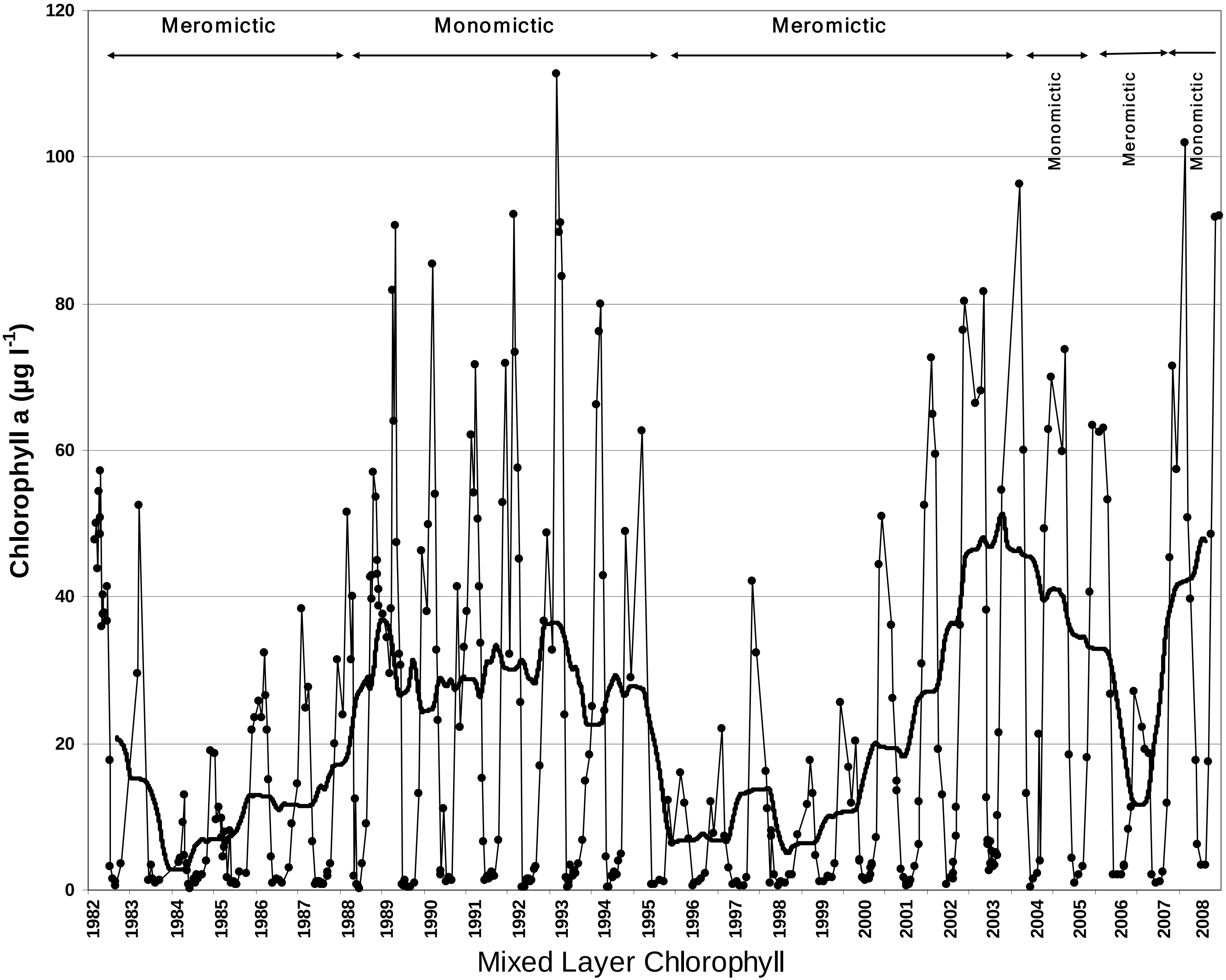
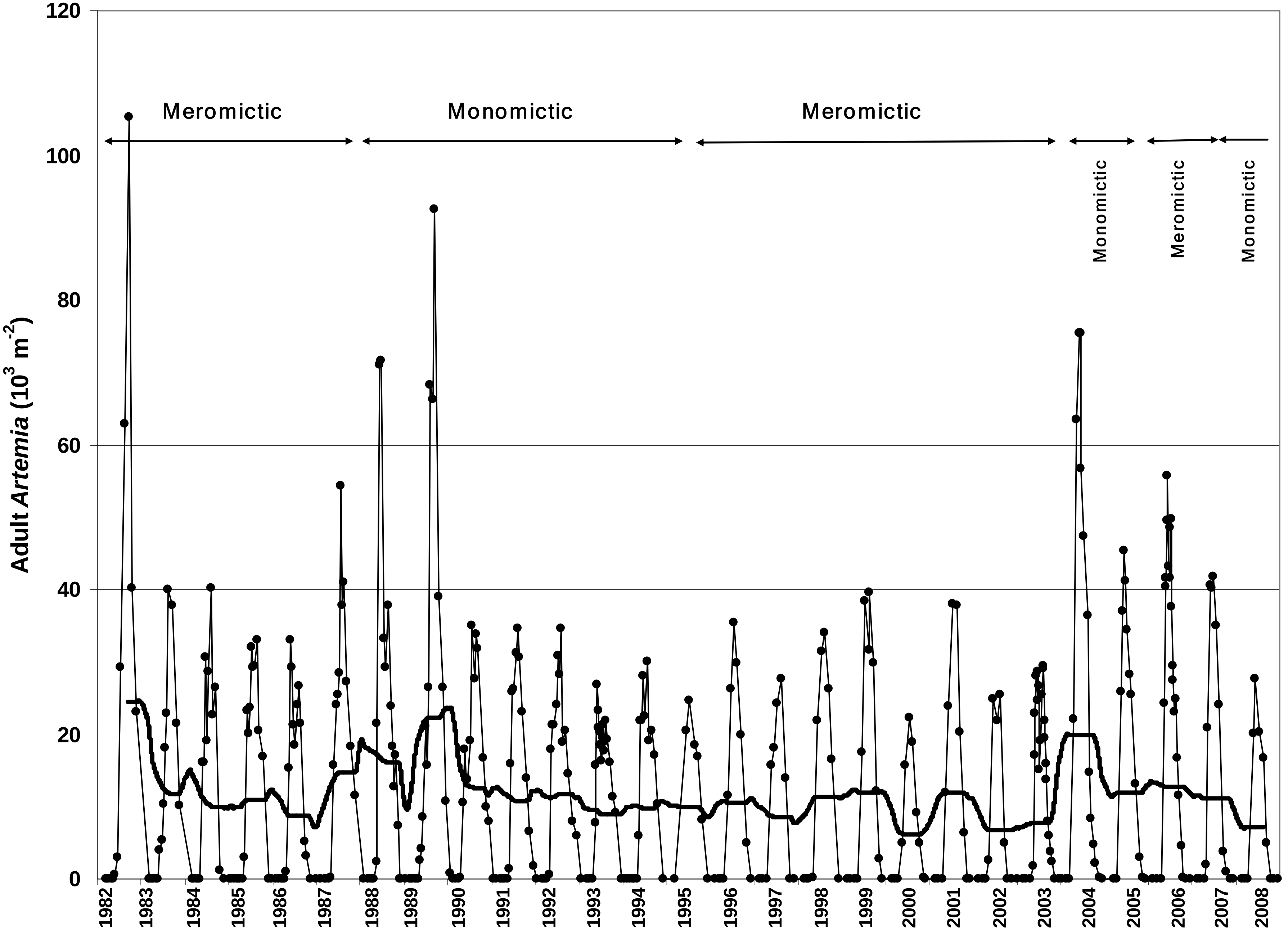

Meromictic
Monomictic
Meromictic
Monomictic
Meromictic
Monomictic
120
100
80
60
40
20
0
Chlorophyll a (µg l$^{-1}$)
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Mixed Layer Chlorophyll

Figure 31



Adult *Artemia* Abundance

Figure 32

# APPENDIX 2

# Ornithology

# MONO LAKE WATERFOWL POPULATION MONITORING

## 2008 Annual Report

LOS ANGELES DEPARTMENT OF WATER AND POWER
PREPARED BY DEBBIE HOUSE
WATERSHED RESOURCES SPECIALIST
BISHOP, CA 93514
April 2008

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## EXECUTIVE SUMMARY

Waterfowl populations were monitored in 2008 at Mono Lake, Bridgeport Reservoir, and Crowley Reservoir, in compliance with State Water Resources Control Board (SWRCB) Order 98-05. At Mono Lake, three summer ground surveys and six fall aerial surveys for waterfowl were conducted. In order to determine whether or not long-term trends observed at Mono Lake are mirrored at other Eastern Sierra water bodies, fall aerial surveys were also conducted at Bridgeport and Crowley Reservoirs.

The elevation of Mono Lake has slowly declined since the summer of 2007 from its most recent high point in 2006 after the above-normal runoff year of that year. Many of the brackish lagoons and fresh water ponds that formed along the south shore during the rise in elevation that occurred in 2006 have contracted to a point that they no longer provide suitable habitat for nesting or brooding waterfowl. Summer ground counts in 2008 indicate a decrease in the summer use of Mono Lake by waterfowl, as compared to the previous year. The number of broods detected along shoreline habitats at Mono Lake in 2008 (58) was notably less than the previous two years. The five species that used the Mono Lake shoreline habitats for brooding were Canada Goose, Gadwall, Mallard, Northern Pintail, and Ruddy Duck. The proportional use of lagoon habitats by summering dabbling ducks also decreased, likely a function of the reduction in availability and quality of this habitat type as compared to the last two years. Fewer ducks and broods were also encountered at the Restoration Ponds (DeChambeau Pond complex and the two County Ponds) as compared to 2007. A total of six broods of two species (Gadwall and Ruddy Duck) were observed at the Restoration Ponds in 2008.

In contrast to summer, use of Mono Lake by migratory ducks in the fall 2008 was greater than 2007. A total of nine waterfowl species were recorded at Mono Lake during fall aerial surveys. The total number of waterfowl detected in 2008 (38,289) was 62% higher than 2007. The peak one-day count of 13,914 was approximately 40% higher than occurred in 2007.

Twelve waterfowl species were recorded at Bridgeport Reservoir during the fall 2008 aerial surveys. A total of 17,184 waterfowl were detected during the six surveys at Bridgeport Reservoir. The peak number of waterfowl detected at Bridgeport Reservoir was 5,486 individuals, and occurred on October 1. The most abundant species was Northern Shoveler.

A total of 18 waterfowl species were recorded at Crowley Reservoir during the 2008 fall aerial surveys. The peak number detected at Crowley Reservoir was 6,035 which occurred during the October 15 survey. A total of 29,442 waterfowl were detected at Crowley Reservoir over the six fall season surveys. The most abundant species were Ruddy Duck, Northern Pintail and Mallard.

The data from the past six years indicates that brood production has been significantly positively correlated with the elevation of Mono Lake. The use of Mono Lake by waterfowl during fall migration has shown no direct relationship to lake level since regular waterfowl surveys were initiated in 1996. There has been a significant positive trend in the peak number of waterfowl, exclusive of Ruddy Ducks, since 1996.

## WATERFOWL MONITORING COMPLIANCE

This report fulfills the Mono Lake waterfowl population survey and study requirement set forth in compliance with the SWRCB No. 98-05. The waterfowl monitoring program consists of summer ground counts at Mono Lake, fall migration counts at Mono Lake, fall comparative counts at Bridgeport and Crowley Reservoirs, and photos of waterfowl habitats taken from the air. Three summer grounds counts and six fall aerial surveys were conducted at Mono Lake in 2008. Six comparative fall aerial counts were completed at Bridgeport and Crowley Reservoirs. Photos of shoreline habitats and the restoration ponds were taken from a helicopter on September 17, 2008.

# LIST OF TABLES

# LIST OF FIGURES

# 2008 Mono Lake Waterfowl Population Monitoring
Los Angeles Department of Water and Power
Prepared by Debbie House
Watershed Resources Specialist
Bishop, CA

## INTRODUCTION

In 1996, the Mono Basin Waterfowl Habitat Restoration Plan (Plan) was prepared by the Los Angeles Department of Water and Power (LADWP) for the SWRCB. This plan identified restoration objectives and potential projects in addition to land management efforts designed to mitigate for the loss of waterfowl habitat due to the lowered elevation of Mono Lake. The key components of the Plan are:

a) increasing the water surface elevation of Mono Lake to 6,392 feet,
b) rewatering Mill Creek,
c) rewatering specific distributaries in the Rush Creek bottomlands,
d) implementation of the DeChambeau Pond and County Pond Restoration Project,
e) development and implementation of a prescribed burn program, and
f) control of salt cedar in lake-fringing wetlands (LADWP 1996).

The item identified as being the restoration measure of highest importance and priority was to increase the water surface elevation of Mono Lake to 6,392 feet.

The SWRCB Order WR 98-05 directed LADWP to implement the above restoration measures in the Plan and conduct monitoring to assess the success of waterfowl habitat restoration efforts. Components of the waterfowl habitat monitoring plan include the monitoring of lake levels, lake limnology and secondary producers, the mapping of riparian and lake-fringing wetland habitats, and waterfowl population surveys. The purpose of the waterfowl population survey component of the Plan is to provide information to track changes in population levels of waterfowl and assess waterfowl use of the various wetland habitats.

This report describes and discusses monitoring efforts related to evaluating waterfowl population responses to increases in Mono Lake water surface elevations.  Survey data for the DeChambeau and County Restoration Ponds are also presented.

Summer ground surveys were conducted in order to determine the size of breeding and/or summering populations, species composition, spatial distribution and habitat use of waterfowl during the summer.  Fall aerial surveys were conducted to provide an index of waterfowl numbers using Mono Lake during fall migration, as well as provide information on species composition and spatial distribution.  Fall waterfowl surveys are also conducted at Bridgeport and Crowley Reservoirs in an effort to determine whether long-term trends observed at Mono Lake are mirrored at other Eastern Sierra water bodies or are specific to Mono Lake.

The monitoring of waterfowl populations in the Mono Basin is expected to continue until at least the year 2014, or until the targeted lake level (6,392 foot elevation) is reached and the lake cycles through a complete wet/dry cycle (LADWP 2000a).

All summer surveys were conducted by the author.  Fall surveys were conducted by the author with assistance from Mr. Bill Deane, LADWP Watershed Resources Specialist and Mr. Brian Tillemans, LADWP Environmental Affairs Officer.

## METHODS

### Summer Ground Surveys

Three ground-count surveys were conducted at Mono Lake at three-week intervals beginning in early June. These were conducted as either transect surveys, or by making observations from a stationary point. Three days were required to complete each ground survey of Mono Lake.

Locations surveyed were those identified in the Waterfowl Restoration Plan (LADWP 1996) as current or historic waterfowl concentration areas (Figure 1), namely: South Tufa (SOTU); South Shore Lagoons (SSLA); Sammann's Spring (SASP); Warm Springs (WASP); Wilson Creek (WICR); Mill Creek (MICR); DeChambeau Creek Delta (DECR); Rush Creek Delta (RUCR); Lee Vining Creek bottomlands and delta (LVCR); DeChambeau Ponds (DEPO); and County Ponds (COPO).

Transect surveys along the shoreline were conducted at South Tufa, South Shore Lagoons, Sammann's Spring, Warm Springs, DeChambeau Creek, Wilson Creek, and Mill Creek. Transect surveys were conducted by walking at an average rate of approximately 1.5 km/hr, depending on conditions, and recording waterfowl species as they were encountered. Because waterfowl are easily flushed, and females with broods are especially wary, the shoreline was frequently scanned well ahead of the observer in order to increase the probability of detecting broods.

Transect surveys were also conducted in lower Rush and Lee Vining Creeks, from the County Road to the deltas. Surveys along lower Rush Creek were conducted by walking along the southern bluff above the creek, and traversing the delta along existing sandbars. This route offered a good view of the creek while limiting wildlife disturbance and flushing of waterfowl ahead of the observer. In Lee Vining Creek, surveys of the creek channel were conducted by walking along the north bank of the main channel, which offered the best view of the channel. At the mouth of the creek, the main channel splits in two and forms two delta areas separated by a tall earthen berm-like formation. In order to obtain good views of both delta areas, it was necessary to cross the main channel and walk on top of this berm. After viewing both delta areas from the berm, the delta areas were also traversed. In both areas, birds were observed and recorded within 100 meters on either side of the deltas.

At the DeChambeau Pond complex, observations were taken from a single stationary point at each of the five ponds. Observation points that provided a full view of each pond were selected. At the County Ponds, observations were taken from a single location that allowed full viewing of both ponds simultaneously. A minimum of five minutes was spent at each observation point at the DeChambeau and County Ponds.

All summer ground surveys began within one hour of sunrise and were completed within approximately six hours. The order in which the various sites were visited was varied in order to minimize the effect of time-of-day on survey results. Total survey time was recorded for each area. The date and time of day for each survey during 2008 are provided in Appendix 1.

The following data was recorded for all waterfowl when an individual or group was first detected: time of the observation; habitat type the individual or group was using; and an activity code indicating how the bird; or birds were using the habitat. The activity codes used were resting, foraging, flying over, nesting, brooding, sleeping, swimming, and "other". The common name, scientific name, and four-letter code for each species mentioned in the document can be found in Appendix 2.

When a waterfowl brood was detected, the size of the brood was recorded, a GPS reading was taken (UTM, NAD 27, Zone 11, CONUS), and the location of each brood was marked on an aerial photograph while in the field. Each brood was also assigned to an age class based on its plumage and body size (Gollop and Marshall 1954). Since the summer surveys were conducted at three-week intervals, any brood assigned to Class I using the Gollop and Marshall age classification scheme (which includes subclasses Ia, Ib, and Ic), would be a brood that had hatched since the previous visit. Assigning an age class to broods allowed for the determination of the minimum number of "unique broods" using the Mono Lake wetland and shoreline habitats.

The habitat categories used generally follow the classification system found in the report entitled 1999 Mono Basin Vegetation and Habitat Mapping (LADWP 2000b). The habitat classification system defined in that report is being used for the mapping of lakeshore vegetation and the identification of changes in lake-fringing wetlands associated with changes in lake level. The specific habitat categories used in that mapping effort (and in this project) include: marsh, wet meadow, alkaline wet meadow, dry meadow/forb, riparian scrub, Great Basin scrub, riparian forest, freshwater stream, ria, freshwater pond, brackish lagoon, hypersaline lagoon, and unvegetated. Salinity measurements of ponds and lagoons were taken using an Extech EC400 Conductivity/TDS/Salinity probe in order to aid in the proper classification of fresh vs. brackish lagoons and ponds. Ponds with salinity less than 500 ppm were classified as fresh. Lagoons with vegetation present and salinity greater than 500 ppm were classified as brackish. Lagoons lacking vegetation and without freshwater inflow were generally classified as hypersaline. For reference, the definition of each of these habitat types is provided in Appendix 3. Representative photos of these habitats can be found in the report entitled Mono Lake Waterfowl Population Monitoring 2002 Annual Report (LADWP 2003).

Two additional habitat types: open-water near-shore (within 50 meters of shore), and open-water offshore (>50 meters offshore), were added to the existing classification system in order to more completely represent areas used by waterfowl. Although a ">50 meter" category was used at the time of data collection, these observations will not be included in the final calculations unless the presence of waterfowl in the open-water offshore zone was determined to be due to observer influence (e.g., the observer sees that a female duck is leading her brood offshore and is continuing to swim away from shore).

## FALL AERIAL SURVEYS

### Overview of Methodology

Aerial surveys were conducted in the fall at Mono Lake, Bridgeport Reservoir, and Crowley Reservoir using a small high-winged airplane. A total of six surveys were conducted at two-week intervals, with the first survey beginning during the first week of September, and the last occurring in the middle of November. A summary of the fall survey schedule has been provided as Appendix 4.

Each aerial survey began at Mono Lake at approximately 0900 hours Mono Lake was surveyed in approximately one and one-half hours. Bridgeport Reservoir was surveyed next, and Crowley Reservoir was surveyed last. All three surveys were completed in a single flight by 1200 hours on the day of the survey.

Observations were verbally recorded onto a handheld digital audio recorder and later transcribed by the observer.

A second observer was present on all six flights. At Mono Lake, the second observer sat on the same side of the plane as the primary observer during the perimeter flight. During the cross-lake transect counts, the second observer sat on the opposite side of the plane and censused Ruddy Ducks. At Bridgeport and Crowley, the second observer sat on the same side of the plane as the primary observer during the entire survey, and counted all waterfowl.

### Mono Lake Aerial Surveys

Aerial surveys of Mono Lake consisted of a perimeter flight of the shoreline and a set of fixed cross-lake transects. The shoreline was divided into 15 lakeshore segments (Figure 2) in order to document the spatial use patterns of fall migrant waterfowl. Coordinates forming the beginning of each segment were derived from the 2002 aerial photo of Mono Lake (2002 aerial image taken by I. K. Curtis, and processed by Air Photo, USA) and can be found in Appendix 5, along with the four-letter code for each lakeshore segment. The segment boundaries are the same as those used by Jehl (2002), except for minor adjustments made in order to provide the observer with obvious landmarks that are easily seen from the air.

Eight parallel cross-lake transects were conducted over the open water at Mono Lake. The eight transects are spaced at one-minute (1/60 of a degree, approximately one nautical mile) intervals and correspond to those used by Boyd and Jehl (1998) for the monitoring of Eared Grebes during fall migration. The latitudinal alignment of each transect is provided in Appendix 6.

Each of the eight transects is further divided into two to four sub-segments of approximately equal length (see Figure 2). The total length of each cross-lake transect was first determined from the 2002 aerial photo. These lengths were then sub-divided into the appropriate number of subsections to a total of twenty-five sub-segments, each approximately 2-km in length. This approach creates a grid-like sampling system that allows for the evaluation of the spatial distribution of Ruddy Ducks offshore. Since the survey aircraft's airspeed was carefully controlled, and the approximate length of each subsection was known, it was possible to use a stopwatch to determine the beginning and ending points of each subsection when over open water.

LADWP contracted with Black Mountain Air Service to conduct fixed-winged aerial counts. Black Mountain Air Service has obtained a low-altitude flight waiver from the Federal Aviation

Administration in order to conduct these flights. Aerial surveys were conducted in a Cessna 180 at a speed of approximately 130 kilometers per hour, and at a height of approximately 60 meters above ground. Perimeter surveys were conducted over water at approximately 250 meters from the shoreline. When conducting aerial surveys, the perimeter of the lake was flown first in a counterclockwise direction, starting in the Ranch Cove area. Cross-lake transects were flown immediately afterward, starting with the southernmost transect and working northwards.

In order to reduce the possibility of double-counting, only birds seen from or originating from the observer's side of the aircraft were recorded. Even though the flight path of the aircraft along the latitudinal transects effectively alternated the observer's hemisphere of observation in a North-South fashion due to the aircraft's heading on successive transects, the one-nautical-mile spacing between the transects worked in conjunction with the limited detection distance of the waterfowl (<< 0.5 nautical mile) to effectively prevent double-counting of birds on two adjacent transects.

### Bridgeport Reservoir Aerial Surveys

The shoreline of Bridgeport was divided into three segments (Figure 3). Appendix 5 contains the four-letter code for each lakeshore segment and the coordinates of the beginning of each section. Survey flights started at the dam at the north end of the reservoir and proceeded counterclockwise. The distance from shore, flight speed, and height above ground were the same as employed at Mono Lake. The reservoir was circumnavigated twice during each survey due to the small size of the reservoir and the presence of large concentrations of waterfowl. The second pass around the reservoir allowed for the confirmation of both the number of birds counted and the species composition.

### Crowley Reservoir Aerial Surveys

The shoreline of Crowley Reservoir was divided into seven segments (Figure 4). Coordinates forming the beginning of each segment were generated from the 2000 aerial photo of Crowley Reservoir (2000 aerial image taken by I. K. Curtis, and processed by Air Photo, USA) and can be found in Appendix 5, as well as the four-letter code used for each segment. Each survey began at the mouth of the Owens River (UPOW) and proceeded over water in a counterclockwise direction along the shoreline. The distance from shore, flight speed, and height above the water were the same as at Mono Lake during most of each flight. Temporary diversions of distance from shore or height above ground were made by the pilot as necessary to avoid direct or low flight over float-tubers or boats. The reservoir was circumnavigated twice during each survey, due to presence of large concentrations of waterfowl. The second pass allowed for the confirmation of both the number of birds counted and the species composition.

### Ground Verification Counts

Ground verification counts were conducted whenever flight conditions (e.g., lighting, background water color, etc.) did not allow the positive identification of a significant percentage of the waterfowl encountered, or to confirm the species or number of individuals present. During a ground validation count, the total number of waterfowl present in an area was recorded first, followed by a count of the number of individuals of each species present.

## Data Summary and Analysis

### *Summer Ground Count Data*

Total detections of each species were summed by lakeshore segment for each survey. Total detections were also summed over the entire summer survey period, and the percent of total detections per lakeshore segment was calculated. Total numbers of broods per species, survey and lakeshore segment were also summed.

Chi-square goodness-of-fit analysis was used to determine if individual waterfowl species used any of the various habitats in a disproportionate manner. This analysis was done for the most abundant summering species, provided that the behavior of at least 30 individuals had been recorded. All observations (e.g., foraging, resting, brooding, etc.) except those of flyovers were included in this analysis. The waterfowl species for which habitat use data were analyzed were Canada Goose, Gadwall, Mallard, and Ruddy Duck. For all significant goodness-of-fit tests, Bonferonni confidence intervals were calculated for each category, following Byers and Steinhorst (1984), to determine which specific habitats were used out of proportion with respect to the others.

### *Fall Counts – Data Summary and Analysis*

The total number of ducks of each species was summed by lakeshore segment and survey for each survey and waterbody. The spatial distribution of waterfowl at each body of water was determined by calculating the proportion of fall detections that occurred in each lakeshore segment or offshore area.

### *Trend Analysis*

One way repeated measures ANOVA was used to evaluate variations in the mean number of waterfowl summering at the lake since 2002. Simple linear regression analysis was used to evaluate the trend total summer waterfowl detections at Mono Lake since 2002. Simple linear regression was used to evaluate the trend in the number of broods and total fall detections as a function of lake elevation. Simple linear regression analysis was used to evaluate the trend in peak one-day waterfowl counts at Mono Lake since 1996. The analysis of peak one-day counts was done excluding Ruddy Duck numbers due to the difference in survey methods employed for this species from 1996 to 2001 versus 2002 to present. The regression equations were then tested using ANOVA to determine the significance of the regression, (i.e. "Is the slope significantly different from zero?"; Zar 1996).

## Photo Documentation

As required by the Order 98-05, photo documentation of lake-fringing waterfowl habitats was completed in 2008. Photos were taken from a helicopter at all bodies of water on September 17, 2008. In 2008, shoreline conditions were also documented using a helicopter-mounted, geo-referenced video camera. The photos are described under Data Summary below.

The photos of Mono Lake were geo-referenced using the 2005 satellite images of Mono Lake. The extent of the shoreline included in each digital photo taken from the helicopter was determined using the aerial photos. The coordinates for the shoreline area depicted in each photo were then generated from the 2005 satellite images, and are shown on each shoreline photo. The general shoreline area depicted in each photo is also indicated on an outline diagram of Mono Lake that has been provided along with the photos.

For Bridgeport Reservoir and Crowley Reservoir, the general shoreline area depicted in each photo is indicated on an outline diagram of the reservoirs.

## DATA SUMMARY

### 2008 Conditions

Mono Lake

The 2007-2008 water year in the Mono Basin was “Normal” with a predicted runoff of 86% of the 1941-1990 average runoff. At 6382.2 feet, the lake level was 1.3 feet lower in early summer (June) than it had been during the same time in 2007. After a 0.1 foot increase in July, the level of Mono Lake gradually decreased through the remainder of the summer and fall survey period. During 2008, the level of Mono Lake was between 0.8 feet and 1.3 feet lower than during the same period in 2007, and up to 2.4 feet lower than fall of 2006. The decrease in lake elevation resulted in qualitative differences in lake-fringing habitats for waterfowl during the 2008 monitoring period, some of which are discussed below.

*South Shoreline Areas (South Tufa, South Shore Lagoons, and Sammann’s Spring)*

The drop in lake elevation resulted in an increase in exposed shoreline and a decrease in the size and extent of lake-fringing lagoons. The South Tufa area supported few lake-fringing lagoons in 2008, as lagoons at the east end of the area that had formed in 2006 were small and hypersaline in summer, and non-existent by fall. The area near the South Tufa visitor area supported mudflats due to spring outflow, while the shoreline area east of Navy Beach was dominated by exposed dry playa (Figure 5).

The numerous isolated lagoons along the length of the South Shore Lagoons area continued to contract as the lake level has dropped over the last two years. The areas that continued to attract waterfowl include the lagoon at the west end of the South Shore Lagoons area (Figure 6), the fresh water pond approximately 1.2 km farther east (Figure 7), and the Goose Springs outflow area (Figure 8). In the Goose Springs outflow area there was an extensive brackish lagoon present in summer and through fall. Large numbers of Northern Shovelers congregated in the vicinity of Goose Springs outflow area during fall migration in 2008. Sand Flat Spring outflow continued to be isolated from the lake, and received only limited use by waterfowl (Figure 9).

In the Sammann’s Spring area, the area west of the large tufa formations supported extensive mudflats where spring outflow areas spread over exposed lakeshore (Figure 10). Small freshwater ponds persisted up gradient of littoral bars. East of the tufa formations, brackish lagoons continued to persist, although they became increasingly isolated from the shoreline as the season progressed (Figure 11).

### *Warm Springs and Northeast Shore*

The decrease in lake elevation resulted in further decreases in the size and extent of lagoons in the Warm Springs area. The “north lagoon”, which is supported by the outflow of Pebble and Twin Warm Springs, continued to retract in size. The “north lagoon” continued to be the primary area of waterfowl use on the east side of the lake (Figure 12). The south lagoon, supported by outflow from Warm Springs Marsh Channel, Warm B, and Bug Warm springs was essentially dry in 2008. Since 2002, this south lagoon has been much smaller than the northern lagoon and less attractive to ducks and other waterbirds. In 2008 the Northeast Shore area was dominated by barren playa and did not support lagoons (Figure 13).

### *Bridgeport Creek to Black Point*

This area of the shoreline typically consists of several small lagoons with alkali meadow and or small areas of wet alkali meadow adjacent. Small isolated lagoons continued to persist in the Bridgeport Creek to Black Point area (Figures 14 and 15) although the lagoons have also contracted as the lake elevation has dropped. These lagoons typically attract small numbers of waterfowl in the fall.

### *Northwest Shore (DeChambeau Creek, Mill Creek, and Wilson Creek)*

Qualitative changes were also noted along the northwest shore of the lake, from DeChambeau Creek area to the Wilson Creek area. In the Wilson Creek area (Figure 16), the area east of Wilson Creek bay had dried considerably as compared to the previous two years, and supported little waterfowl use. At Mill Creek, the fresh water pond perched behind a gravel bar along the shoreline continued to persist, although it appeared slightly reduced in size as compared to last year (Figure 17). In the DeChambeau Creek area (Figure 18), there was an increase in the amount of exposed shoreline as compared to 2006. Due to the numerous springs in the area, the exposed shoreline creates extensive mudflats with fresh water outflow areas. Very small fresh water ponds existed near shore where spring outflow was retained behind small sandbars.

### *Lee Vining Creek*

No significant changes were noted at Lee Vining Creek in 2008 as compared to the previous year (Figure 19).

### *Rush Creek*

Creek flows at the delta were deflected into the southern part of the bay by a sandbar (Figure 20). The decline in lake elevation exposed more sandbars in the delta.

### *Restoration Ponds*

Both County Ponds were flooded in 2008. All of the DeChambeau Ponds were flooded except DeChambeau Pond five, which remained dry all year.

## Bridgeport Reservoir

Conditions at Bridgeport Reservoir appeared similar to those encountered in 2007. Figure 21 shows an overview of the reservoir as viewed from the south end looking north toward the dam. The south end of the reservoir, which includes the area referred to as “West Bay”, and part of the “East Arm” area, receives fresh water inflows from Buckeye and Robinson Creeks and the East Walker River, creating extensive mudflat areas adjacent to these creek inflow areas. The northern arm of the reservoir includes primarily sandy beaches bordered by upland vegetation. The water level was fairly low as in September as the reservoir held 5,980 acre-feet. As a point of reference, the storage capacity of Bridgeport Reservoir is 42,600 acre-feet.

## Crowley Reservoir

Conditions at Crowley Reservoir appeared similar to those encountered in 2007. Figures 22-24 shows the variation in habitat conditions at Crowley in 2008. The McGee Bay area (Figure 22) supported vast mudflat areas immediately adjacent to wet meadow habitats. The Upper Owens River delta area (Figure 23) includes large areas of exposed mudflats and reservoir bottom adjacent to the mouth of the Upper Owens River. The Chalk Cliffs area lacks fresh water inflow areas and wetland habitats, and is dominated by sandy beaches adjacent to steep, sagebrush-covered slopes (Figure 24). In early September, Crowley Reservoir held 91,390 acre-feet (Figures 22-24). As a point of reference, the storage capacity of Crowley Reservoir is 183,465 acre-feet.

Fall Aerial Survey Weather Conditions

Relatively mild conditions prevailed throughout the fall survey period. Weak cold fronts passed through the area, but temperatures remained mild.

## Summer Ground Counts

### Waterfowl

The number of waterfowl detected in each shoreline area during each survey can be found in Table 1. Table 2 summarizes the summer survey data in terms of the number of detections of each species at each location, the total waterfowl detections at each location, and the percent of total detections for each shoreline area. A total of 9 species of waterfowl were detected during summer surveys. The total number of waterfowl using the shoreline (exclusive of dependent young) detected during summer surveys ranged from 162 to 330 individuals in 2008. The highest proportion of detections was in the South Shore Lagoons area, followed by Wilson, DeChambeau and Mill Creeks. The fewest number of waterfowl were detected in Lee Vining Creek and South Tufa area.

The waterfowl species that brooded in the lake-fringing wetlands and creeks at Mono Lake in 2008 were Canada Goose, Gadwall, Mallard, Northern Pintail and Ruddy Duck. The number of broods of each species in each shoreline area can be found in Table 3. Figure 25 shows the locations of all of the broods detected in 2008. The number of broods detected in lake-fringing habitats (58) was notably less than that seen in 2007. The South Shore Lagoon area was the most heavily used area for brooding as 21 broods were detected in this area. The second most heavily used areas for brooding in 2008 were the DeChambeau Creek and Wilson Creek areas. Gadwall was still the most abundant breeding species accounting for 41 of the 58 broods.

### Waterfowl Habitat Use

All four waterfowl species analyzed showed a disproportionate use of the various shoreline habitats in 2008. Table 4 provides the tabulated habitat use data, the chi-squared goodness-of-fit results, and the Bonferonni test results for Canada Goose, Gadwall, Mallard, and Ruddy Duck. Figure 26 is a bar graph depicting the proportional use of habitats by each of these species. Canada Geese were observed using unvegetated areas, ria, and meadow habitats. Gadwall used brackish lagoons, ria and freshwater ponds significantly more than other habitats. Mallard were also seen primarily in brackish lagoons, ria and freshwater ponds and used brackish lagoons proportionally more than other habitats. Ruddy Ducks were observed using only freshwater ponds and open water areas on Mono Lake and used these two habitats in proportion to one another.

### Fall Aerial Surveys

Mono Lake

A total of nine waterfowl species and 38,289 individuals were recorded at Mono Lake during fall aerial surveys (Table 5). The peak number of waterfowl detected at Mono Lake on any single count was 13,914 and occurred on the October 1 survey (Table 5, Figure 27). Compared to the 2007 counts, the total number of detections was 62% higher than 2007 (38,289 vs 23,618 in 2007) while the one-day peak count in 2008 was approximately 40% greater than that observed in 2007 (13,914 vs. 9,926 in 2007). The peak number of Northern Shoveler (11,567) occurred on October 1, and the peak number of Ruddy Ducks (2,102) occurred on October 15.

In terms of total detections, Ruddy Ducks and Northern Shovelers were the dominant species during fall migration with Ruddy Ducks accounting for 23.8% (9,185) of all detections, and Northern Shovelers accounting for 71% (27,400) of all detections. Use of Mono Lake by Northern Shoveler was significantly higher in 2008 than 2007 as evidenced by a comparison of the total detections. The total number of Northern Shoveler detected at Mono Lake in 2008 was 1.6 times that in 2007.

Tables 6 through 11 provide the results of each of the six fall surveys in terms of the number of individuals of each species detected in each lakeshore segment. The main areas of waterfowl use during fall 2008 were South Shore Lagoons, Wilson Creek, and Mill Creek (Figure 28).

Bridgeport Reservoir

A total of 12 waterfowl species and 17,184 individuals were recorded at Bridgeport Reservoir during the 2008 fall aerial surveys (Table 12). The peak number of waterfowl detected on any single count at Bridgeport Reservoir was 5,486 individuals, which occurred on October 1 (Table 12, Figure 27). Tables 13-18 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment. The most heavily used area of the lake was the West Bay, accounting for 90% of all detections (Figure 29).

Crowley Reservoir

A total of 18 waterfowl species and 29,442 individuals were detected at Crowley Reservoir during the 2008 fall aerial surveys (Table 19). The peak number of waterfowl detected on any single count at Crowley Reservoir was 6,035 individuals and occurred on October 15 (Table 19, Figure 27). The most abundant species, in terms of total detections, were Ruddy Ducks, Northern Pintail and Mallard. Tables 20-25 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment. The primary areas of waterfowl use were McGee Bay and Layton Springs (close to the inflow of the Upper Owens River) (Figure 30).

Mono Lake Restoration Ponds

A total of five species and 51 waterfowl were detected at the Restoration Ponds during summer surveys (Table 26). The most abundant species were Gadwall and Ruddy Duck. A total of six broods were seen, including five Gadwall and one Ruddy Duck brood (Table 27).

A total of three waterfowl species and 276 individuals were detected at the DeChambeau and County Pond complexes during fall surveys (Table 28).

### Analysis of Trend – Mono Lake

The mean number of waterfowl summering at Mono Lake (250) (Figure 31) was significantly lower than last year ($p = 0.005$, $df = 6$, $F = 4.478$), however there is no established trend in the summering population $R^2 = 0.0179$ $p > 0.05$). Figure 32 shows how the distribution of broods has varied as a function of lake elevation since 2002. From 2002-2005, the lake elevation was declining, and during this period, the northwest shore and ponds supported the bulk of the broods, and the proportion of broods detected in this region increased through this period. From 2006-2007 the lake experienced an increase in elevation, and the proportion of broods in the northwest shore area and ponds decreased while the proportion increased along the south shore. As the lake declined further in 2008, breeding waterfowl have again shifted back towards the northwest shore area. Based on survey data from the last six years, the number of broods at Mono Lake has been positively correlated with lake elevation ($r = 0.86$, $p<0.05$) (Figure 33).

The total number of fall detections has varied independently of lake elevation based on waterfowl counts conducted since 1996 ($r = - 0.456$, $p > 0.05$), Figure 34. Figure 35 illustrates the trend in the peak number of waterfowl detected at Mono Lake from 1996-2008. There has been a significant positive trend in the peak number of waterfowl, exclusive of Ruddy Ducks ($r^2 = 0.339$, $p = 0.037$, $F = 5.633$, $df = 12$).

## RESPONSE OF WATERFOWL POPULATIONS TO RESTORATION EFFORTS

The data from the past six years indicates that brood production has been significantly positively correlated with the level of Mono Lake. Between 2002 and 2004, Mono Lake experienced a drop in elevation followed by a subsequent rise in elevation from 2004 to 2006, and then a decline from 2007 to 2008. The main effect of increases in elevation appears to be that lake-fringing lagoons along the south shore increase noticeably in number and extent. Based on field observations, these lagoons enlarged due either to an increase in the groundwater table or as a result of increased spring flow. The response of the breeding population of waterfowl at Mono Lake to these changes was a shift in distribution. From 2002-2005, the lake elevation was declining, and during this period, the northwest shore and ponds supported the bulk of the broods, and the proportion of broods detected in this region increased through this period. From 2006-2007 the lake experienced an increase in elevation, and the proportion of broods in the northwest shore area and ponds decreased while the proportion increased along the south shore. As the lake declined further in 2008, breeding waterfowl have again shifted back towards the northwest shore area. While the increase in lake elevation seen in 2006-2007 was accompanied by an increase in the diversity of breeding waterfowl and broods, the decrease in lake elevation in 2008 was subsequently accompanied by a decrease in the number of broods as well as a decrease in the diversity of breeding waterfowl as compared to 2007.

Summering and breeding waterfowl have shown a great deal of annual variability with regard to their proportional use of the various lake-fringing habitats. The dabbling ducks have generally been encountered in brackish lagoons, fresh water ponds, using “ria” or areas of freshwater outflow at the mouths of creeks and spring outflow onto the lake, and in unvegetated areas along the shoreline. Canada Geese have typically been encountered in unvegetated areas or meadow habitats. The habitats in which waterfowl at Mono Lake are encountered are ephemeral or highly variable in nature and extent on a yearly basis. The availability of the more ephemeral habitat types on a yearly or seasonal basis are being documented through field observations of conditions during the summer and annual photography of shoreline areas in the fall, but the habitat conditions that may explain waterfowl use and the spatial distribution of waterfowl at Mono Lake are not easily quantified during vegetation mapping efforts being conducted every five years.

The use of Mono Lake by waterfowl during fall migration has shown no direct relationship to lake level. There has been a significant positive trend in the peak number of waterfowl during fall migration (exclusive of Ruddy Ducks) for the time period of 1996-2008. The relationship between trends in waterfowl use and lake limnology will be presented in a future document.

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**Table 1. 2008 Summer Ground Count Data**

| Survey 1 | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| Canada Goose | 14 | | | | | | | | 1 | 15 |
| Cinnamon Teal | 3 | | | | 4 | | | 4 | | 11 |
| Gadwall | 44 | 4 | 68 | 9 | 53 | 5 | 28 | 14 | 16 | 241 |
| Green-winged Teal | | | | 5 | | | 5 | | | 10 |
| Mallard | | 5 | | 9 | 5 | | 19 | 6 | 2 | 46 |
| Northern Pintail | | | | | 2 | | | 2 | | 4 |
| Red-breasted Merganser | | | | | | | 1 | | | 1 |
| Ruddy Duck | | | 2 | | | | | | | 2 |
| **Total Waterfowl by Area** | **61** | **9** | **70** | **23** | **64** | **5** | **53** | **26** | **19** | **330** |

| Survey 2 | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| Canada Goose | 14 | | | | 2 | | | | | 16 |
| Cinnamon Teal | 1 | | | | 3 | | 3 | | | 7 |
| Gadwall | 12 | | 2 | 4 | | 11 | 20 | 4 | 31 | 84 |
| Green-winged Teal | 2 | | | | | | 1 | | | 3 |
| Mallard | 1 | 6 | 2 | | 12 | | 54 | | 2 | 77 |
| Northern Pintail | | | | | 2 | | | | | 2 |
| Red-breasted Merganser | | | | | | | 1 | | | 1 |
| Redhead | | | 12 | | | | | | | 12 |
| Ruddy Duck | | | 3 | | | | 1 | | 2 | 6 |
| **Total Waterfowl by Area** | **30** | **6** | **19** | **4** | **19** | **11** | **80** | **4** | **35** | **208** |

| Survey 3 | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| Canada Goose | 5 | | | | | | 8 | | 11 | 24 |
| Gadwall | 9 | | 1 | 38 | | | 14 | | 28 | 90 |
| Mallard | | | | 1 | 3 | | 26 | | 1 | 31 |
| Northern Pintail | | | | | | | 1 | | | 1 |
| Red-breasted Merganser | | | | 1 | | | 1 | | | 2 |
| Ruddy Duck | | | | | | | 1 | | 13 | 14 |
| **Total Waterfowl by Area** | **14** | **0** | **1** | **40** | **3** | **0** | **51** | **0** | **53** | **162** |

**Table 2. Summary of 2008 Summer Ground Counts.** Table shows the total detections of each species in each shoreline area, total waterfowl detections by area, and the percent of total detections by area.

| **Total Detections by Species** | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| Canada Goose | 33 |  |  |  | 2 |  | 8 |  | 12 | 55 |
| Cinnamon Teal | 4 |  |  |  | 7 |  | 3 | 4 |  | 18 |
| Gadwall | 65 | 4 | 71 | 51 | 53 | 16 | 62 | 18 | 75 | 415 |
| Green-winged Teal | 2 |  |  | 5 |  |  | 6 |  |  | 13 |
| Mallard | 1 | 11 | 2 | 10 | 20 |  | 99 | 6 | 5 | 154 |
| Northern Pintail |  |  |  |  | 4 |  | 1 | 2 |  | 7 |
| Red-breasted Merganser |  |  |  | 1 |  |  | 3 |  |  | 4 |
| Redhead |  |  | 12 |  |  |  |  |  |  | 12 |
| Ruddy Duck |  |  | 5 |  |  |  | 2 |  | 15 | 22 |
| **Total Waterfowl by Area** | **105** | **15** | **90** | **67** | **86** | **16** | **184** | **30** | **107** | **700** |

| **Total Waterfowl Detections** | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR |
|---|---|---|---|---|---|---|---|---|---|
| Number of Waterfowl | 105 | 15 | 90 | 67 | 86 | 16 | 184 | 30 | 107 |
| % of Detections | 15.0% | 2.1% | 12.9% | 9.6% | 12.3% | 2.3% | 26.3% | 4.3% | 15.3% |

**Table 3. 2008 Brood Data.** Table shows the number of broods by species per visit in shoreline survey area.

| | Shoreline Segment | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total Broods** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Survey 1** | Canada Goose | 6 | | | | | | | | | **6** |
| | Gadwall | | | | | | | | | | **0** |
| | Mallard | | | | | | | | | 1 | **1** |
| | Northern Pintail | | | | | | | | | | **0** |
| | Ruddy Duck | | | | | | | | | | **0** |
| | Total broods | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | **7** |
| | | | | | | | | | | | |
| **Survey 2** | Canada Goose | 1 | | | | 1 | | | | | **2** |
| | Gadwall | | | 1 | 3 | | | 4 | | 5 | **13** |
| | Mallard | | | | | | | 3 | | | **3** |
| | Northern Pintail | | | | | | | | | | **0** |
| | Ruddy Duck | | | | | | | 1 | | | **1** |
| | Total broods | 1 | 0 | 1 | 3 | 1 | 0 | 8 | 0 | 5 | **19** |
| | | | | | | | | | | | |
| **Survey 3** | Canada Goose | | | | | | | 1 | | | **1** |
| | Gadwall | 7 | | 1 | 4 | | | 9 | | 7 | **28** |
| | Mallard | | | | | | | 1 | | | **1** |
| | Northern Pintail | | | | | | | 1 | | | **1** |
| | Ruddy Duck | | | | | | | 1 | | | **1** |
| | Total broods | 7 | 0 | 1 | 4 | 0 | 0 | 13 | 0 | 7 | **32** |
| | | | | | | | | | | | |
| **Total** | Shoreline Segment | DECR | LVCR | MICR | RUCR | SASP | SOTU | SSLA | WASP | WICR | **Total Broods** |
| | Canada Goose | 7 | | | | 1 | | 1 | | | **9** |
| | Gadwall | 7 | | 2 | 7 | | | 13 | | 12 | **41** |
| | Mallard | | | | | | | 4 | | 1 | **5** |
| | Northern Pintail | | | | | | | 1 | | | **1** |
| | Ruddy Duck | | | | | | | 2 | | | **2** |
| | Total broods per area | 14 | 0 | 2 | 7 | 1 | 0 | 21 | 0 | 13 | 58 |

**Table 4. Chi Square Goodness-of-Fit Results for Waterfowl Habitat Use Data.** Grayed categories were excluded from analysis. The results of the Bonferroni Test are indicated in the “Sign” (= significance) column. NS indicates that there was no significant difference between expected and observed use of a habitat type at the $p < 0.05$ level.

| | Canada Goose | | | | Gadwall | | | | Mallard | | | | Ruddy Duck | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Habitat** | Obs | Exp | $\chi^2$ | Sign | Obs | Exp | $\chi^2$ | Sign | Obs | Exp | $\chi^2$ | Sign | Obs | Exp | $\chi^2$ | Sign |
| Marsh | | | | | 5 | 48.7 | 39.2 | - | | | | | | | | |
| Wet Meadow | 13 | 12.5 | 0.02 | NS | 1 | 48.7 | 46.7 | - | | | | | | | | |
| Alkali Wet Meadow | 2 | 12.5 | 8.82 | - | | | | | | | | | | | | |
| Riparian Scrub | | | | | | | | | 1 | 23.1 | 21.1 | - | | | | |
| Freshwater Stream | | | | | 6 | 48.7 | 37.4 | - | 1 | 23.1 | 21.1 | - | | | | |
| Ria | 20 | 12.5 | 4.5 | NS | 140 | 48.7 | 171.1 | + | 26 | 23.1 | 0.4 | NS | | | | |
| Fresh Water Pond | | | | | 94 | 48.7 | 42.1 | + | 23 | 23.1 | 0.0 | NS | 14 | 15.5 | 0.1 | - |
| Brackish Lagoon | | | | | 85 | 48.7 | 27.1 | + | 105 | 23.1 | 290.3 | + | | | | |
| Hypersaline Lagoon | | | | | 11 | 48.7 | 29.1 | - | 4 | 23.1 | 15.8 | - | | | | |
| Unvegetated | 15 | 12.5 | 0.5 | NS | 45 | 48.7 | 0.3 | NS | 2 | 23.1 | 19.3 | - | | | | |
| Open Water | | | | | 51 | 48.7 | 0.1 | NS | | | | | 17 | 15.5 | 0.1 | - |
| **Total** | 50 | | 13.84 | | 438 | | 393.1 | | 162 | | 368.0 | | 31 | | 0.3 | |

**Table 5. Summary of 2008 Mono Lake Fall Aerial Survey Counts**

| **Species** | 4-Sep | 18-Sep | 1-Oct | 15-Oct | 29-Oct | 17-Nov | **Total Detections** | **% Total** |
|---|---|---|---|---|---|---|---|---|
| Canada Goose |  | 10 | 12 | 37 | 144 | 124 | 327 | 0.85 |
| Gadwall | 66 | 23 | 17 | 18 |  |  | 124 | 0.37 |
| Greater White-fronted Goose |  |  |  |  |  | 1 | 1 | 0.00 |
| Green-winged Teal | 88 | 61 | 28 | 106 | 76 | 10 | 369 | 0.99 |
| Mallard | 152 | 17 | 129 | 3 | 70 | 117 | 488 | 1.27 |
| Northern Pintail |  |  |  | 8 |  |  | 8 | 0.02 |
| Northern Shoveler | 7282 | 8121 | 11567 | 274 | 126 | 30 | 27400 | 71.05 |
| Ruddy Duck | 1980 | 1224 | 2050 | 2102 | 1289 | 540 | 9185 | 23.82 |
| Snow Goose |  |  |  |  |  | 6 | 6 | 0.02 |
| *Anas* spp. | 82 | 54 | 111 | 71 | 43 | 20 | 381 | 1.62 |
| **Total Waterfowl** | 9650 | 9510 | 13914 | 2619 | 1748 | 848 | 38289 |  |

## Table 6.  Mono Lake - Fall Aerial Survey, September 4, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shoreline Total** | **Offshore Total** | **Lakewide Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Gadwall | 20 | | 18 | | 18 | | | | | | | | 6 | 4 | | 66 | | 66 |
| Green-winged Teal | 4 | | 80 | | 4 | | | | | | | | | | | 88 | | 88 |
| Mallard | 17 | | | 20 | | | | | | 80 | 12 | 15 | | 8 | | 152 | | 152 |
| Northern Shoveler | | | 2212 | | | | | 5 | | 5000 | 30 | 25 | | | | 7272 | 10 | 7282 |
| Ruddy Duck | | | | | | 39 | | | | | | | | | 2 | 41 | 1939 | 1980 |
| *Anas* spp. | 4 | | | | | | | | | | 78 | | | | | 82 | | 82 |
| **Total Waterfowl** | **45** | **0** | **2310** | **20** | **22** | **39** | **0** | **5** | **0** | **5080** | **120** | **40** | **6** | **12** | **2** | **7701** | **1949** | **9650** |

## Table 7.  Mono Lake - Fall Aerial Survey, September 18, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shoreline Total** | **Offshore Total** | **Lakewide Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Canada Goose | | | | | | | | 10 | | | | | | | | 10 | | 10 |
| Gadwall | 8 | | | | | | | 8 | | | | | | | | 16 | 7 | 23 |
| Green-winged Teal | | | | | 8 | | | | | 40 | | | | 10 | | 58 | 3 | 61 |
| Mallard | | | 10 | | | | | 7 | | | | | | | | 17 | | 17 |
| Northern Shoveler | | | 7000 | 290 | | 11 | | 5 | | 750 | 60 | | | 5 | | 8121 | | 8121 |
| Ruddy Duck | | 5 | | | | 49 | 120 | | | | 500 | 12 | 14 | | 40 | 740 | 484 | 1224 |
| *Anas* spp. | 7 | | | 25 | 2 | | | | | | | | | 20 | | 54 | | 54 |
| **Total Waterfowl** | **15** | **5** | **7010** | **315** | **10** | **60** | **120** | **30** | **0** | **790** | **560** | **12** | **14** | **35** | **40** | **9016** | **494** | **9510** |

## Table 8. Mono Lake - Fall Aerial Survey, October 1, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shoreline Total** | **Offshore Total** | **Lakewide Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Canada Goose | | | | 12 | | | | | | | | | | | | 12 | | 12 |
| Gadwall | | | 6 | | 10 | | | | | | | | | | 1 | 17 | | 17 |
| Green-winged Teal | 20 | | | | | | | | | | | 8 | | | | 28 | | 28 |
| Mallard | 6 | | | 32 | 15 | | 14 | 2 | | | 60 | | | | | 129 | | 129 |
| Northern Shoveler | | | 1700 | 52 | | | | 64 | | 4900 | 4640 | 97 | 89 | 25 | | 11567 | | 11567 |
| Ruddy Duck | 35 | 8 | 85 | 32 | | 180 | 20 | 7 | | | 62 | 112 | 134 | 34 | 224 | 933 | 1117 | 2050 |
| *Anas* spp. | 49 | | 30 | | 12 | | | | | | | 10 | | 10 | | 111 | | 111 |
| **Total Waterfowl** | **110** | **8** | **1821** | **128** | **37** | **180** | **34** | **73** | **0** | **4900** | **4762** | **227** | **223** | **69** | **225** | **12797** | **1117** | **13914** |

## Table 9. Mono Lake - Fall Aerial Survey, October 15, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shoreline Total** | **Offshore Total** | **Lakewide Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Canada Goose | | | | 13 | | | | 15 | | 3 | | 6 | | | | 37 | | 37 |
| Gadwall | | | 5 | 2 | 5 | | | | 5 | | | | 1 | | | 18 | | 18 |
| Green-winged Teal | | | | 29 | | | | 12 | | | | 65 | | | | 106 | | 106 |
| Mallard | | | | | | | | 2 | | | 1 | | | | | 3 | | 3 |
| Northern Pintail | | | | | | | | 8 | | | | | | | | 8 | | 8 |
| Northern Shoveler | | | 40 | 120 | 20 | | | 23 | | 17 | | 51 | 3 | | | 274 | | 274 |
| Ruddy Duck | 92 | 20 | | | | 11 | | 10 | 6 | 3 | 12 | 82 | 185 | 28 | 76 | 525 | 1577 | 2102 |
| *Anas* spp. | | | 25 | 10 | 10 | | | | | 6 | | 20 | | | | 71 | | 71 |
| **Total Waterfowl** | **92** | **20** | **70** | **174** | **35** | **11** | **0** | **70** | **11** | **29** | **13** | **224** | **189** | **28** | **76** | **1042** | **1577** | **2619** |

## Table 10. Mono Lake - Fall Aerial Survey, October 29, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shoreline Total** | **Offshore Total** | **Lakewide Total I** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Canada Goose | | | 37 | 75 | | | | 18 | | | | 14 | | | | 144 | | 144 |
| Green-winged Teal | | | | 70 | 4 | | | 2 | | | | | | | | 76 | | 76 |
| Mallard | | | 8 | 41 | 5 | | | 4 | | | | | | 12 | | 70 | | 70 |
| Northern Shoveler | | | | | | | | 8 | 8 | 4 | | 106 | | | | 126 | | 126 |
| Ruddy Duck | 80 | 61 | 5 | 30 | | 4 | | 11 | 9 | | 5 | 12 | 110 | 73 | 72 | 472 | 817 | 1289 |
| *Anas* spp. | | | 3 | 15 | 5 | | | | | | | 20 | | | | 43 | | 43 |
| **Total Waterfowl** | **80** | **61** | **53** | **231** | **14** | **4** | **0** | **43** | **17** | **4** | **5** | **152** | **110** | **85** | **72** | **931** | **817** | **1748** |

## Table 11. Mono Lake - Fall Aerial Survey, November 17, 2008

| **Waterfowl Count** | Lakeshore segment | | | | | | | | | | | | | | | **Shore-line Total** | **Off-shore Total** | **Lake-wide Total** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | RUCR | SOTU | SSLA | SASP | WASP | NESH | BRCR | DEEM | BLPO | WICR | MICR | DECR | WESH | LVCR | RACO | | | |
| Canada Goose | | | | 120 | 4 | | | | | | | | | | | 124 | | **124** |
| Greater White-fronted Goose | | | | 1 | | | | | | | | | | | | 1 | | **1** |
| Green-winged Teal | | | | 10 | | | | | | | | | | | | 10 | | **10** |
| Mallard | | | | 105 | 3 | | | 6 | | | | | | 3 | | 117 | | **117** |
| Northern Shoveler | | | | 10 | | | | | | | | 20 | | | | 30 | | **30** |
| Ruddy Duck | 51 | 6 | 3 | | | | | 3 | 26 | | 3 | 6 | 67 | 5 | 26 | 196 | 344 | **540** |
| Snow goose | | | | | | | | | | | | | | | | | 6 | **6** |
| *Anas* spp. | | | | 20 | | | | | | | | | | | | 20 | | **20** |
| **Total Waterfowl** | **51** | **6** | **3** | **266** | **7** | **0** | **0** | **9** | **26** | **0** | **3** | **26** | **67** | **8** | **26** | **498** | **350** | **848** |

## Table 12. Summary of 2008 Fall Aerial Survey Counts - Bridgeport Reservoir

| **Species** | 4-Sep | 18-Sep | 1-Oct | 15-Oct | 29-Oct | 17-Nov | **Total Detections** | **% Total** |
|---|---|---|---|---|---|---|---|---|
| Bufflehead | 1 | | | | 24 | 38 | 63 | 0.37 |
| Canada Goose | 120 | 48 | | 65 | | 235 | 468 | 2.72 |
| Common Merganser | 10 | | 40 | 28 | 2 | | 80 | 0.47 |
| Gadwall | 696 | 269 | 169 | 8 | 3 | | 1145 | 6.66 |
| Green-winged Teal | 112 | 400 | 260 | 453 | 200 | 65 | 1490 | 8.67 |
| Lesser Scaup | | | | | 4 | 102 | 106 | 0.62 |
| Mallard | 79 | 220 | 794 | 156 | | 71 | 1320 | 7.68 |
| Northern Pintail | | 550 | 121 | 362 | 505 | 40 | 1578 | 9.18 |
| Northern Shoveler | 552 | 1100 | 2900 | 791 | 220 | 8 | 5571 | 32.42 |
| Redhead | | | | | 1 | | 1 | 0.01 |
| Ring-necked Duck | | | | | 13 | 2 | 15 | 0.09 |
| Ruddy Duck | 110 | 1100 | 150 | 16 | 108 | 34 | 1518 | 8.83 |
| *Anas* spp. | 955 | 1020 | 1052 | 500 | 202 | 100 | 3829 | 22.28 |
| **Total Waterfowl** | **2635** | **4707** | **5486** | **2379** | **1282** | **695** | **17184** | |

## Table 13. Bridgeport Reservoir Fall Survey, September 4, 2008

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Bufflehead | 1 | | | 1 |
| Canada Goose | | 120 | | 120 |
| Common Merganser | 10 | | | 10 |
| Gadwall | 17 | 515 | 164 | 696 |
| Green-winged Teal | | 100 | 12 | 112 |
| Mallard | | 45 | 34 | 79 |
| Northern Shoveler | 2 | 460 | 90 | 552 |
| Ruddy Duck | | 110 | | 110 |
| *Anas* spp. | | 955 | | 955 |
| **Total Waterfowl** | **30** | **2305** | **300** | **2635** |

## Table 14. Bridgeport Reservoir Fall Aerial Survey, September 18, 2008

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Canada Goose | | 48 | | 48 |
| Gadwall | 49 | 200 | 20 | 269 |
| Green-winged Teal | | 400 | | 400 |
| Mallard | | 200 | 20 | 220 |
| Northern Pintail | | 550 | | 550 |
| Northern Shoveler | | 1100 | | 1100 |
| Ruddy Duck | | 1100 | | 1100 |
| *Anas* spp. | | 500 | 520 | 1020 |
| **Total Waterfowl** | **49** | **4098** | **560** | **4707** |

## Table 15. Bridgeport Reservoir Fall Aerial Survey , October 1, 2008

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Common Merganser | 40 | | | 40 |
| Gadwall | 13 | 150 | 6 | 169 |
| Green-winged Teal | | 250 | 10 | 260 |
| Mallard | | 400 | 394 | 794 |
| Northern Pintail | | 100 | 21 | 121 |
| Northern Shoveler | | 2900 | | 2900 |
| Ruddy Duck | | 150 | | 150 |
| *Anas* spp. | | 1000 | 52 | 1052 |
| **Total Waterfowl** | **53** | **4950** | **483** | **5486** |

**Table 16. Bridgeport Reservoir Fall Aerial Survey, October 15, 2008**

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Canada Goose | | 65 | | 65 |
| Common Merganser | 28 | | | 28 |
| Gadwall | 5 | | 3 | 8 |
| Green-winged Teal | | 450 | 3 | 453 |
| Mallard | 1 | 100 | 55 | 156 |
| Northern Pintail | | 360 | 2 | 362 |
| Northern Shoveler | 14 | 770 | 7 | 791 |
| Ruddy Duck | 6 | 10 | | 16 |
| *Anas* spp. | | 460 | 40 | 500 |
| **Total Waterfowl** | **54** | **2215** | **110** | **2379** |

**Table 17. Bridgeport Reservoir Fall Aerial Survey, October 29, 2008**

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Bufflehead | 14 | 10 | | 24 |
| Common Merganser | 2 | | | 2 |
| Gadwall | 3 | | | 3 |
| Green-winged Teal | | 200 | | 200 |
| Lesser Scaup | 1 | | 3 | 4 |
| Northern Pintail | | 500 | 5 | 505 |
| Northern Shoveler | | 220 | | 220 |
| Redhead | 1 | | | 1 |
| Ring-necked Duck | 3 | 10 | | 13 |
| Ruddy Duck | 3 | 100 | 5 | 108 |
| *Anas* spp. | | 180 | 22 | 202 |
| **Total Waterfowl** | **27** | **1220** | **35** | **1282** |

**Table 18. Bridgeport Reservoir Fall Aerial Survey, November 17, 2008**

| **Species** | Lakeshore segment | | | **Total** |
|---|---|---|---|---|
| | NOAR | WEBA | EASH | |
| Bufflehead | | 30 | 8 | 38 |
| Canada Goose | | 235 | | 235 |
| Green-winged Teal | | 60 | 5 | 65 |
| Lesser Scaup | | 102 | | 102 |
| Mallard | | 65 | 6 | 71 |
| Northern Pintail | | 20 | 20 | 40 |
| Northern Shoveler | | 8 | | 8 |
| Ring-necked Duck | | 2 | | 2 |
| Ruddy Duck | | 32 | 2 | 34 |
| *Anas* spp. | | 100 | | 100 |
| **Total Waterfowl** | **0** | **654** | **41** | **695** |

## Table 19. Summary of 2008 Fall Aerial Survey Counts - Crowley Reservoir

| **Species** | 4-Sep | 18-Sep | 1-Oct | 15-Oct | 29-Oct | 17-Nov | **Total Detections** | **% Total** |
|---|---|---|---|---|---|---|---|---|
| American Wigeon |  | 14 |  |  |  |  | 14 | 0.05 |
| Blue-winged Teal |  | 2 |  |  |  |  | 2 | 0.01 |
| Bufflehead |  |  | 2 | 2 | 124 | 105 | 233 | 0.79 |
| Canada Goose | 132 | 50 | 145 | 24 | 50 | 40 | 441 | 1.50 |
| Canvasback |  |  |  |  |  | 10 | 10 | 0.03 |
| Cinnamon Teal | 24 |  |  |  |  |  | 24 | 0.08 |
| Common Merganser |  |  |  | 1 | 4 |  | 5 | 0.02 |
| Gadwall | 147 | 92 | 85 | 136 | 14 | 67 | 541 | 1.84 |
| Greater White-fronted Goose |  | 1 |  |  |  |  | 1 | 0.00 |
| Green-winged Teal | 917 | 70 | 108 | 818 | 332 | 31 | 2276 | 7.73 |
| Lesser Scaup |  |  |  |  |  | 12 | 12 | 0.04 |
| Mallard | 246 | 117 | 150 | 1004 | 569 | 553 | 2639 | 8.96 |
| Northern Pintail |  | 1030 | 587 | 1239 | 445 | 225 | 3526 | 11.98 |
| Northern Shoveler | 765 | 355 | 220 | 317 | 33 |  | 1690 | 5.74 |
| Redhead | 20 |  |  | 48 |  |  | 68 | 0.23 |
| Ring-necked Duck |  |  |  |  | 10 |  | 10 | 0.03 |
| Ruddy Duck | 616 | 101 | 3666 | 1685 | 2962 | 3645 | 12675 | 43.05 |
| Tundra Swan |  |  |  |  | 1 | 2 | 3 | 0.01 |
| *Anas* spp. | 462 | 2197 | 673 | 761 | 1003 | 176 | 5272 | 17.91 |
| **Total Waterfowl** | **3329** | **4029** | **5636** | **6035** | **5547** | 4866 | 29442 |  |

## Table 20. Crowley Reservoir Fall Aerial Survey, September 4, 2008

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| Canada Goose | | | | 25 | 15 | 2 | 90 | 132 |
| Cinnamon Teal | | | | | 20 | | 4 | 24 |
| Gadwall | | 8 | 60 | | 60 | 9 | 10 | 147 |
| Green-winged Teal | 30 | | 15 | 802 | 10 | | 60 | 917 |
| Mallard | | 1 | | 180 | 25 | | 40 | 246 |
| Northern Shoveler | 148 | | | 500 | | | 117 | 765 |
| Redhead | | | | 20 | | | | 20 |
| Ruddy Duck | | | 16 | 600 | | | | 616 |
| *Anas* spp. | 462 | | | | | | | 462 |
| **Total Waterfowl** | **640** | **9** | **91** | **2127** | **130** | **11** | **321** | **3329** |

## Table 21. Crowley Reservoir Fall Aerial Survey, September 18, 2008

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| American Wigeon | 12 | | | | | | 2 | 14 |
| Blue-winged Teal | | | | 2 | | | | 2 |
| Canada Goose | | | | 50 | | | | 50 |
| Gadwall | 50 | | 2 | 10 | | | 30 | 92 |
| Greater White-fronted Goose | | | | 1 | | | | 1 |
| Green-winged Teal | | | | | | | 70 | 70 |
| Mallard | 2 | | | 110 | | | 5 | 117 |
| Northern Pintail | 20 | | | 1000 | 7 | | 3 | 1030 |
| Northern Shoveler | 40 | | | 250 | | | 65 | 355 |
| Ruddy Duck | 85 | | 16 | | | | | 101 |
| *Anas* spp. | 300 | 7 | | 1450 | 120 | 45 | 275 | 2197 |
| **Total Waterfowl** | **509** | **7** | **18** | **2873** | **127** | **45** | **450** | **4029** |

## Table 22. Crowley Reservoir Fall Aerial Survey, October 1, 2008

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| Bufflehead | | | | 2 | | | | 2 |
| Canada Goose | 35 | | | 21 | 42 | | 47 | 145 |
| Gadwall | | | 1 | | 2 | 2 | 80 | 85 |
| Green-winged Teal | | | 8 | 100 | | | | 108 |
| Mallard | 2 | | | | 80 | 28 | 40 | 150 |
| Northern Pintail | 20 | | 15 | 400 | 32 | | 120 | 587 |
| Northern Shoveler | | | | 160 | | | 60 | 220 |
| Ruddy Duck | 300 | | 66 | 3300 | | | | 3666 |
| *Anas* spp. | | 3 | | 340 | 30 | | 300 | 673 |
| **Total Waterfowl** | **357** | **3** | **90** | **4323** | **186** | **30** | **647** | **5636** |

**Table 23. Crowley Reservoir Fall Aerial Survey, October 15, 2008**

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| Bufflehead | | | | | 2 | | | 2 |
| Canada Goose | 6 | | | | | | 18 | 24 |
| Common Merganser | | | | | | | 1 | 1 |
| Gadwall | | 8 | 2 | 80 | 5 | 21 | 20 | 136 |
| Green-winged Teal | | 8 | | 760 | 28 | 2 | 20 | 818 |
| Mallard | | 10 | | 800 | 48 | 36 | 110 | 1004 |
| Northern Pintail | | 1 | 25 | 860 | | | 353 | 1239 |
| Northern Shoveler | | | | 305 | | | 12 | 317 |
| Redhead | | | | 48 | | | | 48 |
| Ruddy Duck | 138 | 3 | 64 | 500 | 70 | 420 | 490 | 1685 |
| *Anas* spp. | | 1 | | 700 | 20 | | 40 | 761 |
| **Total Waterfowl** | **144** | **31** | **91** | **4053** | **173** | **479** | **1064** | **6035** |

**Table 24. Crowley Reservoir Fall Aerial Survey, October 29, 2008**

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| Bufflehead | 23 | 30 | 10 | 25 | 10 | 14 | 12 | 124 |
| Canada Goose | | | | 50 | | | | 50 |
| Common Merganser | | | | | 4 | | | 4 |
| Gadwall | 5 | | 6 | | | 3 | | 14 |
| Green-winged Teal | 40 | | 6 | 206 | | | 80 | 332 |
| Mallard | | 13 | 22 | 130 | 34 | 350 | 20 | 569 |
| Northern Pintail | | 1 | 4 | 440 | | | | 445 |
| Northern Shoveler | | 5 | | 28 | | | | 33 |
| Ring-necked Duck | | | | 10 | | | | 10 |
| Ruddy Duck | 350 | 20 | 35 | 2000 | 22 | 190 | 345 | 2962 |
| Tundra Swan | | | | 1 | | | | 1 |
| *Anas* spp. | 20 | | 8 | 350 | 55 | 280 | 290 | 1003 |
| **Total Waterfowl** | **438** | **69** | **91** | **3240** | **125** | **837** | **747** | **5547** |

**Table 25. Crowley Reservoir Fall Aerial Survey, November 17, 2008**

| **Species** | Lakeshore segment | | | | | | | **Total** |
|---|---|---|---|---|---|---|---|---|
| | UPOW | SAPO | NOLA | MCBA | HIBA | CHCL | LASP | |
| Bufflehead | 18 | | 35 | 8 | 29 | 2 | 13 | 105 |
| Canada Goose | | | | | | | 40 | 40 |
| Canvasback | | 10 | | | | | | 10 |
| Gadwall | | | 5 | 3 | 5 | 50 | 4 | 67 |
| Green-winged Teal | 5 | | | 12 | 12 | | 2 | 31 |
| Lesser Scaup | | 12 | | | | | | 12 |
| Mallard | 20 | | | 16 | 45 | 447 | 25 | 553 |
| Northern Pintail | 110 | | | 12 | 3 | 60 | 40 | 225 |
| Ruddy Duck | 52 | 943 | | 1781 | 3 | 183 | 683 | 3645 |
| Tundra Swan | | | | | | | 2 | 2 |
| *Anas* spp. | 150 | | | 6 | | 20 | | 176 |
| **Total Waterfowl** | **355** | **965** | **40** | **1838** | **97** | **762** | **809** | **4866** |

## Table 26. Mono Lake Restoration Ponds - Total Summer Detection

| **Waterfowl Totals** | COPO | DEPO | **Total** |
|---|---|---|---|
| Cinnamon Teal | 3 | 6 | 9 |
| Gadwall | 12 | 13 | 25 |
| Green-winged Teal | 2 |  | 2 |
| Mallard | 3 |  | 3 |
| Ruddy Duck | 3 | 9 | 12 |
| **Total Waterfowl by Area** | **23** | **28** | **51** |

## Table 27. Mono Lake Restoration Ponds - Total Waterfowl Broods

| **Species** | COPO | DEPO |
|---|---|---|
| Gadwall | 3 | 2 |
| Ruddy Duck |  | 1 |
| **Total broods** | **3** | **3** |

## Table 28. Mono Lake Restoration Ponds - 2008 Fall Survey Counts

| **DeChambeau Ponds** | 4-Sep | 18-Sep | 1-Oct | 15-Oct | 29-Oct | 17-Nov | **Total Fall Detections** |
|---|---|---|---|---|---|---|---|
| Green-winged Teal | 8 |  |  |  |  |  | 8 |
| Mallard |  |  |  | 2 |  |  | 2 |
| *Anas* spp. | 12 | 46 | 31 | 26 | 87 | 6 | 208 |
| **Total Waterfowl** | 20 | 46 | 31 | 28 | 87 | 6 | 218 |

| **County Ponds** | 4-Sep | 18-Sep | 1-Oct | 15-Oct | 29-Oct | 17-Nov | **Total Fall Detections** |
|---|---|---|---|---|---|---|---|
| Gadwall | 12 | 4 |  |  | 3 |  | 19 |
| Green-winged Teal |  | 3 |  |  |  |  | 3 |
| *Anas* spp. |  |  | 6 | 10 | 20 |  | 36 |
| **Total Waterfowl** | 12 | 7 | 6 | 10 | 23 | 0 | 58 |

Figure 1. Summer Ground Count Survey Areas

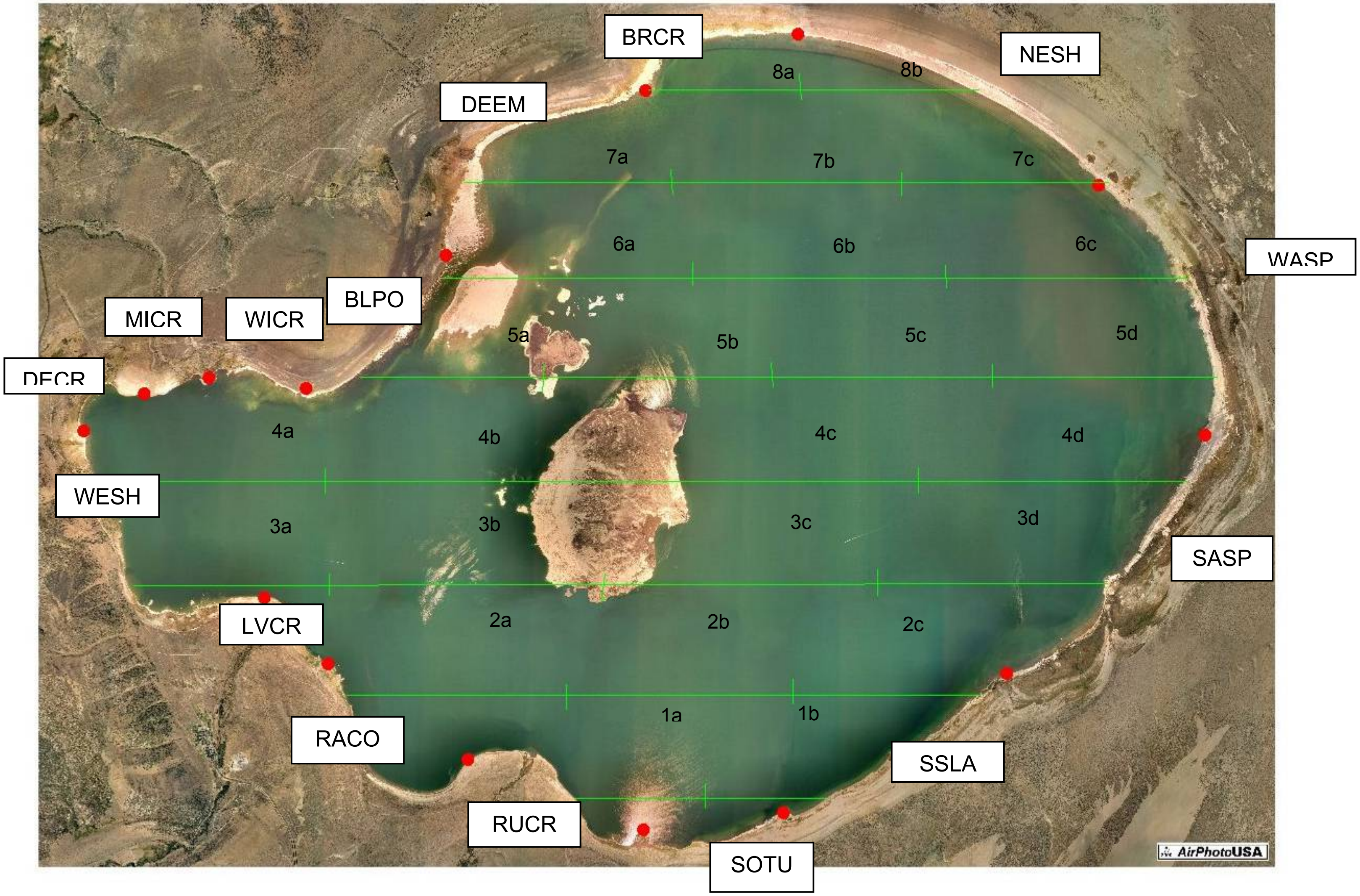


**Figure 2. Lakeshore Segment, Segment Boundaries, and Cross-Lake Transects for Fall Aerial Surveys of Mono Lake**

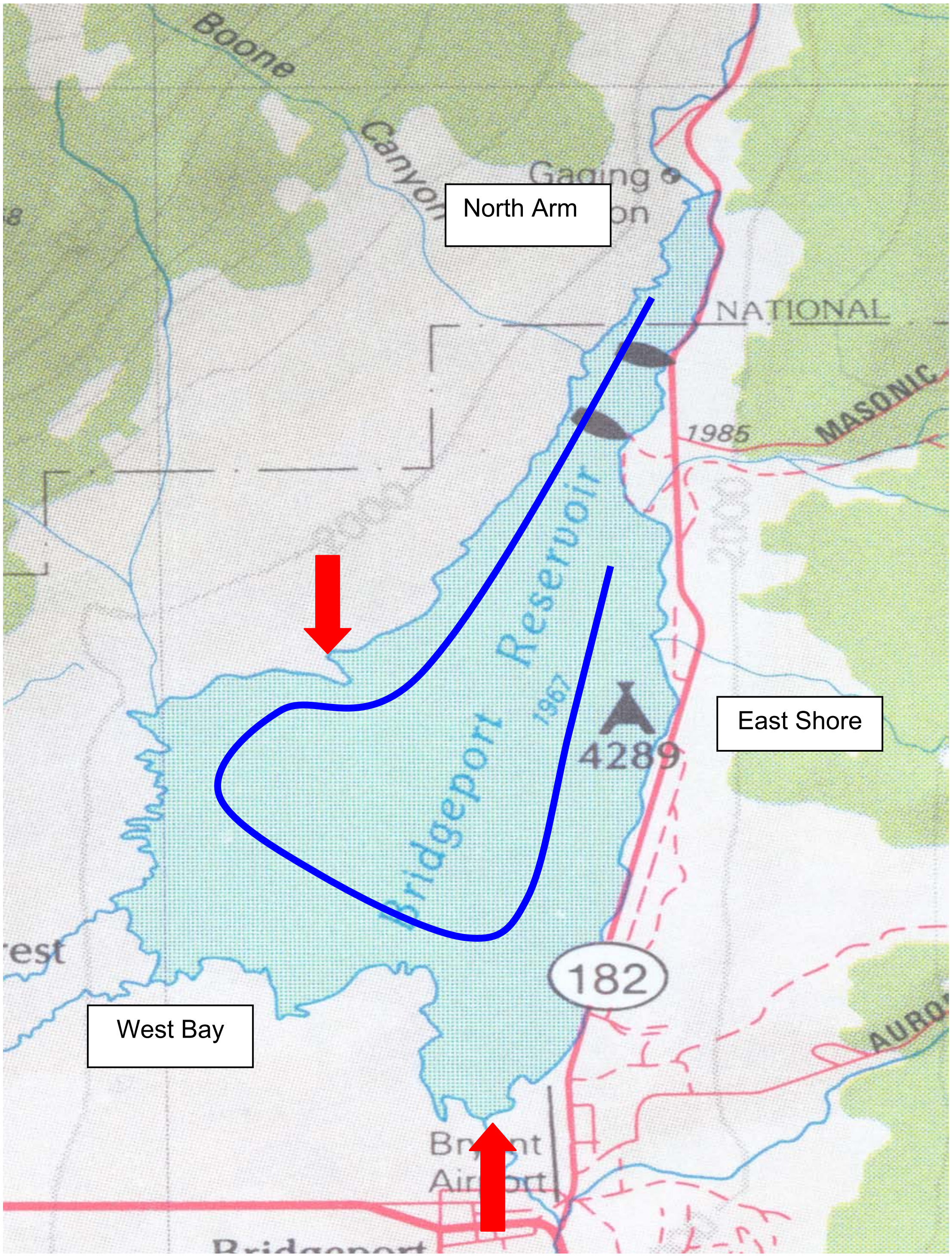


**Figure 3. Lakeshore Segments and Segment Boundaries Used for Fall Aerial Surveys of Bridgeport Reservoir**

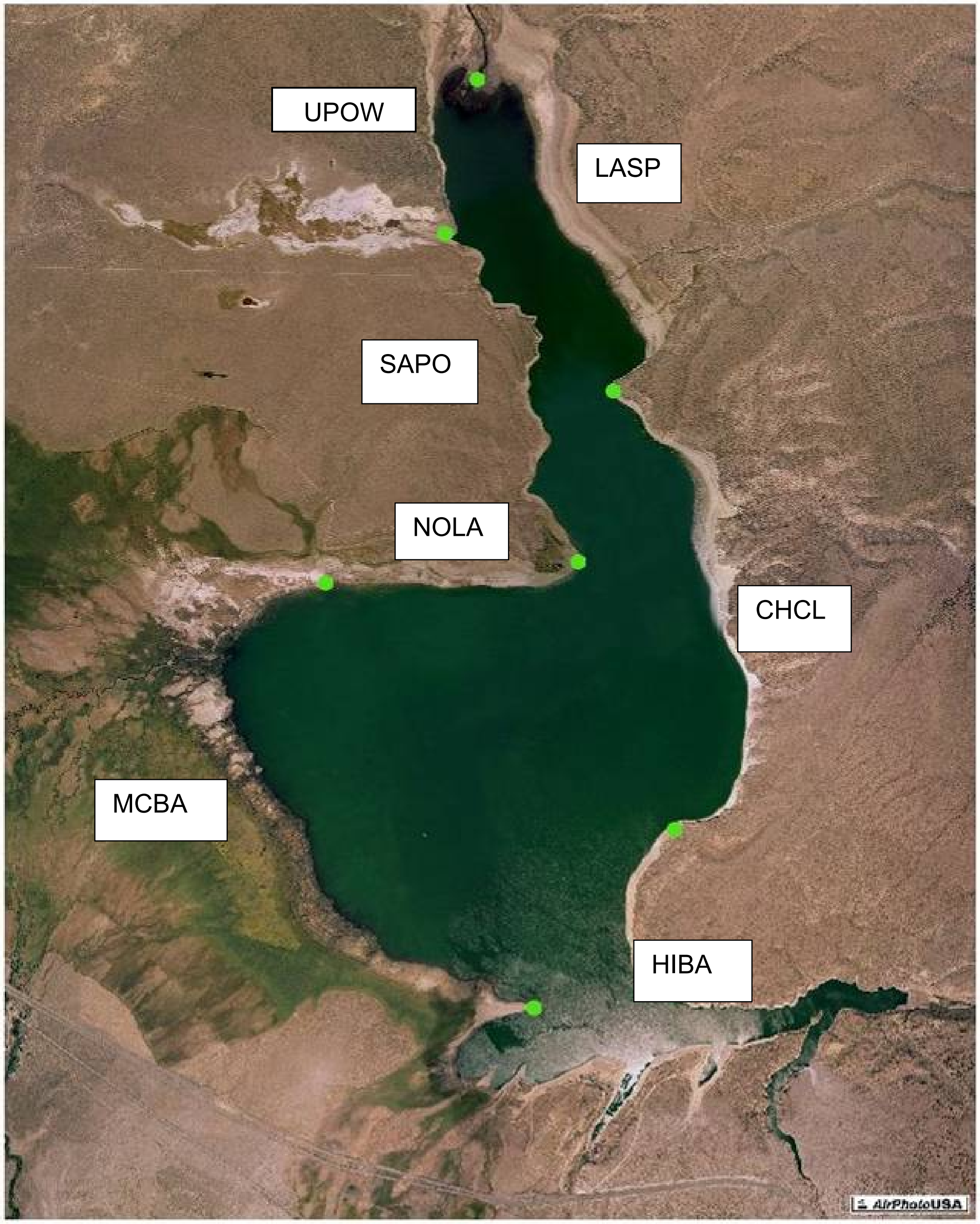


Figure 4. Lakeshore Segments and Segment Boundaries Used for Aerial Surveys of Crowley Reservoir

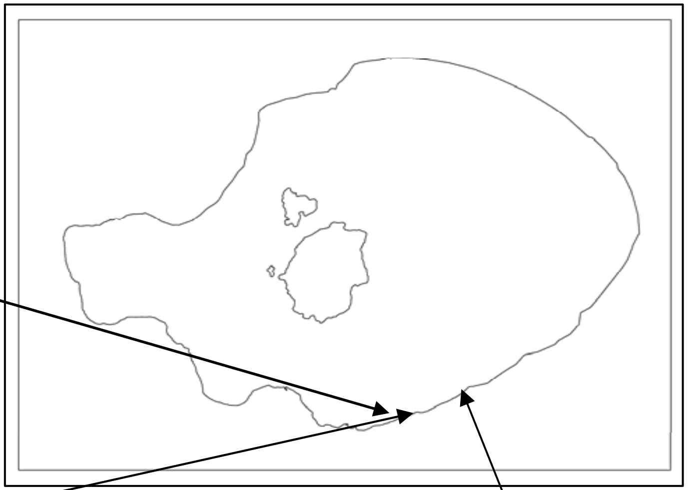


Figure 5. South Tufa Shoreline Area – East of Navy Beach

Figure 6. South Shore Lagoons Area – West End

Figure 7. South Shore Lagoons Area - Freshwater Pond

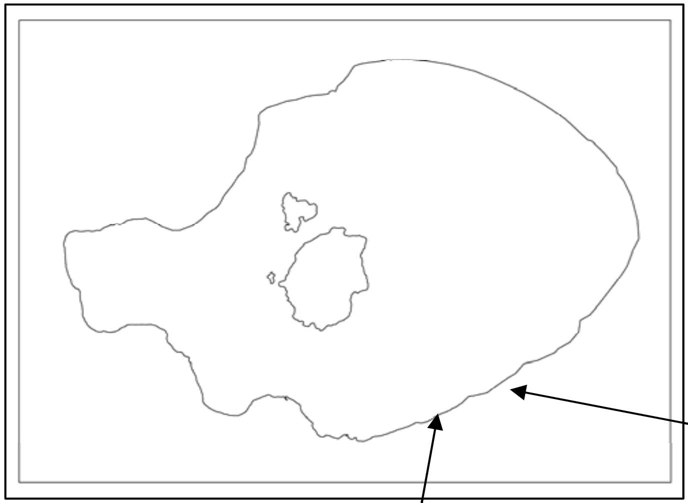
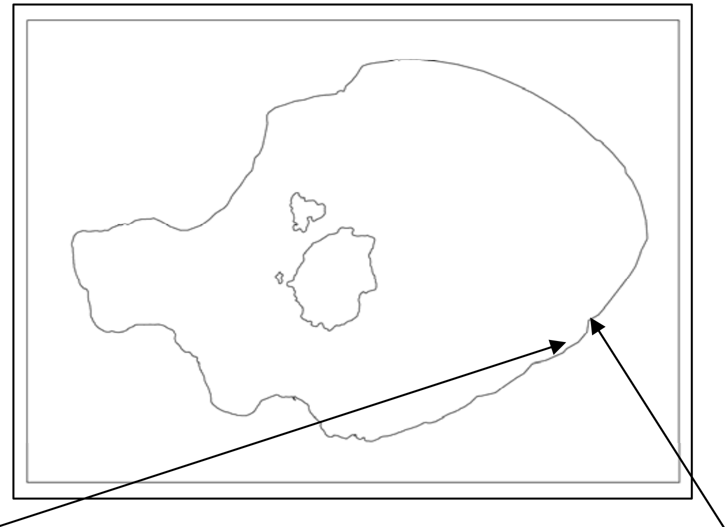


Figure 8.  South Shore Lagoons – Goose Springs

Figure 9.  South Shore Lagoons Sand Flat Spring



Sammann's Spring
**329876E, 4204777N**
**328621E, 4204205N**

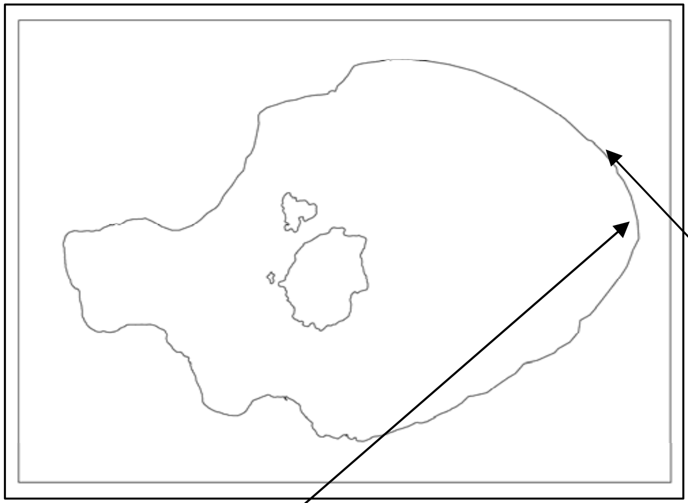
09/17/2008

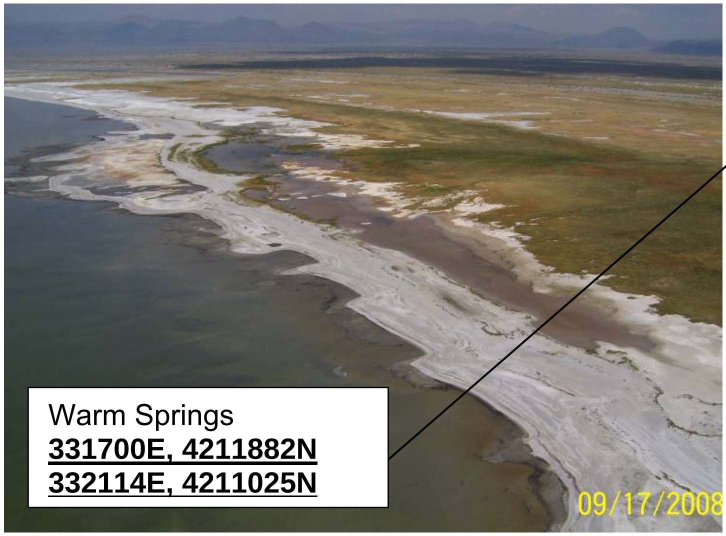
**Figure 10. Sammann's Spring Area, West of Sammann's Spring Tufa**

Sammann's Spring
**330982E, 4206294N**
**330446E, 4205832N**

09/17/2008

**Figure 11. Sammann's Spring Area, east of Sammann's Spring Tufa**





Warm Springs
**<u>331700E, 4211882N</u>**
**<u>332114E, 4211025N</u>**

09/17/2008

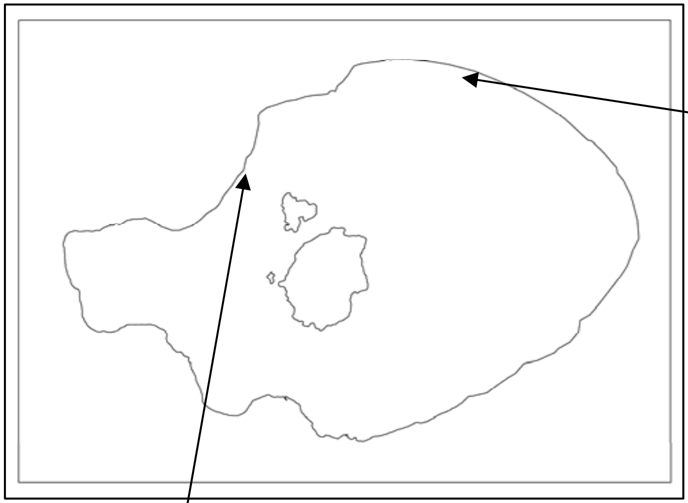
**Figure 12. Warm Springs Shoreline Area**

.

Northeast Shore
**<u>325368E, 4215970N</u>**
**<u>330056E, 4213481N</u>**

09/17/2008

**Figure 13. Northeast Shore Area**T



Bridgeport Creek
**322383E, 4215605N**
**324109E, 4215830N**

09/17/2008

Figure 14.  Bridgeport Creek Shoreline Area

Black Point
**315710E, 4209254N**
**317446E, 4210300N**

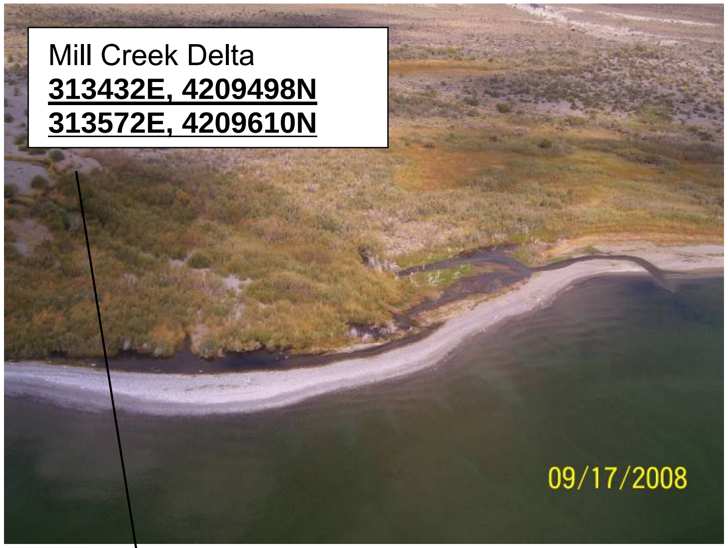
09/17/2008

Figure 15.  Black Point Shoreline Area


Wilson Creek Delta
**313986E, 4209679N**
**314440E, 4209700N**

09/17/2008

**Figure 16. Wilson Creek Area**


Mill Creek Delta
**313432E, 4209498N**
**313572E, 4209610N**

09/17/2008

**Figure 17. Mill Creek Delta**


DeChambeau Creek
**311559E, 4209123N**
**311766E, 4209343N**

09/17/2008

**Figure 18. DeChambeau Creek Shoreline Area**

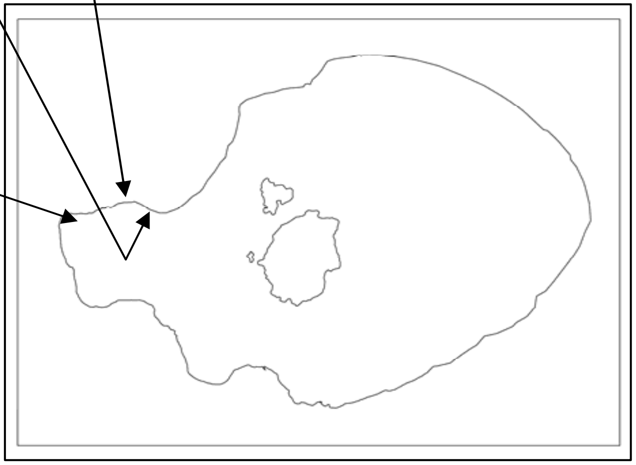
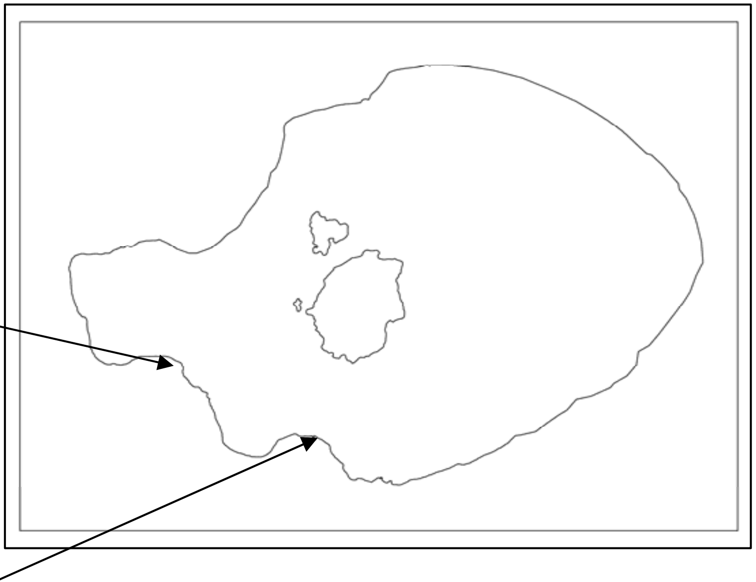


Figure 19.  Lee Vining Creek Delta



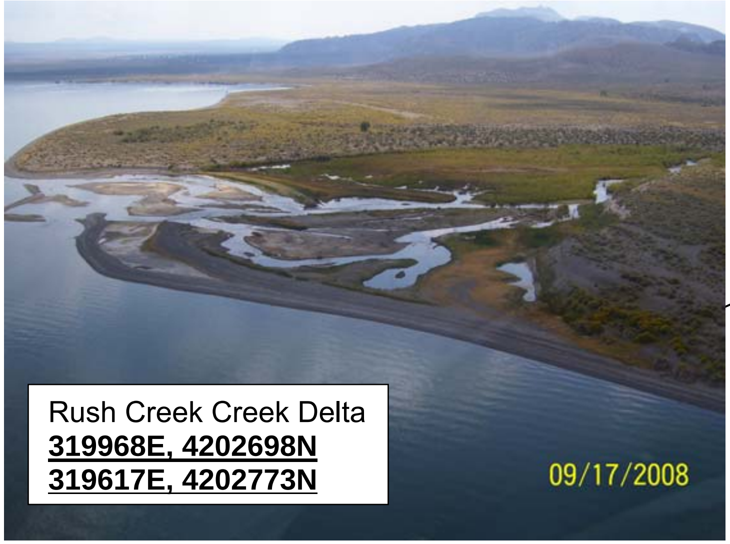


Figure 20.  Rush Creek Delta

**Figure 21. Photo of Bridgeport Reservoir, Looking North.** Photo shows the West Bay area and the south end of the East Shore area. The majority of waterfowl that use Bridgeport Reservoir in the fall congregate in this southern end of the reservoir.

Figure 22. McGee Bay Area – Crowley Reservoir

Figure 23. Upper Owens River delta - Crowley Reservoir

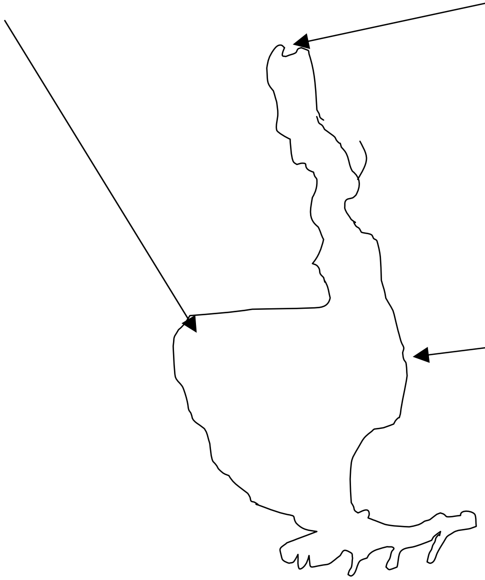


Figure 24. Chalk Cliffs Area of Crowley

**Figure 25. Brood Locations.** The number in parentheses indicates the number of broods found in each area.

**Figure 26. Habitat Use from Summer Waterfowl Species.** The numbers in parentheses indicate sample size. The bars represent the percent of the total observations .

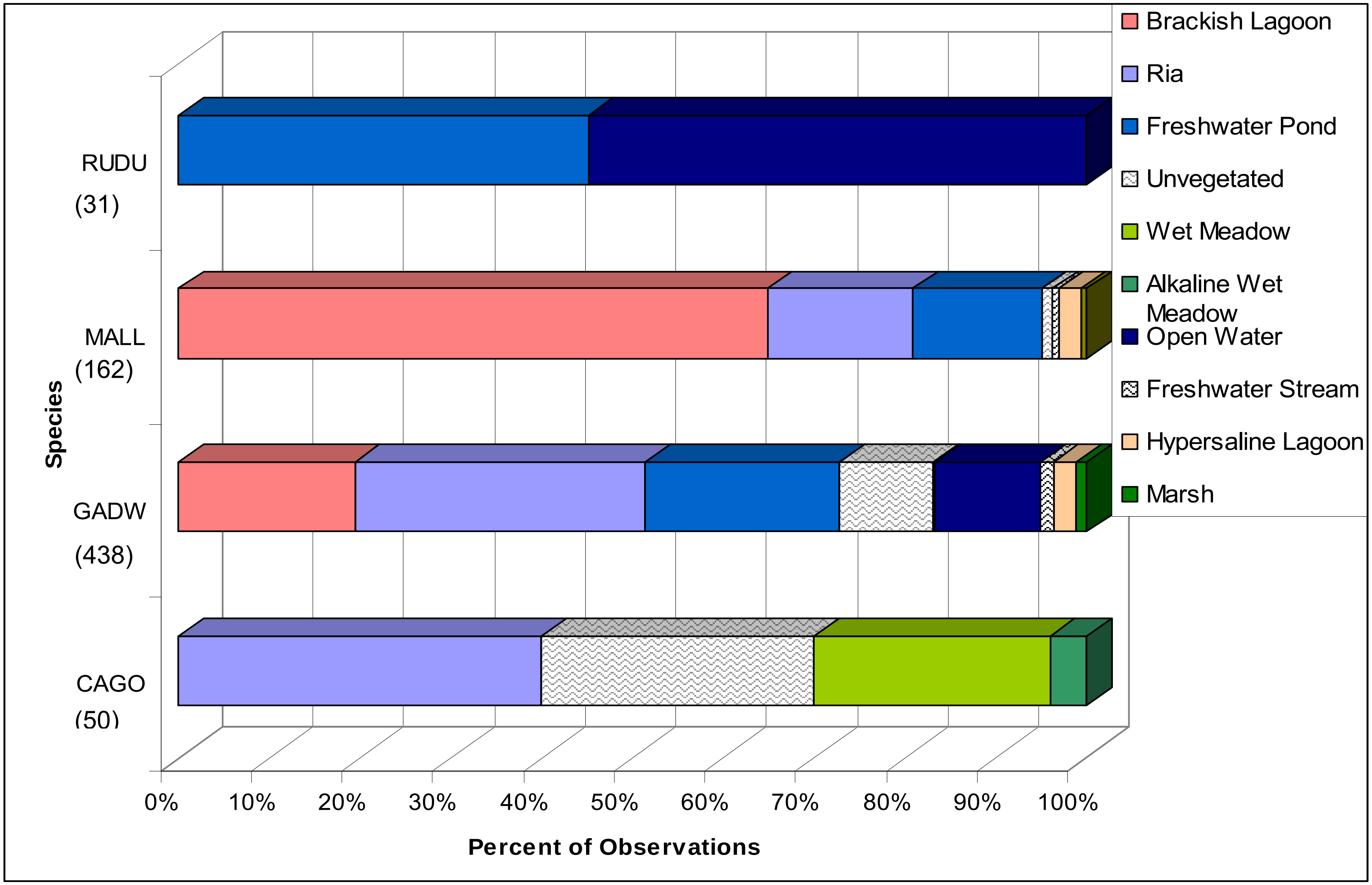
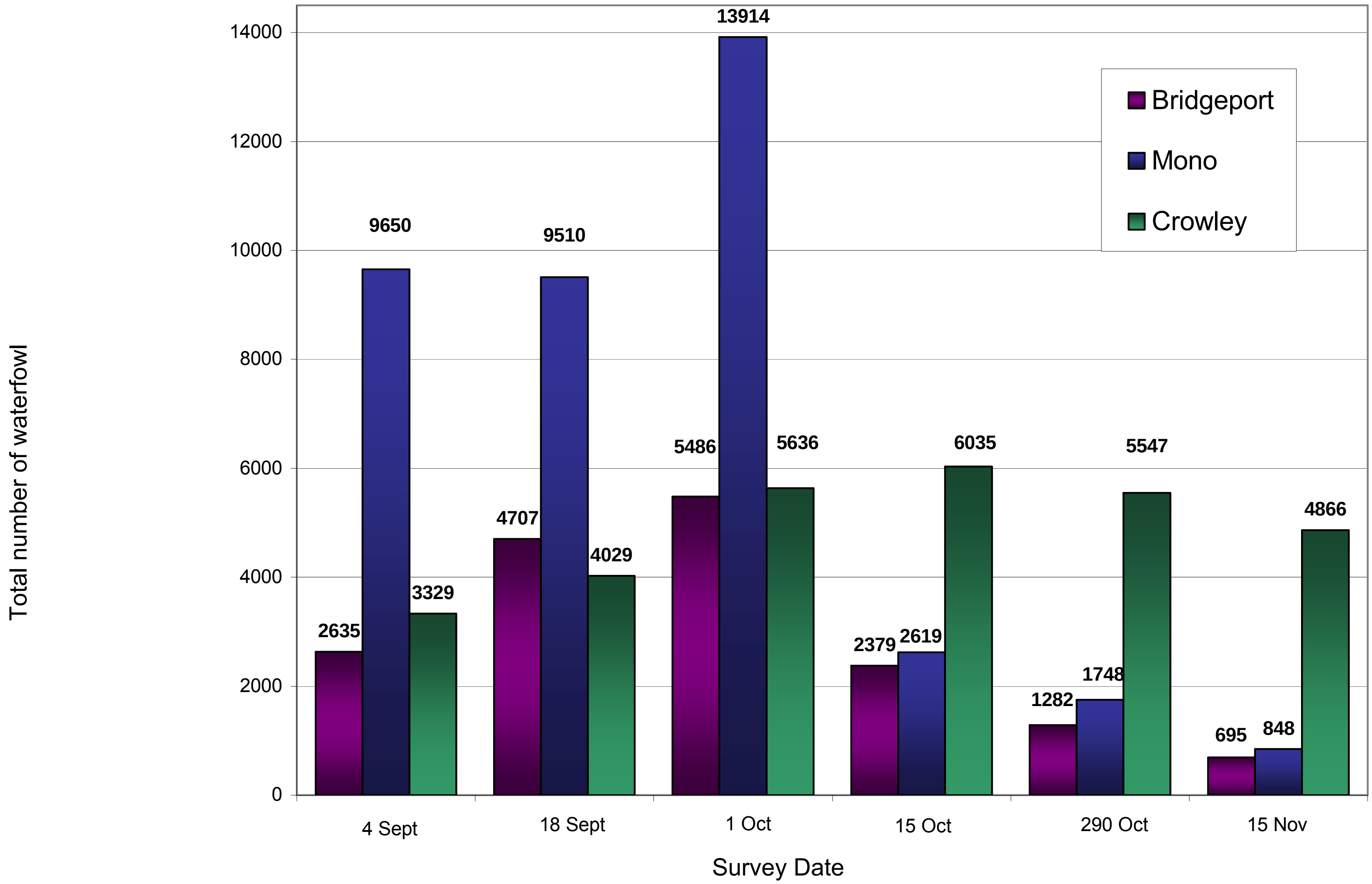


**Figure 27. Total Waterfowl Detected from Fall Aerial Surveys**



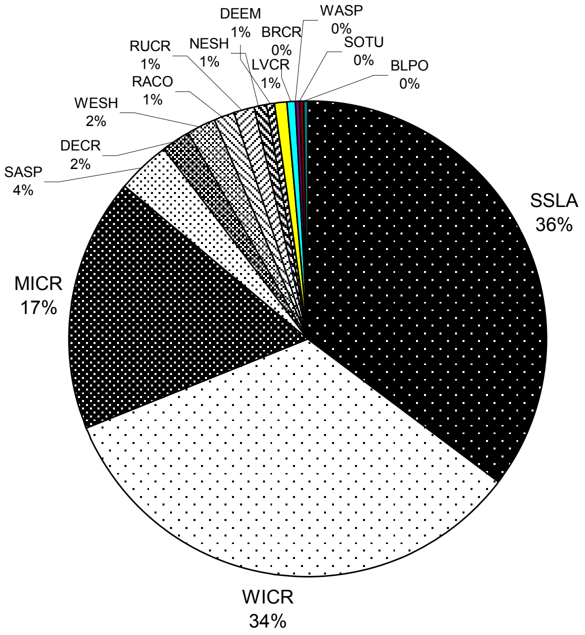


**Figure 28. Proportional use of shoreline areas by waterfowl – Mono Lake**

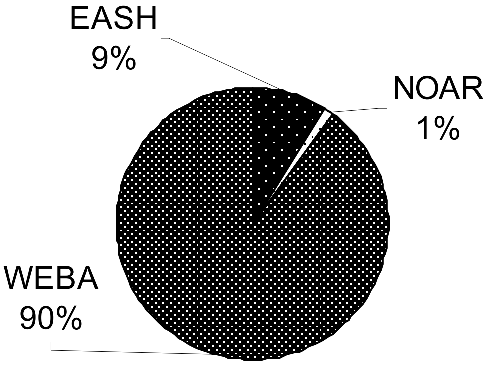


**Figure 29. Proportional use of shoreline areas – Bridgeport Reservoir**

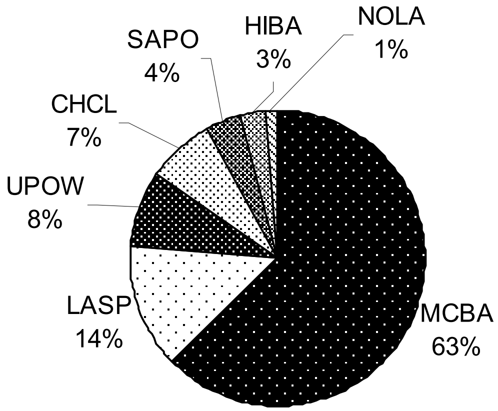


**Figure 30. Proportional use of shoreline areas – Crowley Reservoir**

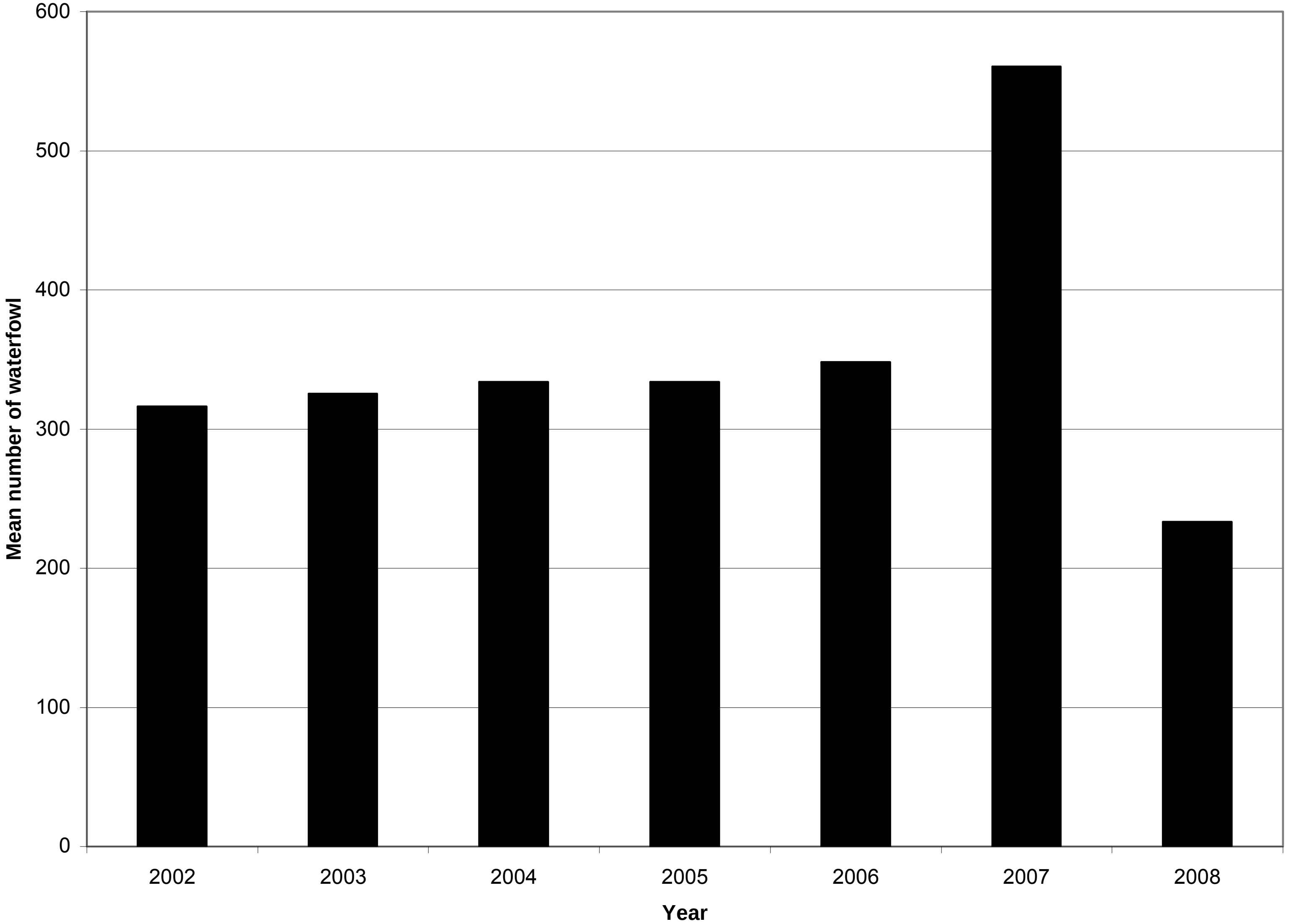


Figure 31. Mean Number of Summering Waterfowl at Mono Lake 2002-2008

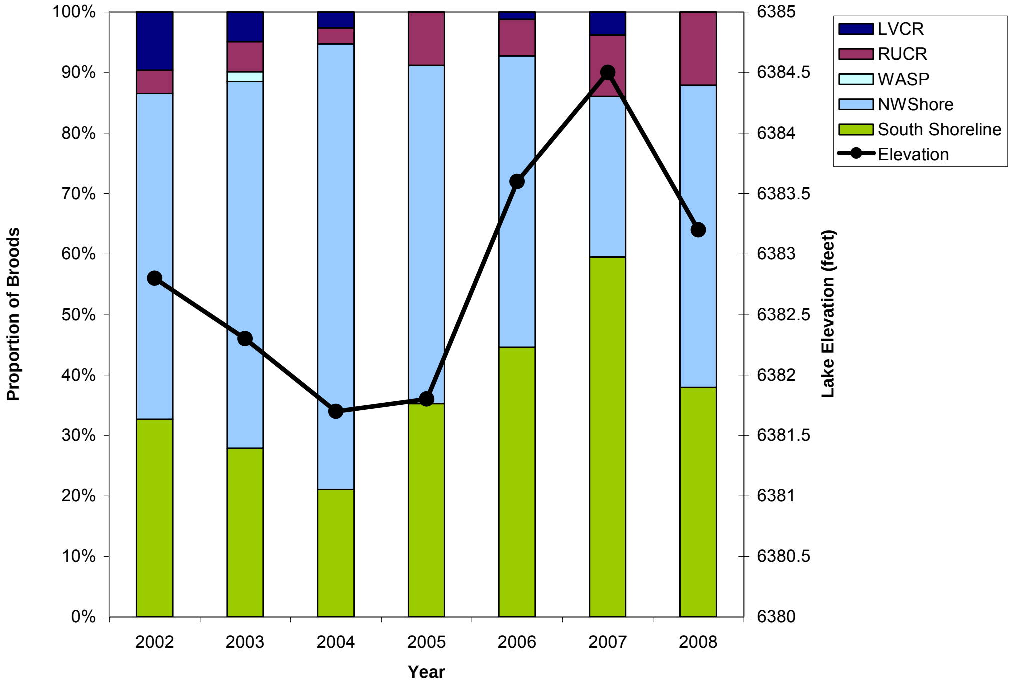


Figure 32. Proportional Use of Mono Lake Shoreline Areas for Brooding 2002-2008

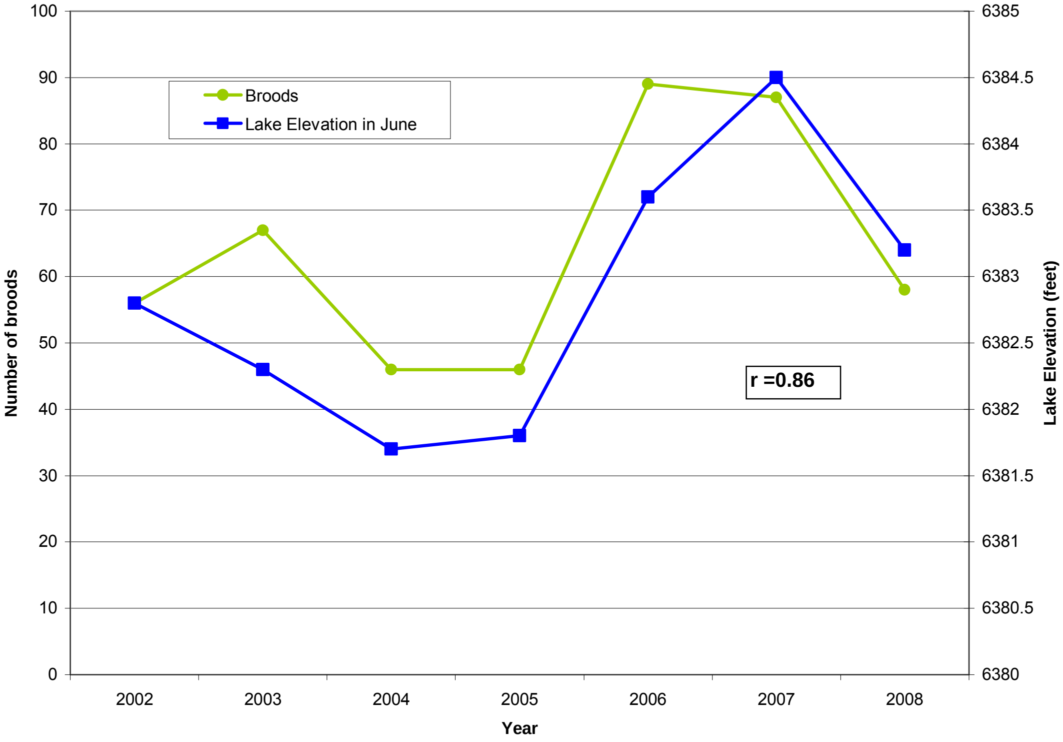


Figure 33. Number of Broods at Mono Lake vs. Lake Elevation 2002-2008

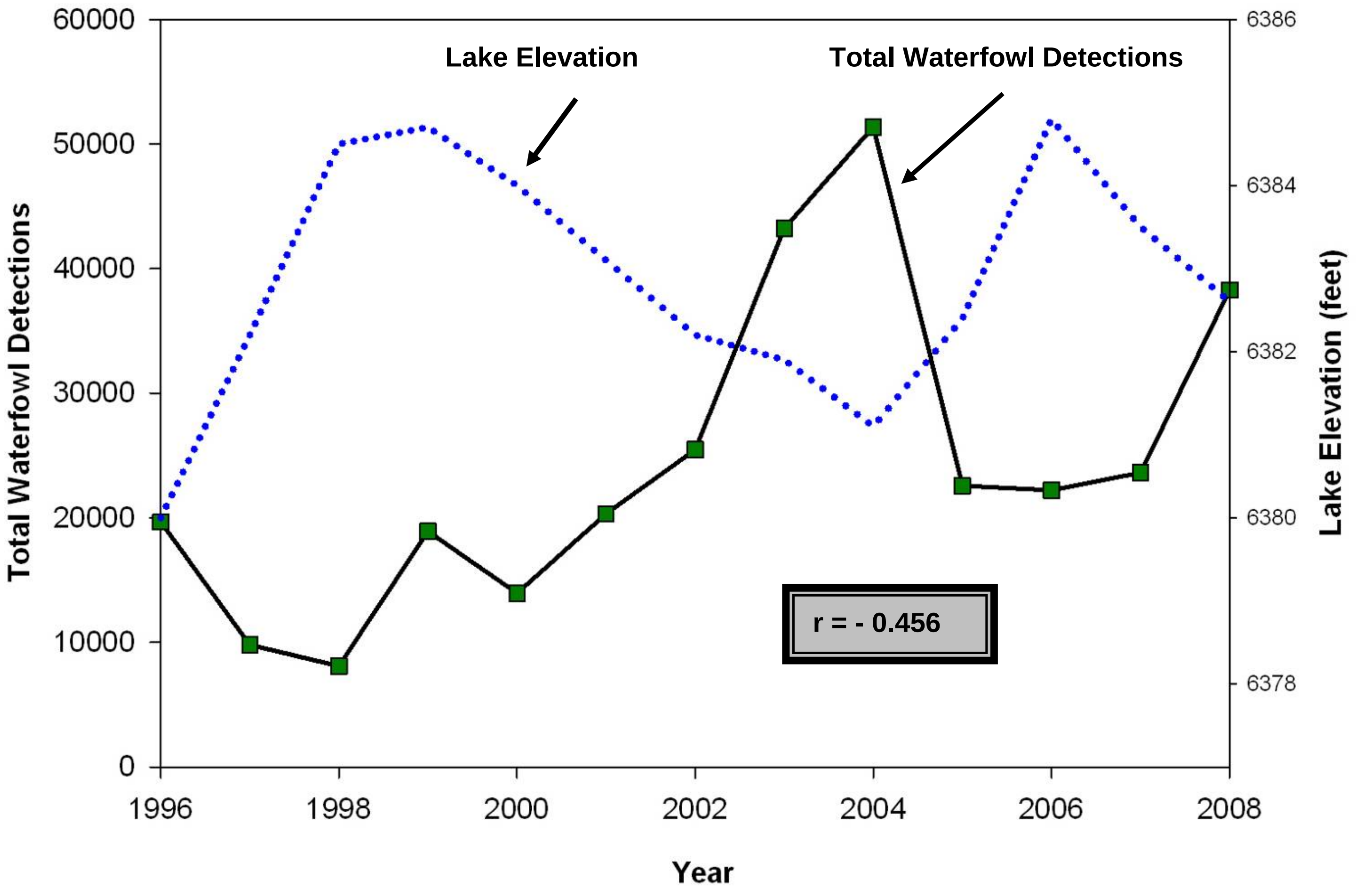


Figure 34.  Total Waterfowl Detections vs. Lake Elevation

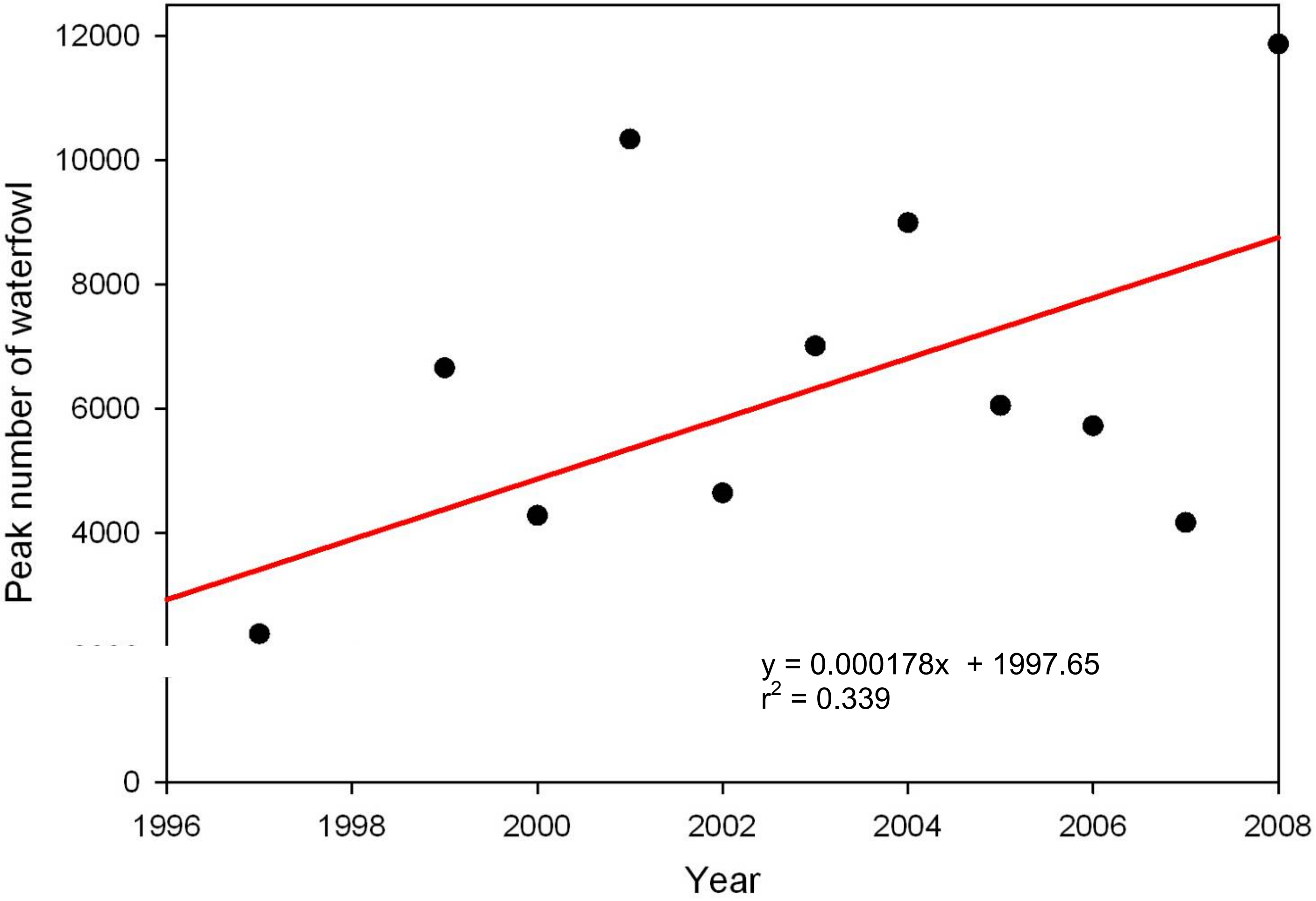


**Figure 35. Trend in Peak Waterfowl Numbers (not including Ruddy Ducks) at Mono Lake 1996-2008**

# APPENDICES

## Appendix 1. 2008 Ground Count Surveys - Dates and Times that Surveys were Conducted at Each Survey Area.

**Survey 1**

| Survey area | Survey Date and Time | | |
|---|---|---|---|
| | 9-Jun | 10-Jun | 11-Jun |
| **RUCR** | 0535 - 0630 hrs | | |
| **SOTU** | 0715 - 0812 hrs | | |
| **SSLA** | 0812 - 1030 hrs | | |
| **SASP** | | | 0552- 0900 hrs |
| **WASP** | | | 0900 – 1040 hrs |
| **WICR** | | 0749 - 0833 hrs | |
| **MICR** | | 0649 - 0748 hrs | |
| **DECR** | | 0535 - 0647 hrs | |
| **LVCR** | | 1058 - 1200 hrs | |
| **DEPO** | | 1009 - 1026 hrs | |
| **COPO** | | 0945 - 1005 hrs | |

**Survey 2**

| Survey area | Survey Date and Time | | |
|---|---|---|---|
| | 1-Jul | 2-Jul | 3-Jul |
| **RUCR** | 1140 - 1240 hrs | | |
| **SOTU** | 0556 - 0656 hrs | | |
| **SSLA** | 0656 - 0923 hrs | | |
| **SASP** | | | 0810 - 1035 hrs |
| **WASP** | | | 0652 - 0810 hrs |
| **WICR** | | 0754 - 915 hrs | |
| **MICR** | | 0645 - 0753 hrs | |
| **DECR** | | 0545 - 0645 hrs | |
| **LVCR** | | 1053 - 1140 hrs | |
| **DEPO** | | 1221 - 1242 hrs | |
| **COPO** | | 1255 - 1301 hrs | |

## Appendix 1. Continued. 2008 Ground Count Surveys - Dates and Times that Surveys were Conducted at Each Summer Survey Area.

**Survey 3**

| Survey area | Survey Date and Time | | |
|---|---|---|---|
| | 21-Jul | 22-Jul | 23-Jul |
| **RUCR** | 0555 - 0656 hrs | | |
| **SOTU** | 0735 - 0841 hrs | | |
| **SSLA** | 0841 - 1123 hrs | | |
| **SASP** | | | 0604 - 0858 hrs |
| **WASP** | | | 0859 - 1017 hrs |
| **WICR** | | 0755 - 0856 hrs | |
| **MICR** | | 0706 - 0755 hrs | |
| **DECR** | | 0600 - 0706 hrs | |
| **LVCR** | | 1158 - 1253 hrs | |
| **DEPO** | | 1026 - 1100 hrs | |
| **COPO** | | 1110 - 1124 hrs | |

## Appendix 2. Common, Scientific Names and Codes for Species Names Occurring in the Document.

| Common Name | Scientific Name | Code |
|---|---|---|
| | *Fulica americana* | AMCO |
| American Wigeon | *Anas americanus* | AMWI |
| Blue-winged Teal | *Anas discors* | BWTE |
| Bufflehead | *Bucephala albeola* | BUFF |
| Canada Goose | *Branta canadensis* | CAGO |
| Canvasback | *Aythya valisineria* | CANV |
| Cinnamon Teal | *Anas cyanoptera* | CITE |
| Common Merganser | *Mergus merganser* | COME |
| Eared Grebe | *Podiceps nigricollis* | EAGR |
| Lesser Scaup | *Aythya affinis* | LESC |
| Gadwall | *Anas strepera* | GADW |
| Greater White-fronted Goose | *Anser albifrons* | GWFG |
| Green-winged Teal | *Anas crecca* | GWTE |
| Mallard | *Anas platyrhynchos* | MALL |
| Northern Pintail | *Anas acuta* | NOPI |
| Northern Shoveler | *Anas clypeata* | NSHO |
| Red-breasted Merganser | *Mergus serrator* | RBME |
| Redhead | *Aythya americana* | REDH |
| Ring-necked Duck | *Aythya collaris* | RNDU |
| Ruddy Duck | *Oxyura jamaicensis* | RUDU |
| Snow Goose | *Chen caerulescens* | SNGO |
| Tundra Swan | *Cygnus columbianus* | TUSW |
| *Anas* spp. | Unidentified *Anas* species | UNTE |

## Appendix 3. Habitat Categories Used for Documenting Use by Waterfowl Species (from 1999 Mono Basin Habitat and Vegetation Mapping, Los Angeles Department of Water and Power 2000).

### Marsh

Areas with surface water usually present all year and dominated by tall emergent species such as hard-stem bulrush (*Scirpus acutus*), cattail (*Typhus latifolia*), three-square (*Scirpus pungens*), alkali bulrush (*Scirpus maritimus*) and beaked sedge (*Carex utriculata*).

### Wet Meadow

Vegetation with seasonally or permanently wet ground dominated by lower stature herbaceous plant species, such as sedges (*Carex* spp.), rushes (*Juncus* spp.), spikerushes (*Eleocharis* spp.), and some forbs (e.g. monkey flower [*Mimulus* spp.], paintbrush [*Castilleja exilis*]). Wet meadow vegetation was in areas where alkaline or saline soils did not appear to be present. This class included the “mixed marsh” series from Jones and Stokes 1993 mapping.

### Alkaline Wet Meadow

This type was similar in stature to the wet meadow class but occurred in areas clearly affected by saline or alkaline soils. Vegetation was typically dominated by dense stands of Nevada bulrush (*Scirpus nevadensis*), Baltic rush (*Juncus balticus*), and/or saltgrass (*Distichlis spicata*). The high density and lushness of the vegetation indicated that it had a relatively high water table with at least seasonal inundation and distinguished it from the dry meadow vegetation class.

### Dry meadow/forb

This vegetation class included moderately dense to sparse (at least 15 percent) cover of herbaceous species, including a variety of grasses and forbs and some sedges (e.g. *Carex douglasii*). As with the alkaline wet meadow type above, comparison to vegetation series in Jones and Stokes (1993) was sometimes problematic due to difficulty in distinguishing dry meadow from wet meadow types.

### Riparian and wetland scrub

Areas dominated by willows (*Salix* spp.) comprised most of the vegetation classified as riparian.wetlands scrub. Small amounts of buffalo berry (*Shepardia argentea*) and Wood’s rose (*Rosa woodsii*) usually mixed with willow also were included in this class.

### Great Basin scrub

Scattered to dense stands of sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), and/or bitterbrush (*Purshia tridentata*) were classified as Great Basin scrub. This vegetation type included a range of soil moisture conditions, as rabbitbrush was often found in moist areas close to the lakeshore and sagebrush was typically in arid upland areas.

### Riparian forest and woodland

Aspen (*Populus tremuloides*) and black cottonwood (*Populus trichocarpa*) were the two tree species most common in the riparian forest/woodland vegetation type.

### Freshwater-stream

Freshwater-stream habitats are watered; freshwater channels such as exist in Rush Creek and Lee Vining Creeks.

### Freshwater-ria

Freshwater-ria areas were surface water areas at the mouths of streams that likely have some salt/freshwater stratification.

### Freshwater-pond

This type included ponds fed by springs within marsh areas or artificially by diversions from streams (e.g. DeChambeau/County ponds).

### Ephemeral Brackish Lagoon

Lagoons along the shoreline created by the formation of littoral bars with an extensive area of marsh or wet meadow indicating the presence of springs was present landward, were identified as ephemeral brackish lagoons. In some cases, lagoons were not completely cut off from lake water, but were judged to still have brackish water due to freshwater input and reduced mixing.

### Ephemeral Hypersaline Lagoon

Lagoons along the shoreline created by the formation of littoral bars, but without an extensive area of marsh or wet meadow present landward, were identified as ephemeral hypersaline lagoons. These were presumed to contain concentrated brine due to evaporation.

### Unvegetated

Unvegetated areas were defined as those that were barren to sparsely vegetated (<15 percent cover). This class included sandy areas, alkaline flats, tufa, and delta outwash deposits.

## Appendix 4. 2008 Fall Aerial Survey Dates

| Survey Number | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Mono Lake** | 4 Sept | 18 Sept | 1 Oct | 15 Oct | 29 Oct | 17 Nov |
| **Bridgeport Reservoir** | 4 Sept | 18 Sept | 1 Oct | 15 Oct | 29 Oct | 17 Nov |
| **Crowley Reservoir** | 4 Sept | 18 Sept | 1 Oct | 15 Oct | 29 Oct | 17 Nov |

## Appendix 5. Lakeshore Segment Boundaries (UTM, Zone 11, NAD 27, CONUS)

| **Mono Lake** | **Lakeshore Segment** | **Code** | **Easting** | **Northing** |
|---|---|---|---|---|
| | South Tufa | SOTU | 321920 | 4201319 |
| | South Shore Lagoons | SSLA | 324499 | 4201644 |
| | Sammann's Spring | SASP | 328636 | 4204167 |
| | Warm Springs | WASP | 332313 | 4208498 |
| | Northeast Shore | NESH | 330338 | 4213051 |
| | Bridgeport Creek | BRCR | 324773 | 4215794 |
| | DeChambeau Embayment | DEEM | 321956 | 4214761 |
| | Black Point | BLPT | 318252 | 4211772 |
| | Wilson Creek | WICR | 315680 | 4209358 |
| | Mill Creek | MICR | 313873 | 4209544 |
| | DeChambeau Creek | DECR | 312681 | 4209246 |
| | West Shore | WESH | 315547 | 4208581 |
| | Lee Vining Creek | LVCR | 314901 | 4205535 |
| | Ranch Cove | RACO | 316077 | 4204337 |
| | Rush Creek | RUCR | 318664 | 4202603 |
| **Crowley Reservoir** | | | | |
| | Upper Owens | UPOW | 346150 | 4168245 |
| | Sandy Point | SAPO | 345916 | 4167064 |
| | North Landing | NOLA | 346911 | 4164577 |
| | McGee Bay | MCBA | 345016 | 4164414 |
| | Hilton Bay | HIBA | 346580 | 4161189 |
| | Chalk Cliff | CHCL | 347632 | 4162545 |
| | Layton Springs | LASP | 347177 | 4165868 |
| **Bridgeport Reservoir** | | | | |
| | North Arm | NOAR | 306400 | 4244150 |
| | West Bay | WEBA | 304100 | 4240600 |
| | East Shore | EASH | 305600 | 4237600 |

## Appendix 6. Cross-Lake Transect Positions for Mono Lake

| Cross-Lake Transect Number | Latitude |
|---|---|
| 1 | 37º 57’00” |
| 2 | 37º 58’00” |
| 3 | 37º 59’00” |
| 4 | 38º 00’00” |
| 5 | 38º 01’00” |
| 6 | 38º 02’00” |
| 7 | 38º 03’00” |
| 8 | 38º 04’00” |

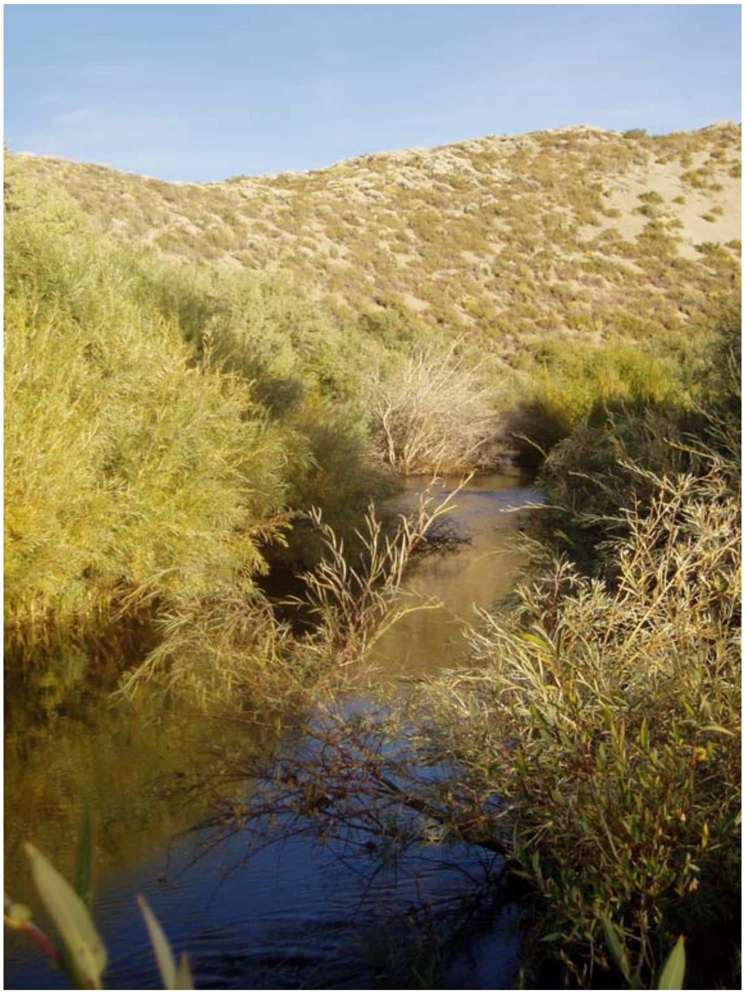
# APPENDIX 3

# Vegetation

# 2008-09

# Mono Lake Vegetation

# Monitoring Report



Prepared by

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# Mono Lake Vegetation Monitoring

## Introduction

Vegetation monitoring began in the riparian areas of Rush and Lee Vining Creeks and at several locations in the lake fringing wetlands of Mono Lake in 1999 (Fig 1). These efforts were undertaken to fulfill State Water Board obligations as directed in Decision 1631 and Order No. 98-05 and are generally described in the Mono Basin Waterfowl Habitat Restoration Plan. The objective of these monitoring efforts is to determine wetland changes as lake levels rise and how those changes may relate to waterfowl activity in the region and to determine the effectiveness of a burning program that is in the developmental phase. Under the restoration plan, the monitoring interval was set to five year intervals or after extremely wet years.

## Vegetation Monitoring

### *Wetland and Riparian Areas*

2008 was not a monitoring year for Mono Basin riparian or lake fringing wetland.

### *Channel opening revegetation*

Visits conducted at the former Marzano site on the west bank across from the 3D indicated that this site is continuing to progress and will likely not require any additional work. The lessee for this site has indicated that if any further work is required they will implement whatever LADWP staff deem necessary.

This was the second year for both the 4bii and the 8 channel. The 4bii floodplain is presently well vegetated and no revegetation work is anticipated. Monitoring will continue at the 8 channel site.

## Opportunistic Placement of Woody Debris

Several times during 2008, large woody debris was placed in the channels of both Lee Vining and Rush Creeks. Although there is still large woody debris along the channels of both creeks, every time staff remove wood for placement, they are disrupting other organisms that have been using the wood. It is recommended that this practice be discontinued.

## Salt Cedar Control

Personnel from LADWP conducted surveys of the delta areas of both Rush and Lee Vining Creeks several times during the 2008 growing season. No plants were observed during these surveys and no treatment occurred.

## Grazing Moratorium

The grazing moratorium will continue in 2009.