Section 5

Mono Basin Waterfowl
Habitat and Population Monitoring
2007-08

Waterfowl Monitoring

In RY 2007-08, LADWP continued the waterfowl habitat monitoring and restoration program. The following is a summary of activities:

- Monitored Mono Lake Hydrology;
- Monitored Mono Lake Limnology
- Monitored Mono Lake Ornithology

Mono Lake Hydrology

The elevation of Mono Lake was monitored on 39 occasions during the runoff year over which time the lake elevation ranged from 6384.8 feet amsl on April 5, 2007 to 6383.3 feet amsl on March 31, 2008.

Mono Lake Limnology

UC Santa Barbara conducted eleven limnological surveys. Annual primary production was the highest on record. Average *Artemia* biomass was 23% lower than the long-term mean as was the total annual cyst production.

Mono Basin Ornithology

Ms. Deborah House, Watershed Resources Specialist with LADWP, conducted three summer waterfowl ground surveys and six fall aerial surveys. Photos of waterfowl habitats at Mono Lake, Bridgeport Reservoir and Crowley Reservoir were taken from an airplane on October 11, 2007.

Mono Lake Waterfowl Restoration Project
Compliance Checklist
2007

Hydrology †	**Chapter 2**
Mono Lake Elevation	☑
Walker Creek Flows	☑
Parker Creek Flows	☑
Lee Vining Creek Flows	☑
Rush Creek Flows	☑
Mono Basin Exports	☑
Limnology ‡	**Appendix 1**
Meteorology	☑
Physicochemical Variables	☑
Primary Producers	☑
Secondary Producers	☑
Ornithology	**Appendix 2**
Population Surveys	☑
Aerial Photos	☑
Time Activity Budget	**Required at Stabilization**
Vegetation	**Required 2010**
Spring Survey	**Required 2009**

Brian White

Brian White
Waterfowl Coordinator

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† Several weekly elevation reads missed due to inclement weather.

‡ Due to equipment malfunctions, Paoha Island precipitation was not measured in 2007.

APPENDIX 1

Limnology

2007 ANNUAL REPORT

MIXING AND PLANKTON DYNAMICS IN MONO LAKE, CALIFORNIA

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EXECUTIVE SUMMARY

Limnological monitoring of Mono Lake was conducted during 2007 as part of a long-term monitoring program begun in 1982. Chapter 1 describes previous results of limnological studies of the seasonal plankton dynamics observed from 1979 through 2006, a period which encompassed a wide range of varying hydrologic and annual vertical mixing regimes including two periods of persistent chemical stratification or meromixis (1983–88 and 1995–2003) and the initiation of a third episode of meromixis in 2005. 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 several 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.

Results of the 2007 limnological monitoring program including a number of integrative measures encompassing the long-term record (1982–2007) are presented in Chapter 3. Declining lake levels associated with well below average snowmelt runoff resulted in weakening of chemical stratification through the year and eventual autumn holomixis following the mid-November survey.

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, adults were virtually gone 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.

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.

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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, 1979–2007, 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 µg chl *a* l^{-1} in February to 0.3 µg chl *a* l^{-1} in June, when the seasonal chlorophyll *a* concentration minimum was reached. After that it increased to 1–2 µg chl *a* l^{-1} during July–October and to ~8 µg 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 µg chl *a* l^{-1}) were similar to those observed in 1998 but slightly higher than the two previous years of meromixis, 1997 (2–3 µg chl *a* l^{-1}) and 1996 (5–8 µg 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 µg 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, 3.02×10^6 m^{-2} compared to 4.03×10^6 m^{-2} in 2000. While this is 37% below the long-term mean of 4.77×10^6 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 (2.5×10^6 m^{-2}), along with abundance of ovigerous females, was less than in the previous three years ($3.0\text{-}4.2 \times 10^6$ 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 4.77×10^6 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* $liter^{-1}$) 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* $liter^{-1}$). 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}.

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 1982–2006. Neither measure indicates a long-term trend in phytoplankton or *Artemia* abundance.

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 and plankton productivity is expected to decrease in 2007 due to the lack of a winter period of holomixis and reduced nutrient availability.

Above average snowfall in winter 2005–06 led to resulted in the initiation of a third episode of meromixis at Mono Lake. Although salinity stratification was weak in late 2005, freshwater inputs in December 2005 were sufficient to prevent the annual winter period of holomixis.

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 highest estimated annual primary production occurred (1,645 g C m^{-2} y^{-1}). Estimated annual productivity declined ranging from 864 to 1,111 g C m^{-2} y^{-1} during 2004–06.

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 lowest annual biomass of *Artemia* (5.3 g m^{-2}) was observed in 1997, the second year of the 1990s episode of meromixis.

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 and 2006 was 8.8 and 6.8 g m^{-2}, respectively.

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). 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). The CTD was deployed by lowering it at a rate of ~0.25 m s^{-1}. An analysis of salinity spiking from the mismatch in the time response of the conductivity and temperature sensors indicated a 1.7 s displacement of the temperature data provided the best fit. The pumped fluorometer data required a 3.7 s shift, and other sensors (pressure, PAR, transmissivity) required a distance offset based on their relative placement. As density variations in Mono Lake can be substantial due to chemical stratification, pressure readings were converted to depth by integrating the mass of the water column above each depth.

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. 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 (α^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 2007. The episode of meromixis begun in 2005 ended in late 2007 as below normal snowfall and evaporation led to declining lake level and increased salinity and density of the mixolimnion (upper mixed layer). The breakdown of even this short 2-year period of meromixis enhances nutrient availability and productivity as nutrients previously sequestered in the monimolimnion are mixed into the euphotic zone. 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 2007, spring water temperature and phytoplankton abundance were in the middle of the range observed over the past 27 years, but salinity was significantly lower. The 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 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 2007 and calculate several long-term integrative measures of ecosystem productivity.

Meteorological Data

The Mono Lake limnological monitoring program includes 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 during most of the year. However, during midwinter the plankton change slowly and are of much less scientific and ecological interest; the upper water column is well-mixed, *Artemia* and avian populations are virtually absent, and phytoplankton populations are slowly changing. For this reason, the difficulty of access, and data storage limitations, meteorological data is collected at hourly intervals during December through February.

Wind Speed and Direction

Mean daily wind speed varied from 1.0-9.4 m s^{-1} over the year, with an overall annual mean of 3.3 m s^{-1} (Fig. 2). This annual mean is slightly lower than observed in 2005 and 2006 (3.5 m s^{-1}) and only slightly higher than the 3.2 m s^{-1} annual mean observed in 2001, 2002, and 2003 and 3.1 m s^{-1} observed in 2004. The daily maximum 10-min averaged wind speeds averaged 3.5 times mean daily wind speeds. The maximum recorded gust (28.7 m s^{-1}, 64.2 mph) occurred on the evening of October 19 (Fig. 2). The mean monthly wind speed varied from 2.4 to 4.1 m s^{-1} (coefficient of variation, 16 %). This was similar to 2006 and 2004 when the mean monthly wind speed varied only from 2.7 to 4.5 and 2.1 to 4.1 m s^{-1} respectively. As observed in the past, winds were predominately from the south (mean, 185.1 deg).

Air Temperature

Mean daily air temperatures ranged from a minimum of –12.1°C on 12 January to a maximum of 23.9°C on 5 July (Fig. 3). Air temperatures ranged from 5.0°C to 34.4°C during the summer (June through August) with a mean daily range of 13.5°C to 23.9°C and from –16.5°C to 18.1°C during the winter (December through February) with a mean daily range of -7.5°C to 9.1°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 2007, the annual mean was 38.7 Einsteins m^{-2} day^{-1}, with daily values ranging from 2.8 Einsteins m^{-2} day^{-1} on 28 January to 64.6 Einsteins m^{-2} day^{-1} on 24 June. The 2007 annual mean was between those observed in 2002, 2003, 2004, 2005 and 2006 (39.9, 35.0, 37.5, 39.0, 38.0 Einsteins m^{-2} day^{-1}) respectively. PAR values presented here were collected at the Cain Ranch stations.

Relative Humidity and Precipitation

Mean daily relative humidity followed a general pattern of high values (mostly 60-80 %) in January, decreasing to lows (mostly 40-70 %) in April through October, and increasing to 60-80 % through December (Fig. 5). The yearly mean was 54.0 %, similar to that observed in during 2003 (54.3 %), 2004 (54 %), 2005 (57.9%) and 2006 (56.4%).

Precipitation data from the Paoha meteorological station are not available for 2007 due to erratic malfunctioning of two different datalogger channels. A new datalogger and tipping rain bucket are currently being installed. Here, we present annual Cain Ranch precipitation data (LADWP, W. Hopper, pers. commun.). In 2007, the annual precipitation measured at Cain Ranch was 7.2 cm with the highest daily value of 1.32 cm on 7 December 2007 (Fig. 6). The 2007 precipitation was only 27 % of the long-term (1930-2007) mean precipitation of 27.3 cm. Annual 2007 precipitation measured at Lee Vining was 14.9 cm (source, Mono Lake Committee). Precipitation generally declines by about half across the lake (LADWP unpub., Vorster 1985).

Surface Elevation

The surface elevation of Mono Lake declined in 2007 as low 2006–07 Sierran winter snowfall resulted in the first “Dry” (80-100% exceedance; <68.5% of average) runoff year in the Mono Basin since the 1994 Water Board Decision. Following a small rise of 0.3 ft from 6384.5 ft asl at the beginning of the year to 6384.8 ft asl on 1 April, the surface elevation declined 2.1 ft during the rest of the year to 6382.7 ft asl on 1 January 2008 (Fig. 7). This yielded a net decrease in surface elevation of 1.8 ft for 2007.

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 of seasonal thermal stratification observed during 1990–94 is typical of large temperate lakes except that in Mono Lake the absences 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.

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 typically initiated in February.

A lakewide survey of 12 stations was conducted on 15 February 2007. The vertical temperature and conductivity profiles at deep stations were fairly complex due to the persistent chemocline, near surface warming and freshwater inputs, and episodic wind-driven mixing events (Table 1, Fig. 8). At the centrally-located deep Station 6, water temperature was 2.0-2.1 °C from the surface to 2.5 m depth. Beneath this near surface layer, temperature increased slightly to 2.5 °C at 5 m depth before decreasing to 1.3–1.5 °C from 12 to 18 m. The near uniform temperatures from 12 to 18 m reflect the late winter mixing depth. Beneath this near-uniform portion of the water column, water temperature increased to 4.0 °C at 24 m depth and then more slowly to 5.0 °C near the bottom (34-38 m depth).

The 13 March 2007 survey followed a relatively calm, warm period of weather which resulted in a shallow thermocline between 3 and 6 m depth. Water temperature ranged from 6.3 to 7.1 °C and specific conductivity from 78.2 to 79.0 mS cm^{-1} above this thermocline. Beneath this thermocline temperature decreased to a minimum of 2.0 °C at 14 m and increased gradually through the broad persistent chemocline extending from 15 to 29 m depth (see below) to 4.1 °C at 29 m.

Seasonal thermal stratification was well-established by the mid-April survey (16 April 2007). At the central, deep station (Station 6) water temperatures were 7.0–7.5 °C in the upper 11.5 m of the water column. A strong thermocline was present below 11.5 m depth with water temperatures decreasing to 3.1 °C at 16 m depth. Below this water temperatures increased slowly to 3.7 °C at 33 m depth.

In May the vertical profile of water temperature was complex reflecting various episodes and depths of mixing during the spring period of warming. Temperature decreased in small steps at 4, 6, and 8 m depth. Water temperature was 13.2–13.3 °C at 0-3 m depth. This was 5 to 6 °C colder than the 18.4–19.7 °C observed during the mid-May survey in 2006. Water temperature decreased from 13.2 °C at 3 m to 8.7 °C at 13 m depth. Temperatures dropped further to 3.4 °C across the slightly steeper seasonal thermocline present from 13.5 to 17.5 m and were 3.4–3.5 °C in the monimolimnion (region beneath the persistent chemocline).

By June, the temperature in the upper 4 m of the water column was 17.0–17.2 °C. Beneath this shallow mixed layer, water temperature decreased almost linearly to 13.9 °C at 12 m depth. Temperature decreased from 13.9 °C to 4.6 °C across the prominent seasonal thermocline present between 12 and 17 m. Then the water temperature decreased more slowly to 4.0 °C at 19 m and gradually to 3.5 °C at 26 m. The temperature was a constant 3.5 °C between 26 and 36 m indicating a well-mixed monimolimnion.

The upper water column was well-mixed to 9 m depth during the 20 July survey with water temperatures of 19.4–19.6 °C. Below 9 m water temperature decreased slowly to 18 °C at 12.5 m before decreasing markedly across the pronounced thermocline to 4.9 °C at 18 m. Below 18 m temperatures decreased slowly to 3.6 °C near the bottom (27–37 m). Seasonal heating and deepening of the epilimnion continued through summer with the 16 August profile showing a well-mixed epilimnion to 13 m depth with temperatures of 20.3–4 °C.

Convective mixing accompanying seasonal cooling and density-driven mixing due to an inverse vertical salinity gradient arising from evaporative concentration resulted in marked deepening of the epilimnion in September and October. On 18 September 2007 the epilimnion was nearly isothermal from surface to 13 m depth on with temperatures of 19.9–20.2 °C. Temperature decreased rapidly across the sharp thermocline between 13 and 17 m to 8.5 °C, then more slowly to 4.1 °C at 24 m depth, and slightly further to 3.8 °C near the bottom (32 m). By 14 October 2007 the upper water column was well-mixed down to 20 m depth with epilimnetic water temperatures of 11.6-12.1 °C. Temperatures decreased through the metalimnion (20-28 m) to 6.0-6.3 °C in the hypolimnion (28.5-40 m).

On 14 November 2007 vertical profiles of temperature and conductivity were highly variable around the lake indicating active vertical mixing and horizontal advection of near isopycnal water masses. At the central deep Station 6, the water column temperatures indicated slight diurnal warming at 1 m (10 °C), decreasing to 9.4 °C at 2 m, followed by an increase to 10.3 °C at 12 m and a gradual decrease to 9.1 °C at 35 m depth. In contrast, at the nearby deep Station 12 just east of Paoha Island, the water column was near isothermal at 9.8 °C with a conductivity of 81.3 mS cm^{-1} from 5.5 m depth to the bottom. These contrasting profiles at nearby deep stations indicate that the lake was in the midst of autumn turnover.

Due to winter conditions, the absence of *Artemia*, and the diminished spatial variability in December, a single mid-lake station (Station 6) is often sampled on the December survey. This year stations 4 and 6 were sampled on 13 December 2007.

Vertical profiles of temperature and conductivity clearly indicated that the lake had fully mixed between the November and December surveys. Water temperatures at the central, deep Station 6 were isothermal at 6.5 °C from the surface to 31 m depth. Beneath this, temperatures decreased slightly to 6.2 °C at 34 m. At the slightly shallower (32 m) Station 4, temperatures were 6.5 °C throughout the water column. In contrast, near-bottom water temperatures were ~9 °C during the November survey.

Conductivity and Salinity

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.

Persistent chemical stratification initiated in 2005 and increased during 2006 due to above average snowmelt runoff. The lake remained chemically stratified through winter 2006–07 and during the 15 February 2007 survey specific conductivity at the centrally-located Station 6 was 78.7 mS cm^{-1} at 1 m depth and 79.4–79.6 mS cm^{-1} in the well-mixed portion (6 to 17 m depth) of the mixolimnion (Table 2, Fig. 9). Beneath this conductivity increased to 81.5 mS cm^{-1}at 25 m and further to 81.8 mS cm^{-1} near the bottom. During the 13 March 2007 survey specific conductivity was slightly lower (78.2 to 79.0 mS cm^{-1}) above a shallow thermocline at 4 m and gradually increased with depth to 81.4 mS cm^{-1} at 30 m and below.

Throughout spring below average snowmelt runoff resulted in only a slight freshening of the mixed layer and mid-May specific conductivities were only slightly lower, ranging from 79.0–79.3 mS cm^{-1} in the upper 16 m of the water column. Monimolimnetic mid-May conductivities (>24 m depth) were 80.8–80.9 mS cm^{-1}. These deep conductivities were slightly less than earlier in the year indicating a small amount of vertical mixing. Monimolimnetic conductivities continued to decrease through September when they were 80.3–80.4 mS cm^{-1}.

Evaporative concentration led to a gradual seasonal increase in conductivities of the upper mixed layer through the summer with values reaching 81.0–81.3 mS cm^{-1} by mid-October. During the September and October surveys the mixolimnetic conductivities were 0.3–0.6 mS cm^{-1} higher than those of the monimolimnion.

Conductivity profiles from the December survey clearly indicate the lake had "turned over" with near bottom water values of 81.1–81.2 mS cm^{-1}. Conductivities were slightly higher (81.4 mS cm^{-1}) in the upper waters as evaporative concentration continued through the end of the year.

Over the year, specific conductivities between 1 and 38 m depth ranged from 78.2 mS cm^{-1} to 81.8 mS cm^{-1}. This corresponds to 73.6 to 78.1 g kg^{-1} salinity.

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 27 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 65.2 to 71.1 kg m^{-3} over the course of the year (Table 3).

In mid-February 2007 salinity stratification between 2 and 32 m contributed 3.35 kg m^{-3} to stratification while slight inverse thermal stratification reduced overall density stratification by 0.39 kg m^{-3} (Table 4, Fig 10). Density stratification increased to annual maximum of 4.87 kg m^{-3} on 2 July when thermal and salinity stratification contributed 3.95 and 0.93 kg m^{-3}, respectively. Density stratification between 2 and 32 m decreased due to evaporative concentration and cooling to low levels by October. On 13 December 2007 a slight inverse gradient was present.

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 2007, average lakewide transparency during spring as measured by Secchi depth was in the middle of the ranged observed since 1994 with mean lakewide values ranging only from 1.29±0.05 m (1 SE) to 1.38±0.03 m during February through April (Fig. 11, Table 5). As *Artemia* grazing reduced phytoplankton, mean lakewide transparency increased to 10.9±0.3 m by 14 June 2007. As observed in many years, transparency was higher in the east in May and June due to a larger spring hatch in this sector and higher in the west during July and August due to a larger second generation of shrimp in this sector.

Secchi depths decreased to ~1.0 during October–December as the shrimp population declined an 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. The annual pattern of Secchi depths during 2007 was within the range observed during the past 27 years (Fig. 12).

The attenuation of PAR within the water column varies seasonally, primarily as a function of changes in algal biomass. In 2007, the depth of the euphotic zone, operationally defined as the depth at which only 1 % of the surface insolation is present, increased from a low of 6 m during the spring, to 17 m during midsummer, 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 2007, epilimnetic dissolved oxygen concentrations ranged from 1.1 to 8.1 mg l^{-1} (Table 6, Fig. 14) with the highest concentrations occurring at 5 m depth during the spring March survey. The lowest values were observed during the October and November surveys when the water column was actively mixing as evidenced by the large temperature increases in the hypolimnion. Beneath the chemocline, the monimolimnion was anoxic (<0.5 mg l^{-1} until autumn turnover between the November and December surveys.

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.

In absence of a winter period of holomixis, February ammonium concentrations were low in the epilimnion and high in the monimolimnion beneath the persistent chemocline (Table 7, Fig. 15). At the central deep Station 6, ammonia concentration was 0.7–0.9 µM in the upper water column (2-16 m) and then increased almost linearly from 8.1 µM at 20 m to 113 µM at 35 m. The concentration at 35 m was somewhat higher than that observed during November-December 2006 (80–92 µM) indicating strong persistent chemical stratification through the winter. February epilimnetic ammonium concentrations were only 0.6–0.7 µM in 9-m integrated samples taken at 7 lakewide stations (Table 8, Fig. 16).

Epilimnetic ammonium concentrations remained low throughout March and April before increasing slightly in May (lakewide mean, 2.1 µM) and then further in June (lakewide mean, 6.6 µM) as the spring cohort of *Artemia* matured. Epilimnetic concentrations decreased (1.0–1.9 µM) in the eastern sector (Stations 7, 8, and 11) by mid-July but remained somewhat higher (2.3–5.2 µM) at stations in the western sector (Stations 1, 2, 5, 6) where *Artemia* were more abundant. While this seasonal feature 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.

Beneath the chemocline, monimolimnetic ammonium concentrations remained relatively constant (~94–116 µM) until mid-September after which they decreased each month as stratification first weakened and then was eliminated at autumn turnover. In most years, near-bottom ammonium concentrations increase through the stratified period. In 2007, this seasonal increase was absent as some degree of deep mixing occurred throughout the year as indicated by decreasing conductivities in the monimolimnion

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 2007, chlorophyll concentrations at the centrally-located Station 6 increased with depth from 16 µg chl l^{-1} at 2 m to 37 µg chl at 12 m depth with concentrations varying from 24 to 49 µg chl l^{-1} at deeper depths (Table 9, Fig. 17). In upper 9-m integrated samples at 7 lakewide stations chlorophyll *a* ranged from 20 to 24 µg chl l^{-1} (Table 10, Fig. 18). This contrasts with February 2006 when upper 9-m integrated samples were 58 to 70 µg chl l^{-1} on the same date and illustrates the effect of persistent chemical stratification and the absence of winter holomixis.

As with past meromictic years, the spring algal bloom was reduced and sub-surface chlorophyll maxima (8 and 12 m) only reached 34 µg chl l^{-1} in April. Higher values (46–79 µg chl l^{-1}) were present at 16 m depth in April and May and are associated with mid-depth peaks in the fluorescence profiles (Fig. 19). By May algal biomass in the upper-9 m, as measured by chlorophyll *a* concentration, had been reduced to only 1.2-2.5 µg chl l^{-1}; much less than the 11 to 32.6 µg liter^{-1} observed in 2006. Lower algal biomass is due to reduced vertical mixing and internal recycling of nutrients accompanying meromixis.

Epilimnetic chlorophyll concentrations remained low (≤3 µg chl l^{-1}) throughout 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 43 to 50 µg liter^{-1} with a lakewide mean of 45.3 µg liter^{-1}. High algal biomass was present during both the November and December surveys as the breakdown of meromixis supplied ample nutrients and the *Artemia* population declined to near zero. A peak chlorophyll concentration of 86 µg chl l^{-1} was observed at 2 m depth on 14 November 2007.

As observed in all years, chlorophyll *a* concentration in deep samples (24 and 28 m depth) were high throughout the year ranging from 31 to 49 µg chl l^{-1} during February through October and slightly higher, 58 to 69 µg chl l^{-1}, in November and December.

In general, the 9-m integrated samples collected from 7 stations showed little variation or consistent patterns across the lake (Fig. 18).

In-situ fluorescence is primarily used to locate mid-depth peaks in phytoplankton populations. These are particularly prominent under meromictic conditions. During 2006, mid-depth maxima were present below 15 m during July through September. In 2007 a deep maxima was observed from April through August. This feature was eroded by deep mixing in late summer and was not present from September through December.

***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. By the 15 February 2007 survey the spring *Artemia* hatch had started with abundance ranging 523 to 6,821 m^{-2} across 12 stations with a mean of 2,713±624 m^{-2} (Table 11). This was significantly less than observed on 13 February 2006 (13,707±4,601 m^{-2}). *Artemia* abundance increased to 14,375±5,715 m^{-2} by the mid-March survey as the spring hatch continued. Nauplii still consisted almost entirely of 1st instars (99.4%) with relatively few (0.6 %) having reached the 2nd instar developmental stage (Table 12). March nauplii were nearly 6-fold more abundant at the eastern stations (stations 7-12) compared to the western stations (stations 1-6). Naupliar abundance continued to increase with 16 April 2007 abundance ranging from 27,200 to 136,500 m^{-2} across the 12 stations with an overall lakewide mean of 51,898 ±8,899 m^{-2}. The population consisted entirely of naupliar instars with instars 1-4 constituting 86 % of the total population. No juveniles or adults were present.

Naupliar abundance remained high and the first adults appeared in May with ovigerous females present by the end of the month. Naupliar abundance was

44,941±11,009 m^{-2}, 50,543±8,837 m^{-2}, 41,516±5,413 m^{-2}, on 1 May, 14 May, and 30 May, respectively. Adult abundance increased to 40,684±6,333 m^{-2} by 30 May at which time they constituted 46% of the total population. Although a few (54 m^{-2}) ovigerous females were present on 14 May, significant numbers of ovigerous females were not present until the 30 May survey.

As observed in most years, hatching of over-wintering cysts was greater in the eastern sectors of the lake and all developmental stages were more abundant in the east through the end of May. On 30 May, adult *Artemia* abundance was 35% higher at the eastern stations (Stations 7-12, 46,707±10,010) than at the western stations (Station 1-6, 34,661±7,860 m^{-2}).

The lakewide mean abundance of adults was almost constant on three successive surveys (30 May, 40,684±6,333 m^{-2}; 14 June, 40,107±3,649 m^{-2}; 2 July, 41,751±7,681 m^{-2}). The 2007 abundance of 1st generation adults (30 May – 2 July) was the 5th highest observed in the 27-yr record (1981-2007) and very similar to values observed in 2005 (Fig. 21).

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.

While adult females were abundant on both the 1 May and 14 May surveys, no individuals were ovigerous (carrying eggs) on 1 May and only 0.5 % of adult females were ovigerous on 14 May (Table 13a, b, c, Fig. 22). Ovigery increased to 13.5 % two weeks later on 30 May at which time 14.6 % of differentiated egg masses were naupliar eggs (as opposed to encapsulated cysts) (Table 13c). While this pulse of ovoviviparous reproduction led to a second prominent peak in the abundance of 1st instar nauplii, the low numbers of later naupliar instars during June–August (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.

While ovigerity increased in a roughly linear fashion to 94.5 % by mid-September (Table 13c, Fig. 22b) the number of adult females decreased linearly from a peak abundance of 21,771±3,594 m^{-2} on 30 May to only 1,066±147 m^{-2} on 17–18 September (Table 11a). A small proportion of females were reproducing ovoviviparously during July and September as indicated by the percentage of differentiated egg masses containing naupliar eggs (3.6–7.7 %, Table 13c).

Fecundity (eggs per brood) is a function of food availability and adult female size. Lakewide mean fecundity ranged from 36 to 53 eggs $brood^{-1}$ during May through August (Table 14). Mean lakewide fecundity increased in September (107 eggs $brood^{-1}$) and October (120 eggs $brood^{-1}$) as the total population declined and food (i.e. phytoplankton) increased.

The mean length of adult females varied from 10.2 to 12.0 mm (Table 14) during the course of the year. These sizes are similar to previous years.

The absence of late summer recruitment led to a near linear decline of adult *Artemia* from 41,751±7,681 m^{-2} on 2 July to only 939±203 m^{-2} on 12–14 October 2007. While the virtual absence of adult *Artemia* in mid-October has only been observed in one other year (2002) over the past 28 years, low (<5,000 m^{-2}) mid-October abundances were also observed in 1986, 2000, 2003, and 2004.

Due to winter conditions and the virtual absence of *Artemia*, only two stations were sampled on the December survey. On 13 December 2007 only a single adult male and 10 naupliar instars were captured in two vertical net tows yielding an areal abundance of 111±111 m^{-2} (Table 11a&b).

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. 23). 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 2007 was ~19,900 m^{-2}. During this 29-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 2007 (18,826 m^{-2}) and the two preceding years (2005, 17,888 m^{-2}; 2006, 21,518 m^{-2}) seasonal abundance was close to the long-term mean of 19,852 m^{-2}.

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 29-yr record from 1979 to 2007 (Table 15, Fig. 24). 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. The 5th largest spring generation of adults was observed in 2007 and thus the overall temporal occurrence of adults (day 186, 5 July) was among the earliest observed and identical to that observed in 2006.

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 2007, a linear regression explains 46 % 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 29-yr period of variable but generally decreasing salinity.

The larger size of the 1st generation of *Artemia* benefits nesting California Gulls. Wrege et al. (2006) found that four variables explained .80% of the variation in the numbers of breeding gulls at Mono Lake between 1987 and 2003: the potential number of four-year-old gulls returning to the lake to breed for the first time, winter coastal conditions associated with the Pacific Decadal Oscillation, density of *Artemia* close to the time of egg-laying, and mean temperature in the month before egg-laying. Of the four factors the latter two, which reflect local conditions near the time of egg-laying, had the most profound direct effect on the numbers of breeding gulls.

The earlier decline in the autumn A*rtemia* population reduces the food resources available to migrating Eared Grebes which stage at Mono Lake during late summer and autumn. Analysis of long-term records (1981-2006) of population means of individual grebe weights indicates that the critical *Artemia* density at which grebes can maintain their body weight is ~6,000 shrimp m^{-2} (Jehl and Jellison unpublished). The date that this critical density is reached during the autumn decline in shrimp abundance has shifted to earlier in the year.

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 (α^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:

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

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 α^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 α^B were estimated from previously derived regressions.

During 2007, 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 (α^B) were determined for each sample by fitting a hyperbolic tangent curve to the data using least-squares nonlinear estimation. Chlorophyll-specific maximum carbon uptakes ($P_m{}^B$) rates for samples collected at 2 m depth ranged from 1.9 g C g Chl a^{-1} h^{-1} on 16 April to 25.7 g C g Chl a^{-1} h^{-1} on 14 June (Table 16, Fig. 27), while light-limited rates (α^B) for these samples ranged from 5 to 134 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 1,766 g C m^{-2} during 2007 (Table 17, Figs. 26-27). 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 high rate measured on 14 June 2007 (Fig. 27). Compared to the previous 5 years, 2007 was most similar to 2003, another year in which meromixis was breaking down and nutrient availability was high. Changes in standing algal biomass are a dominant factor in variation in daily and annual primary productivity (Jellison and Melack 1988, 1993b). While the seasonal trends were roughly similar during 2002–07, higher peak rates in late May and higher algal biomass in late summer in both 2003 and 2007 (Figs. 27–28) led to the highest estimates of annual primary productivity in the entire period of record. 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, and 0.9 to 15.4 g C m^{-2} in 2002, 2003, 2004, 2005, 2006, and 2007, respectively (Fig. 28).

Annual primary production in 2007 was 2.8 times higher than the long-term mean (1982–2007) of 684 g C m^{-2} (Table 17, Fig. 29). 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 2007, *Artemia* biomass was 0.0 g dry weight m^{-2} on 15 February and increased to the yearly peak of 26.5 g dry weight m^{-2} on 2 July. This was slightly less than peak biomass observed in 2005 (30.5 g dry weight m^{-2}) and 2006 (30.7 g dry weight m^{-2}). *Artemia* biomass remained above 20 g dry weight m^{-2} through 16 August and then decreased to 5.9 g dry weight m^{-2} on 17 September and to 1.1 g dry weight m^{-2} by 13 October. Biomass was near zero (<0.02 g dry weight m^{-2}) on the November and December surveys. The 2007 mean annual biomass of 7.0 g m^{-2} was 23 % below the long-term (1983-2007) mean of 9.1 g m^{-2} (Table 17, Fig. 30)

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. 31, Table 17). In 2007, total annual naupliar production (0.29 x 10^6 m^{-2}) was slightly less than observed in 2005 (0.31 x 10^6 m^{-2}) and 2006 (0.32 x 10^6 m^{-2}) but still 16 % above the long-term mean of 0.25 x 10^6 m^{-2}.

Total annual cyst production in 2007 was 3.4 x 10^6 m^{-2}, 22 % below the long-term mean of 4.4 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. 32-33). 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. 32, 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. 33) 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. Also, it is clear that any long-term trend in either measure is either small or obscured by the inter-year variation due to varying mixing regimes.

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Table 1. Temperature (ºC) at Station 6, February – December 2007.

Depth (m)	2/15	3/13	4/16	5/14	6/14*	7/20	8/17	9/18	10/14	11/14	12/13
1	2.0	7.1	7.5	13.3	17.2	19.6	20.3	20.1	11.6	10.0	6.5
2	2.1	6.8	7.3	13.2	17.0	19.5	20.3	20.1	11.7	9.4	6.5
3	2.2	6.3	7.2	13.2	17.0	19.5	20.3	20.1	11.7	9.4	6.5
4	2.4	5.4	7.2	12.8	17.0	19.5	20.3	20.1	11.7	9.5	6.5
5	2.5	4.2	7.1	12.4	16.6	19.5	20.3	20.1	11.8	9.6	6.5
6	2.5	2.7	7.1	11.3	16.1	19.5	20.3	20.0	11.8	9.6	6.5
7	2.1	2.5	7.1	10.8	15.8	19.5	20.3	20.0	11.8	9.7	6.5
8	1.8	2.4	7.1	10.3	15.6	19.5	20.4	20.1	11.8	9.9	6.5
9	1.6	2.3	7.1	10.2	15.1	19.4	20.4	20.2	12.0	9.9	6.5
10	1.5	2.2	7.1	10.0	14.5	19.1	20.4	20.2	12.1	10.2	6.5
11	1.4	2.2	7.0	9.6	14.4	18.6	20.4	20.2	12.1	10.2	6.5
12	1.3	2.1	6.8	9.2	13.9	18.2	20.4	20.1	12.1	10.3	6.5
13	1.3	2.1	5.9	8.7	12.9	15.8	20.4	19.9	12.1	10.2	6.5
14	1.3	2.0	4.3	7.6	9.7	10.9	19.1	19.0	12.1	10.2	6.5
15	1.3	2.0	3.4	6.0	6.8	8.5	14.7	16.1	12.1	10.2	6.5
16	1.4	2.1	3.1	4.7	5.5	7.6	10.4	12.8	12.1	10.1	6.5
17	1.4	2.2	2.9	3.8	4.6	6.9	8.8	8.5	12.0	10.1	6.5
18	1.5	2.3	3.0	3.4	4.4	4.9	6.0	6.7	12.0	10.1	6.5
19	1.7	2.4	3.1	3.2	4.0	4.5	5.1	5.7	12.0	10.1	6.5
20	2.3	2.5	3.1	3.2	3.9	4.3	4.8	5.2	12.0	10.1	6.5
21	2.8	2.6	3.1	3.2	3.8	4.3	4.5	4.9	9.5	10.1	6.5
22	3.1	2.9	3.2	3.2	3.7	4.0	4.3	4.5	9.2	10.1	6.5
23	3.5	3.0	3.3	3.2	3.6	3.9	4.2	4.3	7.6	10.0	6.5
24	4.0	3.3	3.3	3.3	3.6	3.9	4.1	4.1	7.5	10.1	6.5
25	4.2	3.5	3.4	3.3	3.6	3.8	4.0	4.1	7.3	10.1	6.5
26	4.3	3.7	3.4	3.3	3.5	3.7	4.0	4.1	7.3	10.0	6.5
27	4.5	3.9	3.4	3.4	3.5	3.7	4.0	4.0	7.0	10.0	6.5
28	4.5	4.0	3.4	3.4	3.5	3.7	3.9	4.0	6.8	10.0	6.5
29	4.7	4.1	3.6	3.4	3.5	3.6	3.8	4.0	6.2	9.9	6.5
30	4.8	4.2	3.6	3.4	3.5	3.6	3.8	3.9	6.1	9.8	6.5
31	4.8	4.3	3.6	3.5	3.5	3.6	3.8	3.9	6.1	9.5	6.5
32	4.9	4.3	3.6	3.5	3.5	3.6	3.8	3.8	6.0	9.4	6.4
33	4.9	4.4	3.7	3.5	3.5	3.6	3.7	3.8	6.0	9.3	6.4
34	5.0	4.4	-	3.5	3.5	3.6	3.7	3.8	6.1	9.3	6.2
35	5.0	4.4	-	3.6	3.5	3.6	3.7	3.8	6.2	9.1	-
36	5.0	4.4	-	3.6	3.5	3.6	3.7	3.8	6.3	-	-
37	5.0	-	-	3.6	-	3.6	3.7	3.8	6.1	-	-
38	5.0	-	-	3.6	-	-	3.7	-	6.0	-	-

*Station 12 shown due to probe failure at Station 6

Table 2. Conductivity (mS cm^{-1} at 25ºC) at Station 6, February – December 2007.

Depth (m)	2/15	3/13	4/16	5/14	6/14*	7/20	8/17	9/18	10/14	11/14	12/13
1	78.7	78.2	79.3	79.1	79.7	79.8	80.7	81.0	81.0	80.8	81.4
2	78.9	78.9	79.4	79.2	79.7	79.8	80.7	81.0	81.1	80.8	81.4
3	78.8	79.0	79.4	79.2	79.7	79.8	80.7	81.0	81.1	80.8	81.4
4	79.1	79.2	79.4	79.3	79.7	79.8	80.7	81.0	81.1	80.9	81.4
5	79.1	79.2	79.4	79.2	79.7	79.8	80.7	81.0	81.1	80.9	81.4
6	79.4	79.3	79.4	79.2	79.7	79.9	80.7	81.0	81.1	80.9	81.4
7	79.4	79.2	79.4	79.3	79.7	79.9	80.7	81.1	81.1	80.9	81.4
8	79.4	79.2	79.4	79.2	79.7	79.8	80.7	81.1	81.1	81.0	81.4
9	79.5	79.2	79.4	79.3	79.6	79.8	80.7	81.2	81.2	81.0	81.4
10	79.5	79.2	79.4	79.3	79.6	79.8	80.7	81.2	81.3	81.1	81.4
11	79.6	79.3	79.4	79.2	79.6	79.6	80.7	81.2	81.2	81.1	81.3
12	79.6	79.3	79.3	79.2	79.5	79.6	80.7	81.1	81.2	81.1	81.3
13	79.6	79.4	80.3	79.2	79.5	78.3	80.7	81.1	81.2	81.1	81.3
14	79.6	79.4	80.3	79.0	79.2	78.8	80.4	80.9	81.3	81.1	81.3
15	79.6	79.5	80.1	79.0	79.1	78.5	78.9	80.3	81.3	81.1	81.3
16	79.6	79.6	80.0	79.3	79.5	79.1	79.1	79.5	81.3	81.1	81.3
17	79.6	79.6	80.0	79.6	79.7	79.1	79.4	79.6	81.2	81.1	81.3
18	79.7	79.8	80.0	80.0	79.8	79.8	79.1	79.8	81.3	81.1	81.3
19	79.8	79.9	80.1	80.2	80.1	80.2	80.1	80.2	81.3	81.1	81.3
20	79.9	79.9	80.2	80.3	80.3	80.2	80.3	80.2	81.2	81.1	81.3
21	80.5	80.0	80.3	80.4	80.3	80.3	80.3	80.1	80.9	81.1	81.3
22	80.5	80.3	80.4	80.6	80.3	80.3	80.4	80.3	80.7	81.1	81.2
23	80.9	80.4	80.5	80.6	80.4	80.4	80.4	80.4	80.6	81.1	81.2
24	81.2	80.7	80.6	80.7	80.4	80.4	80.4	80.4	80.7	81.1	81.2
25	81.5	80.9	80.7	80.8	80.5	80.4	80.5	80.4	80.8	81.1	81.2
26	81.6	81.1	80.7	80.8	80.6	80.5	80.5	80.4	80.8	81.1	81.2
27	81.6	81.2	80.7	80.8	80.6	80.5	80.5	80.4	80.8	81.1	81.2
28	81.7	81.2	80.8	80.8	80.7	80.5	80.6	80.4	80.7	81.2	81.2
29	81.6	81.3	81.0	80.8	80.7	80.6	80.6	80.3	80.7	81.2	81.2
30	81.8	81.4	81.0	80.8	80.7	80.6	80.6	80.4	80.8	81.2	81.2
31	81.7	81.4	81.0	80.8	80.7	80.6	80.6	80.4	80.8	81.2	81.2
32	81.7	81.4	81.1	80.8	80.7	80.6	80.6	80.4	80.7	81.2	81.2
33	81.7	81.4	81.1	80.9	80.7	80.6	80.6	80.4	80.8	81.2	81.1
34	81.7	81.4	-	80.9	80.7	80.6	80.6	80.4	80.8	81.3	81.1
35	81.7	81.4	-	80.9	80.7	80.6	80.7	80.4	80.9	81.3	-
36	81.8	81.4	-	80.9	80.7	80.7	80.7	80.3	80.9	-	-
37	81.8	-	-	80.9	-	80.6	80.6	80.3	80.8	-	-
38	81.8	-	-	80.8	-	-	80.6	-	80.8	-	-

*Station 12 shown due to probe failure at Station 6

Table 3. Excess density (kg m^{-3}) at Station 6, February – December 2007.

Depth (m)	2/15	3/13	4/16	5/14	6/14*	7/20	8/17	9/18	10/14	11/14	12/13
1	67.9	66.6	67.8	66.3	65.9	65.2	66.0	66.4	68.9	69.0	70.4
2	68.1	67.5	67.9	66.4	65.9	65.2	66.0	66.4	68.9	69.1	70.4
3	68.0	67.7	67.9	66.5	65.9	65.2	66.0	66.5	69.0	69.2	70.4
4	68.4	68.0	68.0	66.7	65.9	65.2	66.0	66.4	69.0	69.2	70.4
5	68.3	68.2	68.0	66.6	66.0	65.3	66.0	66.4	69.0	69.2	70.4
6	68.6	68.5	68.0	66.9	66.1	65.3	66.0	66.4	69.0	69.2	70.4
7	68.7	68.5	67.9	67.1	66.3	65.3	66.0	66.5	69.0	69.2	70.4
8	68.8	68.5	67.9	67.1	66.3	65.3	66.0	66.5	69.0	69.2	70.4
9	68.9	68.5	68.0	67.2	66.3	65.3	66.0	66.6	69.0	69.3	70.4
10	68.9	68.5	68.0	67.2	66.5	65.3	66.0	66.5	69.0	69.3	70.4
11	69.0	68.6	67.9	67.3	66.6	65.3	66.0	66.6	69.0	69.3	70.3
12	69.0	68.6	67.9	67.3	66.6	65.4	66.0	66.6	69.0	69.3	70.3
13	69.0	68.7	69.2	67.4	66.8	64.7	65.9	66.6	69.0	69.3	70.3
14	69.0	68.7	69.5	67.4	67.3	66.5	66.0	66.6	69.1	69.3	70.3
15	69.1	68.8	69.3	67.6	67.7	66.7	65.7	66.8	69.1	69.3	70.3
16	69.1	68.9	69.3	68.3	68.3	67.5	66.9	66.9	69.1	69.3	70.3
17	69.1	69.0	69.3	68.7	68.8	67.7	67.7	67.9	69.1	69.3	70.3
18	69.1	69.1	69.4	69.3	68.9	68.8	67.8	68.5	69.1	69.3	70.3
19	69.2	69.2	69.4	69.5	69.3	69.3	69.2	69.1	69.1	69.3	70.3
20	69.2	69.3	69.5	69.6	69.5	69.4	69.4	69.3	69.0	69.3	70.3
21	69.9	69.4	69.7	69.8	69.5	69.5	69.5	69.2	69.2	69.3	70.3
22	69.9	69.6	69.7	70.0	69.6	69.5	69.6	69.5	69.1	69.3	70.2
23	70.3	69.7	69.8	70.0	69.7	69.6	69.6	69.7	69.3	69.4	70.2
24	70.6	70.0	70.0	70.0	69.7	69.7	69.6	69.6	69.4	69.4	70.2
25	70.8	70.2	70.0	70.2	69.8	69.7	69.7	69.6	69.5	69.4	70.2
26	70.9	70.4	70.1	70.2	69.9	69.8	69.8	69.6	69.6	69.4	70.2
27	71.0	70.6	70.1	70.2	70.0	69.8	69.8	69.6	69.6	69.4	70.2
28	71.1	70.6	70.2	70.2	70.0	69.8	69.9	69.6	69.5	69.4	70.2
29	71.0	70.7	70.4	70.2	70.1	69.9	69.9	69.6	69.6	69.5	70.1
30	71.1	70.7	70.4	70.2	70.0	69.9	69.9	69.6	69.7	69.5	70.1
31	71.1	70.7	70.4	70.2	70.1	69.9	69.9	69.6	69.7	69.6	70.1
32	71.1	70.7	70.5	70.2	70.1	69.9	70.0	69.6	69.7	69.6	70.1
33	71.1	70.8	70.5	70.2	70.1	69.9	70.0	69.6	69.7	69.7	70.1
34	71.1	70.8	-	70.2	70.1	70.0	70.0	69.6	69.8	69.7	70.1
35	71.1	70.8	-	70.3	70.1	70.0	70.0	69.6	69.9	69.7	-
36	71.1	70.8	-	70.2	70.1	70.0	70.0	69.6	69.8	-	-
37	71.1	-	-	70.2	-	70.0	69.9	69.6	69.8	-	-
38	71.1	-	-	70.2	-	-	69.9	-	69.8	-	-

*Station 12 shown due to probe failure at Station 6

Table 4. Temperature, conductivity, and density stratification (kg m^{-3}) at Station 6, February – December 2007 (monthly profiles, bi-weekly surveys).

Date	Temperature		Conductivity		Density Difference due to		
	2 m	32 m	2 m	32 m	Temperature	Conductivity	Both
2/15	2.1	4.9	78.9	81.7	-0.39	3.35	2.97
3/13	6.8	4.3	78.9	81.4	0.41	2.86	3.27
4/16	7.3	3.6	79.4	81.1	0.60	1.99	2.60
5/1	11.8	3.5	79.2	80.8	1.59	1.85	3.44
5/14	13.2	3.5	79.2	80.8	1.92	1.82	3.74
5/30	16.8	3.4	79.2	80.8	2.94	1.90	4.84
6/7	15.1	3.5	79.6	80.7	2.45	1.25	3.70
6/14	17.0	3.5	79.7	80.6	3.01	1.04	4.05
7/2	20.0	3.6	79.8	80.6	3.95	0.93	4.87
7/24	19.5	3.7	79.8	80.5	3.79	0.79	4.58
8/16	20.4	3.8	80.8	80.5	4.06	-0.32	3.75
9/10	20.1	3.8	80.8	80.4	3.97	-0.47	3.51
9/18	20.1	6.0	81.0	80.7	3.62	-0.34	3.27
10/14	11.7	9.4	81.1	81.2	0.51	0.17	0.68
11/14	9.4	6.4	80.8	81.2	0.58	0.41	0.99
12/13	6.5	6.4	81.4	81.2	0.02	-0.31	-0.29

Table 5. Secchi Depths (m), February – December 2007.

	Dates										
Station	2/15	3/13	4/16	5/14	6/14	7/24	8/16	9/17	10/12	11/14	12/13
Western Sector											
1	1.30	1.30	1.10	6.20	10.50	11.50	9.50	2.70	1.00	1.00	-
2	1.30	1.30	1.20	6.40	10.30	12.60	9.50	2.40	1.05	1.00	-
3	1.50	1.20	1.20	4.90	10.00	11.20	8.50	2.50	0.90	0.95	-
4	1.60	1.40	1.60	4.50	9.60	11.20	8.10	2.50	0.90	0.95	1.10
5	1.40	1.40	1.40	5.60	10.50	10.30	10.30	2.20	0.90	0.95	-
6	1.40	1.20	1.40	5.40	10.90	9.60	7.50	2.50	1.00	0.95	1.10
Avg.	1.42	1.30	1.32	5.50	10.30	11.07	8.90	2.47	0.96	0.97	1.10
S.E.	0.05	0.04	0.07	0.30	0.18	0.42	0.43	0.07	0.03	0.01	0.00
n	6	6	6	6	6	6	6	6	6	6	2
Eastern Sector											
7	1.30	1.30	1.60	7.60	11.20	10.00	7.60	2.40	1.00	0.95	-
8	1.30	1.60	1.20	7.20	12.40	9.40	7.70	2.20	1.00	0.95	-
9	1.30	1.60	1.30	6.40	12.60	10.40	8.60	2.60	1.00	0.95	-
10	1.40	1.40	1.20	6.70	10.80	11.20	8.90	2.70	1.20	1.00	-
11	1.40	1.30	1.10	7.30	10.50	10.00	7.80	2.60	1.10	0.95	-
12	1.40	1.40	1.20	6.60	11.60	10.00	7.90	2.50	1.10	0.95	-
Avg.	1.35	1.43	1.27	6.97	11.52	10.17	8.08	2.50	1.07	0.96	-
S.E.	0.02	0.06	0.07	0.19	0.35	0.24	0.22	0.00	1.00	2.00	-
n	6	6	6	6	6	6	6	6	6	6	0
Total Lakewide											
Avg.	1.38	1.37	1.29	6.23	10.91	10.62	8.49	2.48	1.01	0.96	1.10
S.E.	0.03	0.04	0.05	0.28	0.26	0.27	0.26	0.05	0.03	0.01	0.00
n	12	12	12	12	12	12	12	12	12	12	2

Table 6: Dissolved Oxygen (mg l^{-1}) at Station 6, February – December 2007.

Depth (m)	2/15	3/17	4/16	5/14	6/14	7/20	8/17	10/14	11/14	12/13
0	5.8	5.9	6.0	4.4	3.5	3.5	3.8	2.0	3.7	4.5
1	6.2	6.9	6.1	4.6	3.5	3.5	3.8	1.6	4.5	4.4
2	6.5	7.5	6.4	4.6	3.5	3.6	3.8	1.4	4.6	4.2
3	6.6	7.6	6.5	4.5	3.6	3.4	3.8	1.1	4.2	4.2
4	6.5	7.7	6.5	4.4	3.6	3.3	3.8	1.1	3.0	4.1
5	6.5	8.1	6.5	4.5	3.7	3.4	3.8	1.1	2.5	4.2
6	6.2	7.5	6.4	5.2	3.6	3.5	3.8	1.2	2.3	4.2
7	6.0	6.8	6.3	5.3	3.7	3.6	3.8	1.2	2.2	4.1
8	5.4	6.2	6.3	5.6	3.7	3.6	3.8	1.3	1.3	4.0
9	5.3	5.4	6.3	5.6	3.8	3.6	3.8	1.8	1.3	4.0
10	4.5	5.1	6.2	5.6	3.7	3.4	3.8	2.3	1.6	3.9
11	4.2	4.7	6.0	5.6	3.2	3.1	3.8	2.1	1.4	3.8
12	4.2	4.0	5.1	5.2	2.7	3.0	3.8	1.9	1.4	3.8
13	3.9	3.1	2.6	4.8	1.5	2.5	3.7	1.9	1.2	3.7
14	3.4	2.5	0.6	4.2	0.8	0.8	2.5	1.9	1.0	3.7
15	2.9	1.8	<0.5	0.8	<0.5	0.6	1.1	2.0	0.5	3.7
16	2.8	1.3	<0.5	<0.5	<0.5	<0.5	0.6	2.0	0.2	3.7
17	2.8	0.8	<0.5	<0.5	-	-	<0.5	1.8	1.1	3.7
18	2.4	<0.5	<0.5	<0.5	-	-	<0.5	1.6	2.0	3.7
19	1.0	<0.5	-	<0.5	-	-	<0.5	1.6	2.3	3.7
20	<0.5	<0.5	-	-	-	-	<0.5	1.6	1.9	3.7
21	<0.5	-	-	-	-	-	<0.5	1.0	2.7	3.7
22	<0.5	-	-	-	-	-	<0.5	<0.5	1.8	3.7
23	<0.5	-	-	-	-	-	<0.5	<0.5	0.5	3.7
24	<0.5	-	-	-	-	-	<0.5	-	<0.5	3.7
25	<0.5	-	-	-	-	-	<0.5	-	<0.5	3.7
26	<0.5	-	-	-	-	-	<0.5	-	<0.5	3.7
27	<0.5	-	-	-	-	-	<0.5	-	<0.5	3.7
28	<0.5	-	-	-	-	-	<0.5	-	-	3.7
29	<0.5	-	-	-	-	-	-	-	-	3.7
30	-	-	-	-	-	-	-	-	-	3.7
31	-	-	-	-	-	-	-	-	-	3.7
32	-	-	-	-	-	-	-	-	-	3.7
33	-	-	-	-	-	-	-	-	-	3.7
34	-	-	-	-	-	-	-	-	-	3.7
35	-	-	-	-	-	-	-	-	-	3.9
36	-	-	-	-	-	-	-	-	-	4.0
37	-	-	-	-	-	-	-	-	-	4.0

Table 7. Ammonium (µM) at Station 6, February – December 2007.

Depth (m)	2/15	3/13	4/16	5/14	6/14	7/20	8/17	9/18	10/14	11/14	12/13
1	-	-	-	-	-	-	-	-	-	-	-
2	0.7	1.0	1.4	1.9	6.1	3.9	0.4	0.3	6.8	0.3	6.8
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	0.8	1.0	1.2	1.4	6.4	2.4	0.8	0.3	6.9	4.0	6.1
9	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	0.8	1.8	1.3	1.0	5.4	4.3	0.9	0.6	3.1	5.1	6.5
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-
16	0.9	2.0	9.4	1.1	14.1	2.8	5.1	5.1	3.9	7.9	6.4
17	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	8.1	20.0	41.2	43.7	63.0	66.5	57.8	61.5	5.9	2.4	6.6
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	59.1	44.3	83.0	70.8	87.7	75.8	80.7	73.2	58.3	3.0	6.6
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	79.7	86.8	81.1	98.6	98.0	87.1	101.2	92.0	63.8	6.5	6.0
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-
35	113.3	104.7	107.7	98.2	115.9	94.4	112.9	108.4	79.0	22.2	5.5
36	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-

Table 8. Ammonium (µM) at 7 stations in upper 9 m of water column, February – November, 2007.

Station	2/15	3/13	4/16	5/14	6/14	7/24	8/16	9/17	10/12	11/14
1	0.7	1.6	1.3	1.5	8.5	5.2	2.3	0.9	4.2	3.0
2	0.7	1.2	1.3	2.3	6.5	4.6	2.2	1.5	6.2	2.5
5	0.7	1.3	1.2	1.2	6.2	3.8	1.6	1.1	4.8	6.0
6	0.7	1.0	1.2	1.3	6.2	2.3	0.7	1.0	6.8	1.1
7	0.7	1.0	1.3	3.0	5.7	1.3	0.9	0.9	3.3	0.4
8	0.7	1.0	1.2	1.9	6.4	1.0	0.8	0.8	3.9	1.1
11	0.6	1.2	1.2	3.2	6.7	1.9	0.6	0.8	2.1	0.3
Mean	0.7	1.2	1.2	2.1	6.6	2.9	1.3	1.0	4.5	2.1
SE	0.01	0.08	0.03	0.30	0.33	0.63	0.27	0.10	0.62	0.75

Table 9. Chlorophyll *a* ($\mu g\ l^{-3}$) at Station 6, February – December 2007.

Depth (m)	2/15	3/13	4/16	5/14	6/14	7/20	8/17	9/18	10/14	11/14	12/13
1	-	-	-	-	-	-	-	-	-	-	-
2	16.4	9.6	19.6	1.6	1.0	1.2	3.1	13. 8	46.8	85.7	66.2
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	30.8	32.5	21.0	3.9	1.2	1.8	2.8	10.2	44.0	60.3	48.4
9	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	37.3	46.9	34.5	12.0	1.9	1.1	2.7	9.7	46.9	58.4	52.6
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-
16	33.9	28.2	46.0	79.0	25.8	9.2	5.7	10.6	44.9	51.1	69.8
17	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	23.2	24.4	34.7	32.9	30.3	32.3	47.5	28.7	42.2	63.9	62.4
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	42.9	31.3	37.6	36.3	32.9	33.1	36.3	37.4	36.3	59.1	66.5
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	49.1	39.7	38.5	33.7	32.4	33.1	33.8	34.2	33.3	58.5	69.5

Table 10. Chlorophyll *a* (µg l^{-3}) at 7 stations in upper 9 m of water column, February – November 2007.

Station	2/15	3/13	4/16	5/14	6/14	7/24	8/16	9/17	10/12	11/14
1	22.3	17.4	16.6	1.8	0.7	0.9	2.0	10.8	43.3	68.5
2	21.3	22.1	16.3	2.0	1.0	0.7	1.8	12.7	43.6	69.5
5	23.7	17.9	19.4	2.3	1.2	0.9	1.5	14.4	50.0	54.3
6	21.5	19.7	19.8	2.5	1.1	1.0	3.3	14.6	45.1	81.1
7	21.9	18.1	19.8	1.2	1.1	1.6	3.2	9.6	44.7	81.8
8	20.1	20.7	19.1	1.5	0.8	1.8	2.3	12.8	45.4	70.9
11	21.9	15.2	15.4	1.4	0.5	1.1	2.4	7.9	44.8	71.5
Mean	21.8	18.7	18.1	1.8	0.9	1.1	2.4	11.9	45.3	71.1
SE	0.42	0.86	0.71	0.19	0.10	0.15	0.26	0.94	0.84	3.48

Table 11a. *Artemia* lake and sector means, 2007.

	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:										
2/15	2,713	0	0	0	0	0	0	0	0	2,713
3/13	14,375	0	0	0	0	0	0	0	0	14,375
4/16	51,898	0	0	0	0	0	0	0	0	51,898
5/1	44,941	2,653	376	0	1,636	0	0	1,636	2,012	49,606
5/14	50,543	4,708	9,618	54	11,174	0	0	11,227	20,845	76,097
5/30	41,516	5,245	18,913	1,717	18,833	791	429	21,771	40,684	87,445
6/14	24,936	3,595	20,858	765	15,614	2,414	456	19,249	40,107	68,638
7/2	15,037	624	23,850	1,958	9,920	5,533	490	17,901	41,751	57,411
7/24	5,822	282	21,764	731	4,527	7,619	315	13,192	34,956	41,060
8/16	2,830	0	15,580	858	1,362	6,030	335	8,585	24,165	26,995
9/17&18	1,135	82	2,733	55	59	875	77	1,066	3,799	5,017
10/12&14	624	64	686	20	139	92	2	253	939	1,626
11/14	104	8	13	0	8	0	0	8	22	134
12/13	101	0	10	0	0	0	0	0	10	111
Western Sector Mean:										
2/15	1,395	0	0	0	0	0	0	0	0	1,395
3/13	4,349	0	0	0	0	0	0	0	0	4,349
4/16	47,431	0	0	0	0	0	0	0	0	47,431
5/1	23,431	2,086	268	0	778	0	0	778	1,046	26,563
5/14	41,154	4,051	7,700	107	8,719	0	0	8,826	16,526	61,730
5/30	38,203	4,024	17,223	1,771	14,594	537	537	17,438	34,661	76,888
6/14	19,477	3,273	21,891	644	14,111	3,005	429	18,189	40,080	62,830
7/2	17,250	926	32,408	2,334	10,825	6,533	604	20,295	52,703	70,879
7/24	3,675	537	28,947	1,019	6,948	7,968	268	16,204	45,151	49,363
8/16	2,093	0	17,653	1,261	1,985	5,929	376	9,551	27,203	29,296
9/17&18	855	91	2,763	23	70	939	67	1,100	3,863	4,809
10/12&14	168	40	399	20	91	80	3	195	594	801
11/14	94	10	3	0	0	0	0	0	3	107
12/13	101	0	10	0	0	0	0	0	10	111
Eastern Sector Mean:										
2/15	4,031	0	0	0	0	0	0	0	0	4,031
3/13	24,400	0	0	0	0	0	0	0	0	24,400
4/16	56,365	0	0	0	0	0	0	0	0	56,365
5/1	66,452	3,219	483	0	2,495	0	0	2,495	2,978	72,649
5/14	59,933	5,366	11,536	0	13,628	0	0	13,628	25,164	90,463
5/30	44,829	6,465	20,604	1,663	23,072	1,046	322	26,103	46,707	98,001
6/14	30,396	3,917	19,826	885	17,116	1,824	483	20,309	40,134	74,447
7/2	12,824	322	15,292	1,583	9,014	4,534	376	15,506	30,798	43,944
7/24	7,968	27	14,581	443	2,106	7,270	362	10,181	24,762	32,757
8/16	3,568	0	13,508	456	738	6,130	295	7,619	21,127	24,695
9/17&18	1,415	74	2,703	87	47	812	87	1,033	3,736	5,225
10/12&14	1,080	87	973	20	188	104	0	312	1,284	2,451
11/14	114	7	23	0	17	0	0	17	40	161
12/13										

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

Table 11b. Standard errors of *Artemia* sector means (Table 11a), 2007.

	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:										
2/15	624	0	0	0	0	0	0	0	0	624
3/13	5,715	0	0	0	0	0	0	0	0	5,715
4/16	8,899	0	0	0	0	0	0	0	0	8,899
5/1	11,009	853	155	0	758	0	0	758	900	12,628
5/14	8,837	716	2,292	54	2,207	0	0	2,208	4,478	11,439
5/30	5,413	954	2,827	495	3,154	202	183	3,594	6,333	11,136
6/14	3,099	537	1,980	162	1,910	473	74	2,191	3,649	6,148
7/2	2,279	202	4,611	410	2,006	1,383	159	3,536	7,681	9,391
7/24	1,063	146	3,121	224	940	1,205	107	1,907	4,444	4,374
8/16	495	0	1,358	170	268	732	61	1,020	2,051	2,260
9/17&18	138	16	339	16	11	134	18	147	450	479
10/12&14	173	16	181	7	32	29	2	47	203	324
11/14	19	3	5	0	4	0	0	4	7	22
12/13	101	0	10	0	0	0	0	0	10	111
SE of Western Sector Mean:										
2/15	300	0	0	0	0	0	0	0	0	300
3/13	1,380	0	0	0	0	0	0	0	0	1,380
4/16	6,900	0	0	0	0	0	0	0	0	6,900
5/1	3,580	462	90	0	244	0	0	244	259	4,206
5/14	7,849	1,039	1,795	107	1,749	0	0	1,787	3,517	9,840
5/30	5,222	940	3,852	674	3,659	215	307	4,057	7,860	9,383
6/14	1,703	759	3,205	220	1,300	796	107	1,739	4,173	6,139
7/2	2,356	369	7,058	509	2,965	2,298	288	5,088	11,524	12,744
7/24	647	258	1,979	402	1,201	1,916	211	2,927	3,838	3,914
8/16	591	0	1,518	218	385	965	90	1,494	2,010	2,414
9/17&18	138	24	616	13	18	206	12	211	764	843
10/12&14	84	17	96	9	27	53	3	65	146	221
11/14	36	4	3	0	0	0	0	0	3	39
12/13	101	0	10	0	0	0	0	0	10	111
SE of Eastern Sector Mean:										
2/15	964	0	0	0	0	0	0	0	0	964
3/13	10,080	0	0	0	0	0	0	0	0	10,080
4/16	17,113	0	0	0	0	0	0	0	0	17,113
5/1	18,313	1,691	305	0	1,475	0	0	1,475	1,767	21,716
5/14	15,706	1,003	4,292	0	3,995	0	0	3,995	8,271	19,908
5/30	9,863	1,590	4,380	790	4,817	327	220	5,732	10,010	20,322
6/14	5,239	808	2,558	248	3,669	460	110	4,201	6,416	10,730
7/2	3,918	83	3,800	652	2,929	1,653	154	5,180	8,875	12,372
7/24	1,646	27	4,277	158	320	1,635	71	1,951	5,531	6,425
8/16	714	0	2,021	121	107	1,192	87	1,403	3,283	3,812
9/17&18	181	24	357	24	12	187	35	223	552	531
10/12&14	203	24	319	13	52	27	0	65	334	374
11/14	16	4	6	0	6	0	0	6	9	16
12/13										

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

Table 11c. Percentage in different classes for *Artemia* sector means (Table 11a), 2007.

	Instars		adult	adult	adult	adult	adult	adult	adult	
	1-7	8-11	male	fem ?	fem e	fem c	fem n	fem tot	total	total
Lakewide (%):										
2/15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4/16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/1	90.6	5.3	0.8	0.0	100.0	0.0	0.0	3.3	4.1	100
5/14	66.4	6.2	12.6	100.0	99.5	0.0	0.0	14.8	27.4	100
5/30	47.5	6.0	21.6	58.4	86.5	26.9	14.6	24.9	46.5	100
6/14	36.3	5.2	30.4	21.0	81.1	66.4	12.5	28.0	58.4	100
7/2	26.2	1.1	41.5	24.5	55.4	69.3	6.1	31.2	72.7	100
7/24	14.2	0.7	53.0	8.4	34.3	87.9	3.6	32.1	85.1	100
8/16	10.5	0.0	57.7	11.9	15.9	83.5	4.6	31.8	89.5	100
9/17&18	22.6	1.6	54.5	5.5	5.5	86.9	7.7	21.3	75.7	100
10/12&14	38.4	3.9	42.2	17.6	55.0	80.9	1.5	15.6	57.7	100
11/14	77.5	6.3	10.0	0.0	100.0	0.0	0.0	6.3	16.3	100
12/13	90.9	0.0	9.1	0.0	0.0	0.0	0.0	0.0	9.1	100
Western Sector (%):										
2/15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4/16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/1	88.2	7.9	1.0	0.0	100.0	0.0	0.0	2.9	3.9	100
5/14	66.7	6.6	12.5	100.0	8125.0	0.0	0.0	14.3	26.8	100
5/30	49.7	5.2	22.4	62.3	513.2	18.9	18.9	22.7	45.1	100
6/14	31.0	5.2	34.8	15.8	346.1	73.7	10.5	28.9	63.8	100
7/2	24.3	1.3	45.7	24.6	114.3	69.0	6.4	28.6	74.4	100
7/24	7.4	1.1	58.6	11.0	75.1	86.1	2.9	32.8	91.5	100
8/16	7.1	0.0	60.3	16.7	26.2	78.4	5.0	32.6	92.9	100
9/17&18	17.8	1.9	57.5	2.3	6.8	91.2	6.5	22.9	80.3	100
10/12&14	20.9	5.0	49.8	19.4	87.1	77.4	3.2	24.3	74.1	100
11/14	87.5	9.4	3.1	0.0	0.0	0.0	0.0	0.0	3.1	100
12/13	90.9	0.0	9.1	0.0	0.0	0.0	0.0	0.0	9.1	100
Eastern Sector (%):										
2/15	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4/16	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/1	91.5	4.4	0.7	0.0	100.0	0.0	0.0	3.4	4.1	100
5/14	66.3	5.9	12.8	0.0	100.0	0.0	0.0	15.1	27.8	100
5/30	45.7	6.6	21.0	54.9	88.4	34.5	10.6	26.6	47.7	100
6/14	40.8	5.3	26.6	27.7	84.3	57.1	15.1	27.3	53.9	100
7/2	29.2	0.7	34.8	24.4	58.1	69.8	5.8	35.3	70.1	100
7/24	24.3	0.1	44.5	5.5	20.7	90.0	4.5	31.1	75.6	100
8/16	14.4	0.0	54.7	6.6	9.7	89.1	4.3	30.9	85.6	100
9/17&18	27.1	1.4	51.7	8.8	4.5	82.3	8.8	19.8	71.5	100
10/12&14	44.0	3.6	39.7	16.2	60.2	83.8	0.0	12.7	52.4	100
11/14	70.8	4.2	14.6	0.0	100.0	0.0	0.0	10.4	25.0	100
12/13										

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

Table 12. Lakewide *Artemia* instar analysis, 2007.

				Instars						
	1	2	3	4	5	6	7	8-11	adults	total
Mean:										
2/15	2,961	6	0	0	0	0	0	0	0	2,966
3/13	11,676	72	0	0	0	0	0	0	0	11,748
4/16	12,279	14,372	11,498	11,337	6,071	1,656	207	0	0	57,419
5/1	4,921	4,642	5,424	6,220	4,062	3,415	2,966	1,650	1,081	34,381
5/14	7,818	5,381	8,140	6,853	6,899	5,611	4,185	5,151	25,892	75,930
5/30	18,396	6,508	2,989	4,530	4,231	2,529	1,541	4,070	33,872	78,666
6/14	15,867	3,242	0	552	1,127	1,357	1,150	3,403	38,402	65,099
7/2	8,083	6,611	23	0	0	138	207	701	31,607	47,370
7/24	3,012	1,587	230	23	0	0	0	299	35,114	40,264
8/16	1,035	1,253	103	92	0	0	0	0	24,225	26,709
9/17&18	172	282	161	262	144	121	69	72	4,404	5,686
10/12&14	43	55	52	83	103	46	23	69	790	1,265
11/14	40	23	6	17	9	0	3	6	14	118
12/13*	60	80	0	0	0	60	0	0	20	221
Standard error of the mean:										
2/15	971	4	0	0	0	0	0	0	0	972
3/13	5,066	44	0	0	0	0	0	0	0	5,082
4/16	2,864	4,491	3,093	2,364	1,815	408	91	0	0	14,570
5/1	998	1,733	1,938	1,802	805	1,047	852	320	340	7,185
5/14	1,468	1,308	2,456	1,592	1,369	947	840	986	6,688	12,158
5/30	2,892	1,030	1,067	1,077	1,185	704	632	1,363	8,492	14,762
6/14	2,911	1,040	0	207	105	514	170	570	4,079	6,261
7/2	1,325	1,483	23	0	0	96	115	321	8,931	11,016
7/24	811	540	135	23	0	0	0	223	5,599	6,008
8/16	213	537	46	59	0	0	0	0	3,298	3,661
9/17&18	55	106	50	40	28	33	14	20	689	716
10/12&14	29	24	21	33	30	17	11	27	222	321
11/14	18	13	6	8	4	0	3	4	10	33
12/13*										
Percentage in different age classes:										
2/15	99.8	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3/13	99.4	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4/16	21.4	25.0	20.0	19.7	10.6	2.9	0.4	0.0	0.0	100
5/1	14.3	13.5	15.8	18.1	11.8	9.9	8.6	4.8	3.1	100
5/14	10.3	7.1	10.7	9.0	9.1	7.4	5.5	6.8	34.1	100
5/30	23.4	8.3	3.8	5.8	5.4	3.2	2.0	5.2	43.1	100
6/14	24.4	5.0	0.0	0.8	1.7	2.1	1.8	5.2	59.0	100
7/2	17.1	14.0	0.0	0.0	0.0	0.3	0.4	1.5	66.7	100
7/24	7.5	3.9	0.6	0.1	0.0	0.0	0.0	0.7	87.2	100
8/16	3.9	4.7	0.4	0.3	0.0	0.0	0.0	0.0	90.7	100
9/17&18	3.0	5.0	2.8	4.6	2.5	2.1	1.2	1.3	77.5	100
10/12&14	3.4	4.3	4.1	6.6	8.2	3.6	1.8	5.5	62.5	100
11/14	34.1	19.5	4.9	14.6	7.3	0.0	2.4	4.9	12.2	100
12/13*	27.3	36.4	0.0	0.0	0.0	27.3	0.0	0.0	9.1	100

All data in this table are from stations 1, 2, 5, 6, 7, 8, and 11 only.
12/13* All data from station 6.

Table 13a. *Artemia* reproductive summary, lake and sector means, 2007.

	Adult Females					
	Total	Ovigery	e	?	c	n
Lakewide Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	1,636	0	1,636	0	0	0
5/14	11,227	54	11,174	54	0	0
5/30	21,771	2,938	18,833	1,717	791	429
6/14	19,249	3,635	15,614	765	2,414	456
7/2	17,901	7,981	9,920	1,958	5,533	490
7/24	13,192	8,665	4,527	731	7,619	315
8/16	8,585	7,223	1,362	858	6,030	335
9/17&18	1,066	1,008	59	55	875	77
10/12&14	253	114	139	20	92	2
11/14	8	0	8	0	0	0
12/13	0	0	0	0	0	0
Western Sector Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	778	0	778	0	0	0
5/14	8,826	107	8,719	107	0	0
5/30	17,438	2,844	14,594	1,771	537	537
6/14	18,189	4,078	14,111	644	3,005	429
7/2	20,295	9,470	10,825	2,334	6,533	604
7/24	16,204	9,256	6,948	1,019	7,968	268
8/16	9,551	7,565	1,985	1,261	5,929	376
9/17&18	1,100	1,030	70	23	939	67
10/12&14	195	104	91	20	80	3
11/14	0	0	0	0	0	0
12/13	0	0	0	0	0	0
Eastern Sector Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	2,495	0	2,495	0	0	0
5/14	13,628	0	13,628	0	0	0
5/30	26,103	3,032	23,072	1,663	1,046	322
6/14	20,309	3,192	17,116	885	1,824	483
7/2	15,506	6,492	9,014	1,583	4,534	376
7/24	10,181	8,075	2,106	443	7,270	362
8/16	7,619	6,881	738	456	6,130	295
9/17&18	1,033	986	47	87	812	87
10/12&14	312	124	188	20	104	0
11/14	17	0	17	0	0	0
12/13	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), 2007.

	Adult Females					
	Total	Ovigery	e	?	c	n
Standard Error of Lakewide Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	758	0	758	0	0	0
5/14	2,208	18	2,207	54	0	0
5/30	3,594	205	3,154	495	202	183
6/14	2,191	219	1,910	162	473	74
7/2	3,536	591	2,006	410	1,383	159
7/24	1,907	692	940	224	1,205	107
8/16	1,020	498	268	170	732	61
9/17&18	147	78	11	16	134	18
10/12&14	47	12	32	7	29	2
11/14	4	0	4	0	0	0
12/13	0	0	0	0	0	0
Standard Error of Western Sector Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	244	0	244	0	0	0
5/14	1,787	36	1,749	107	0	0
5/30	4,057	280	3,659	674	215	307
6/14	1,739	385	1,300	220	796	107
7/2	5,088	957	2,965	509	2,298	288
7/24	2,927	1,043	1,201	402	1,916	211
8/16	1,494	668	385	218	965	90
9/17&18	211	121	18	13	206	12
10/12&14	65	19	27	9	53	3
11/14	0	0	0	0	0	0
12/13	0	0	0	0	0	0
Standard Error of Eastern Sector Mean:						
2/15	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/16	0	0	0	0	0	0
5/1	1,475	0	1,475	0	0	0
5/14	3,995	0	3,995	0	0	0
5/30	5,732	307	4,817	790	327	220
6/14	4,201	216	3,669	248	460	110
7/2	5,180	701	2,929	652	1,653	154
7/24	1,951	939	320	158	1,635	71
8/16	1,403	758	107	121	1,192	87
9/17&18	223	102	12	24	187	35
10/12&14	65	14	52	13	27	0
11/14	6	0	6	0	0	0
12/13	0	0	0	0	0	0

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

Table 13c. *Artemia* percentages in different reproductive categories (Table 13a), 2007.

	Adult Females					
	Total	Ovigery	e	?	c	n
Lakewide Mean (%):						
2/15	0	0.0	0.0	0.0	0.0	0.0
3/13	0	0.0	0.0	0.0	0.0	0.0
4/16	0	0.0	0.0	0.0	0.0	0.0
5/1	100	0.0	100.0	0.0	0.0	0.0
5/14	100	0.5	99.5	100.0	0.0	0.0
5/30	100	13.5	86.5	58.4	26.9	14.6
6/14	100	18.9	81.1	21.0	66.4	12.5
7/2	100	44.6	55.4	24.5	69.3	6.1
7/24	100	65.7	34.3	8.4	87.9	3.6
8/16	100	84.1	15.9	11.9	83.5	4.6
9/17&18	100	94.5	5.5	5.5	86.9	7.7
10/12&14	100	45.0	55.0	17.6	80.9	1.5
11/14	100	0.0	100.0	0.0	0.0	0.0
12/13	0	0.0	0.0	0.0	0.0	0.0
Western Sector Mean (%):						
2/15	0	0.0	0.0	0.0	0.0	0.0
3/13	0	0.0	0.0	0.0	0.0	0.0
4/16	0	0.0	0.0	0.0	0.0	0.0
5/1	100	0.0	100.0	0.0	0.0	0.0
5/14	100	1.2	98.8	100.0	0.0	0.0
5/30	100	16.3	83.7	62.3	18.9	18.9
6/14	100	22.4	77.6	15.8	73.7	10.5
7/2	100	46.7	53.3	24.6	69.0	6.4
7/24	100	24.9	75.1	11.0	86.1	2.9
8/16	100	73.8	26.2	16.7	78.4	5.0
9/17&18	100	93.2	6.8	2.3	91.2	6.5
10/12&14	100	12.9	87.1	19.4	77.4	3.2
11/14	0	0.0	0.0	0.0	0.0	0.0
12/13	0	0.0	0.0	0.0	0.0	0.0
Eastern Sector Mean (%):						
2/15	0	0.0	0.0	0.0	0.0	0.0
3/13	0	0.0	0.0	0.0	0.0	0.0
4/16	0	0.0	0.0	0.0	0.0	0.0
5/1	100	0.0	100.0	0.0	0.0	0.0
5/14	100	0.0	100.0	0.0	0.0	0.0
5/30	100	11.6	88.4	54.9	34.5	10.6
6/14	100	15.7	84.3	27.7	57.1	15.1
7/2	100	41.9	58.1	24.4	69.8	5.8
7/24	100	79.3	20.7	5.5	90.0	4.5
8/16	100	90.3	9.7	6.6	89.1	4.3
9/17&18	100	95.5	4.5	8.8	82.3	8.8
10/12&14	100	39.8	60.2	16.2	83.8	0.0
11/14	100	0.0	100.0	0.0	0.0	0.0
12/13	0	0.0	0.0	0.0	0.0	0.0

(?): 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, 2007.

	#eggs/brood mean	SE	%cyst	%intended	female length mean	SE	n
Lakewide Mean:							
5/30	53.4	4.8	0.7	0.4	10.7	0.2	7
6/14	37.3	4.0	0.9	0.5	10.2	0.2	7
7/2	40.9	2.8	0.9	0.4	10.5	0.1	7
7/24	50.7	6.5	1.0	0.6	10.5	0.1	7
8/16	36.0	1.2	0.9	0.5	10.2	0.2	7
9/17&18	107.2	5.7	0.9	0.4	12.0	0.3	7
10/12&14	120.1	19.3	1.0	0.8	12.0	0.3	5
Western Sector Mean:							
5/30	58.7	7.5	0.7	0.3	10.9	0.3	4
6/14	40.8	5.7	0.9	0.5	10.4	0.2	4
7/2	45.1	3.7	1.0	0.5	10.8	0.1	4
7/24	37.8	4.2	1.0	0.6	10.4	0.1	4
8/16	36.0	2.0	1.0	0.5	9.8	0.2	4
9/17&18	97.2	3.1	0.9	0.5	11.4	0.1	4
10/12&14	119.0	31.5	1.0	0.8	12.2	0.2	2
Eastern Sector Mean:							
5/30	46.3	1.6	0.9	0.4	10.5	0.2	3
6/14	32.8	5.3	0.9	0.4	10.0	0.2	3
7/2	35.4	0.8	0.9	0.4	10.3	0.1	3
7/24	67.9	0.5	1.0	0.7	10.7	0.1	3
8/16	36.0	1.3	0.9	0.4	10.6	0.3	3
9/17&18	120.6	7.5	0.9	0.4	12.7	0.2	3
10/12&14	120.8	30.1	1.0	0.8	11.9	0.6	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, 1979–2007.

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
Mean	**19,852**	**19,060**	**44,700**	**215**

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

Table 16. Photosynthetic parameters for 2007.

Date	Depth (m)	Temperature (C)	α^B (g C g Chl a^{-1} h^{-1})	P_m^B (g C g Chl a^{-1} $Einst^{-1}$ m^2)
3/13/2007	2	7.0	22.2	3.4
4/16/2007	2	7.3	9.8	1.9
5/14/2007	2	13.1	5.1	10.8
6/14/2007	2	18.0	18.1	25.7
7/20/2007	2	13.1	133.9	16.7
8/17/2007	2	19.5	78.8	7.3
9/18/2007	2	18.0	31.0	5.5
10/14/2007	2	11.3	8.6	3.3
11/14/2007	2	9.7	7.7	2.9

P_m^B: Chlorophyll-specific maximum carbon uptakes rates (g C g Chl a^{-1} h^{-1})
α^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), 1982-2007.

Year	**Planktonic Primary Production** (g C m^{-2} y^{-1})	***Artemia*** **Biomass** (g dry weight m^{-2})	***Artemia*** **Naupliar Production** (10^6 m^{-2})	***Artemia*** **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
Mean	**638**	**9.1**	**0.25**	**4.4**

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 (α^B) versus temperature (see methods).

*Revised estimate due to discovery of programming error in 2006 calculation

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, 2007.

Fig. 3. Daily air temperature; mean, maximum, and minimum, 2007.

Fig. 4. Daily photosynthetically available radiation, 2007.

Fig. 5. Mean daily relative humidity, 2007.

Fig. 6. Daily precipitation, 2007.

Fig. 7. Mono Lake surface elevation (ft asl), 1979–07, USGS datum.

Fig. 8. Temperature (°C) at station 6, 2007.

Fig. 9. Conductivity (mS cm^{-1} corrected to 25°C) at station 6, 2007.

Fig.10. Density difference (kg m^{-3}) between 2 and 32 m at station 6 due to temperature and chemical stratification from 1991–2007.

Fig. 11. Transparency as measured by mean lakewide Secchi depth (m), 1994–07. Error bars show standard errors of the lakewide estimate based on 12-20 stations.

Fig. 12. Mean lakewide Secchi depth ($\log_{10}$ m) 1979–07.

Fig. 13. Light attenuation (% of surface) at station 6, 2007.

Fig. 14. Dissolved oxygen (mg O_2 l^{-1}) at station 6, 2007. Dots denote the dates and depths of samples.

Fig. 15. Ammonium (µM) at station 6, 2007. Dots denote the dates and depths of samples.

Fig. 16. Ammonium (µM) in upper 9 m of the water column at 7 stations, 2007.

Fig. 17. Chlorophyll *a* (µg chl *a* l^{-1}) at station 6, 2007. 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, 2007.

Fig. 19. Seasonal fluorescence profiles at station 6, 2007.

Fig. 20. Lakewide *Artemia* abundance during 2007: nauplii (instars 1-7), juveniles (instars 8-11), and adults (instars 12+).

Fig. 21. Lakewide estimates of adult *Artemia* based on 3-20 stations, 1982–07 (see Methods). The mean relative error of the lakewide estimates is 20-25%.

Fig. 22. Reproductive characteristics of *Artemia* during 2007: 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. 23. Summary statistics of the seasonal (1 May through 30 November) lakewide abundance of adult *Artemia*, 1979–07. Values are based on interpolated daily abundances.

Fig. 24. Temporal center of abundance-weighted centroid of the seasonal (1 May through 30 November) distribution of adult *Artemia*, 1979–07. Centroid is based on interpolated daily abundances of adult *Artemia*.

Fig. 25. Chlorophyll-specific uptake rates during March, August, and December 2007 for samples collected from the surface mixed layer and the deep chlorophyll maximum.

Fig. 26. 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}), 2007.

Fig. 27. Comparison of 2002–07 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. 28. Comparison of 2002–07 daily primary production (g C m^{-2} y^{-1}) calculated with a numerical interpolative model of chlorophyll, temperature, insolation, attenuation, and photosynthetic parameters.

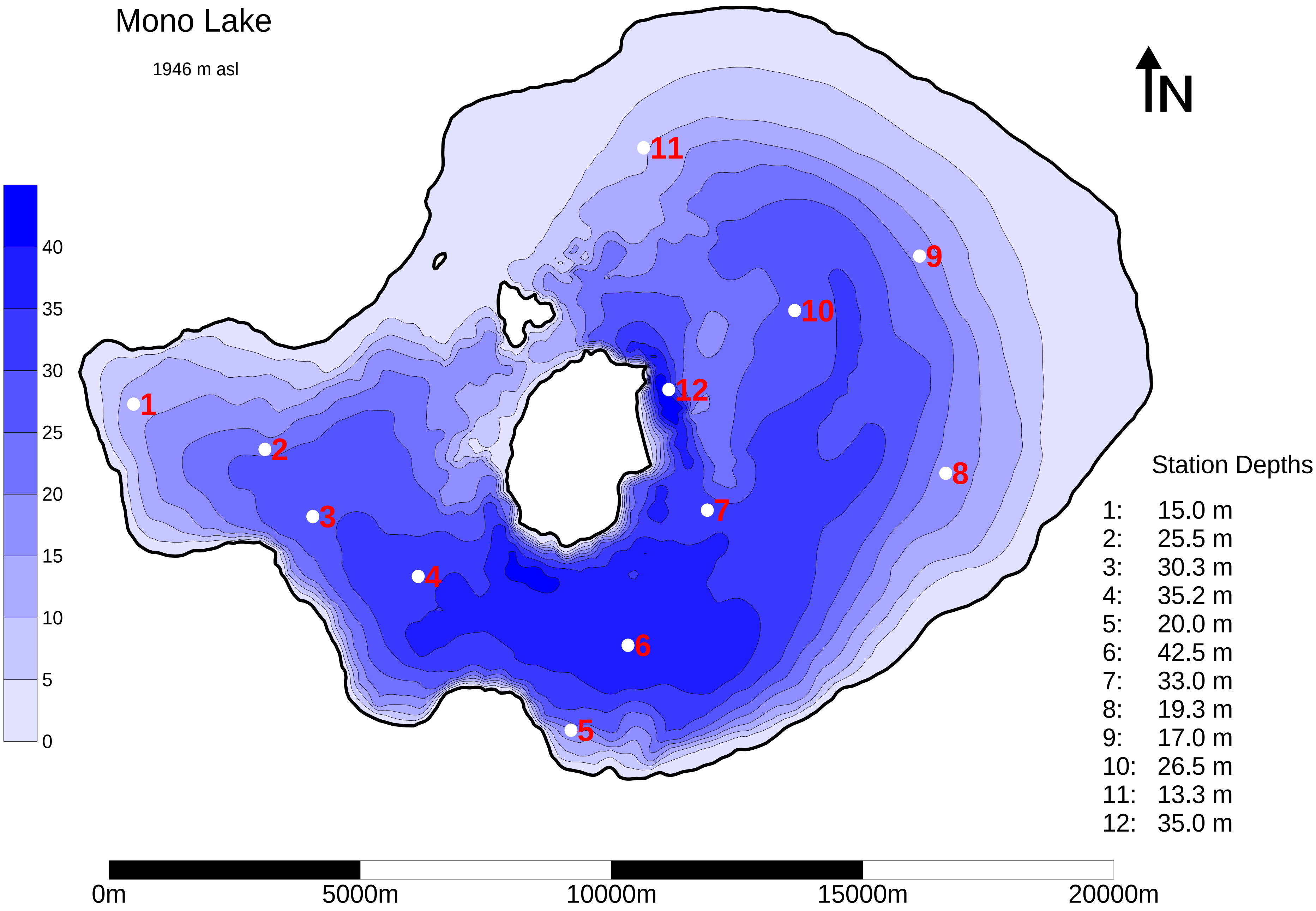
Fig. 29. Annual phytoplankton production estimates (g C m^{-2}), 1982–07.

Fig. 30. Mean annual *Artemia* biomass, 1983–04. Data for the period 1982–99 estimated from instar-specific population data and previously derived weight-length relationships. In 2000–07, *Artemia* biomass was measured directly by determining dry weights of plankton tows.

Fig. 31. Annual *Artemia* reproduction, ovoviviparous (live-bearing) and oviparous (cyst-bearing), 1983–07.

Fig. 32. Lakewide mean of mixolimnetic (<10 m) chlorophyll *a*, 1982–07. 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. 33. Lakewide mean of adult *Artemia* abundance, 1982–07. 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

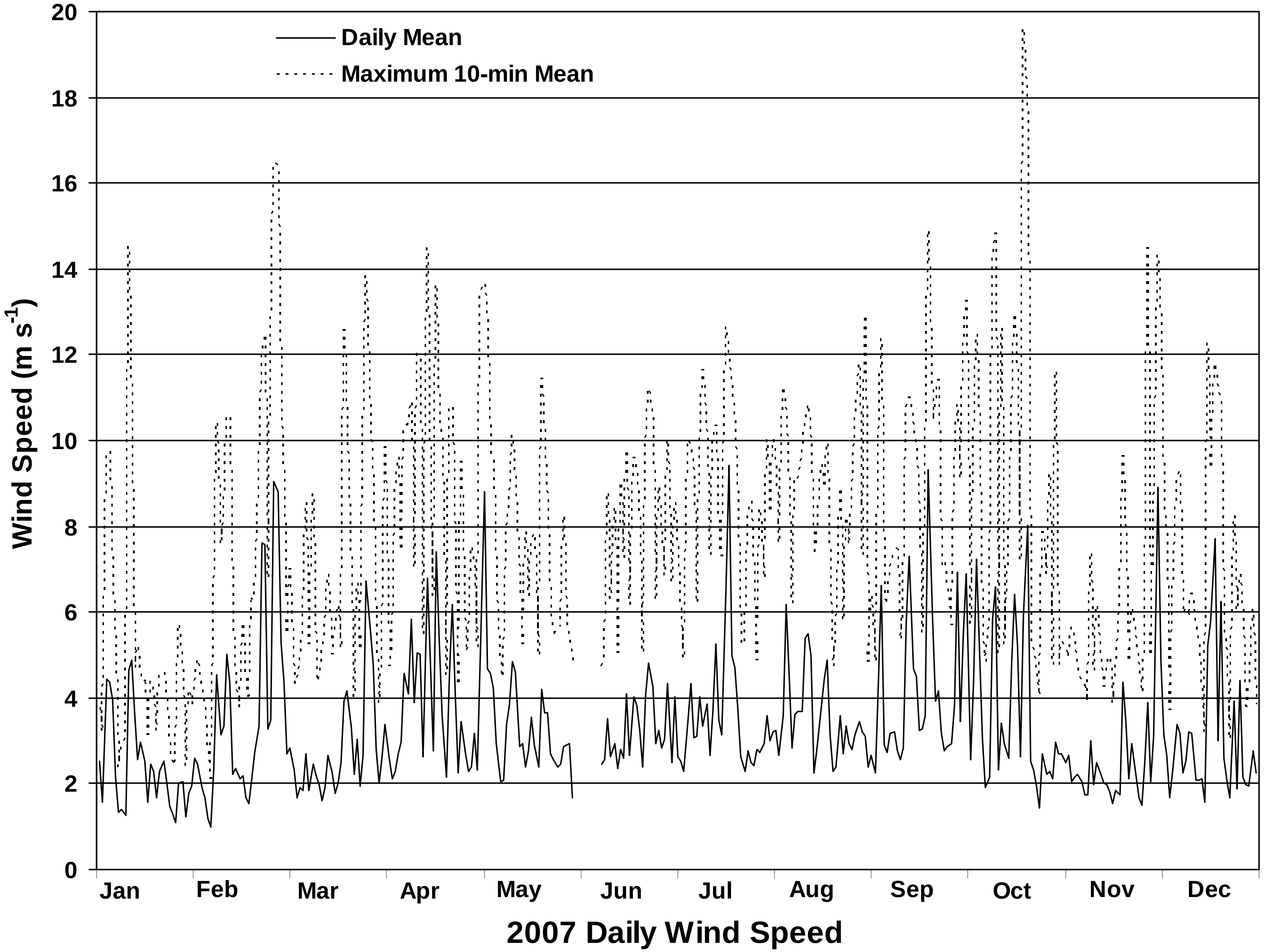

Daily Mean
Maximum 10-min Mean
Wind Speed (m s^{-1})
0
2
4
6
8
10
12
14
16
18
20
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2007 Daily Wind Speed

Figure 2

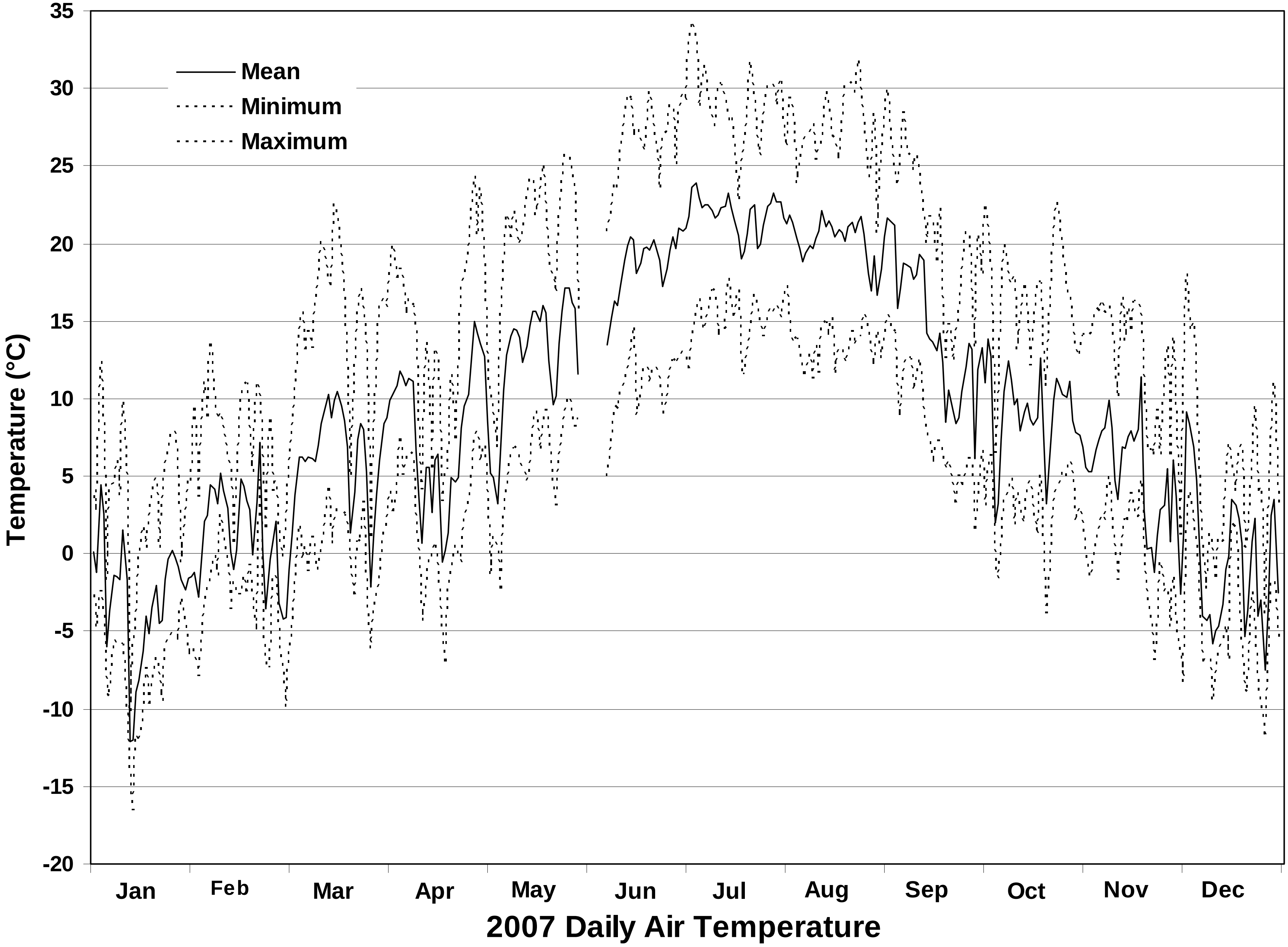
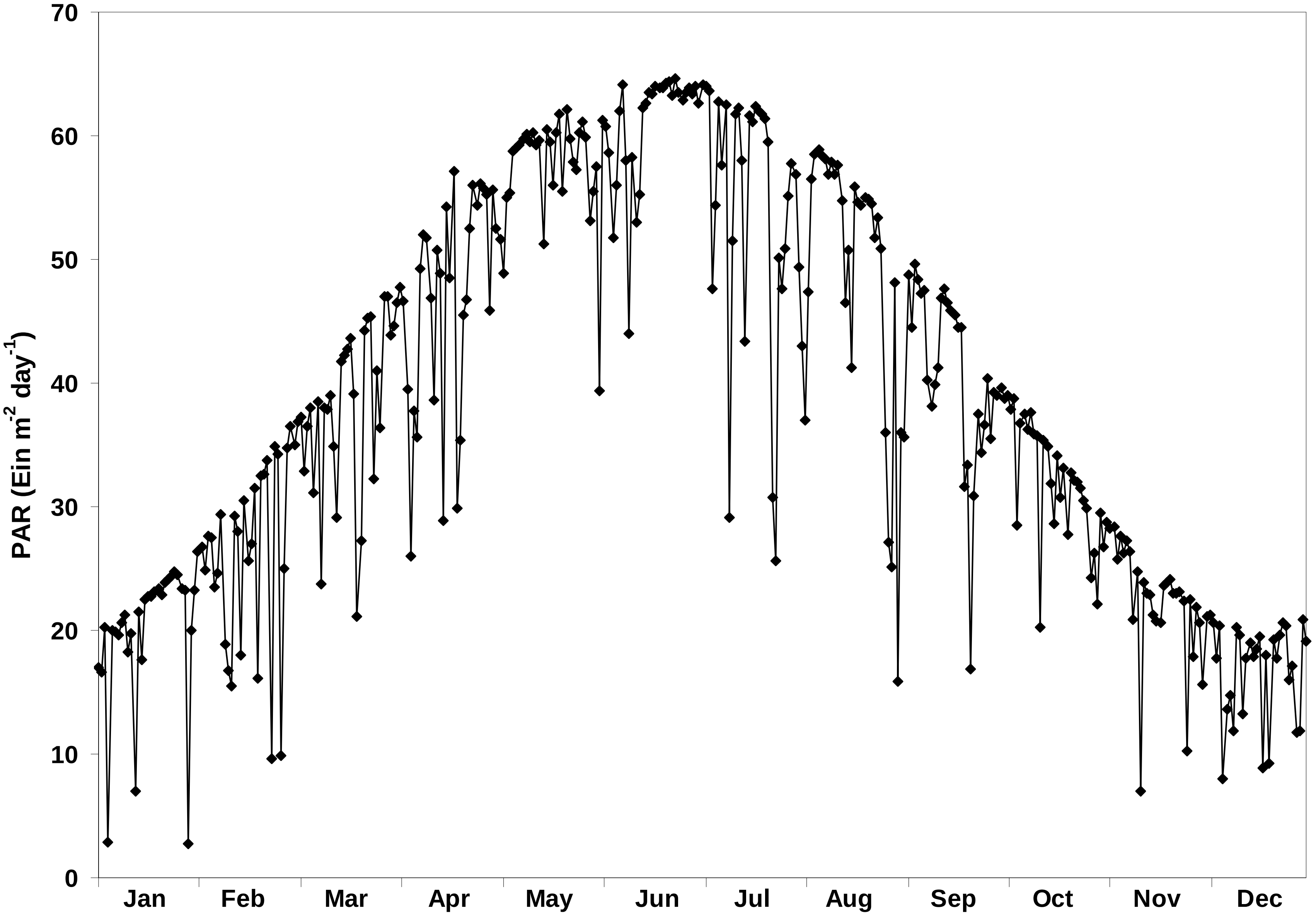
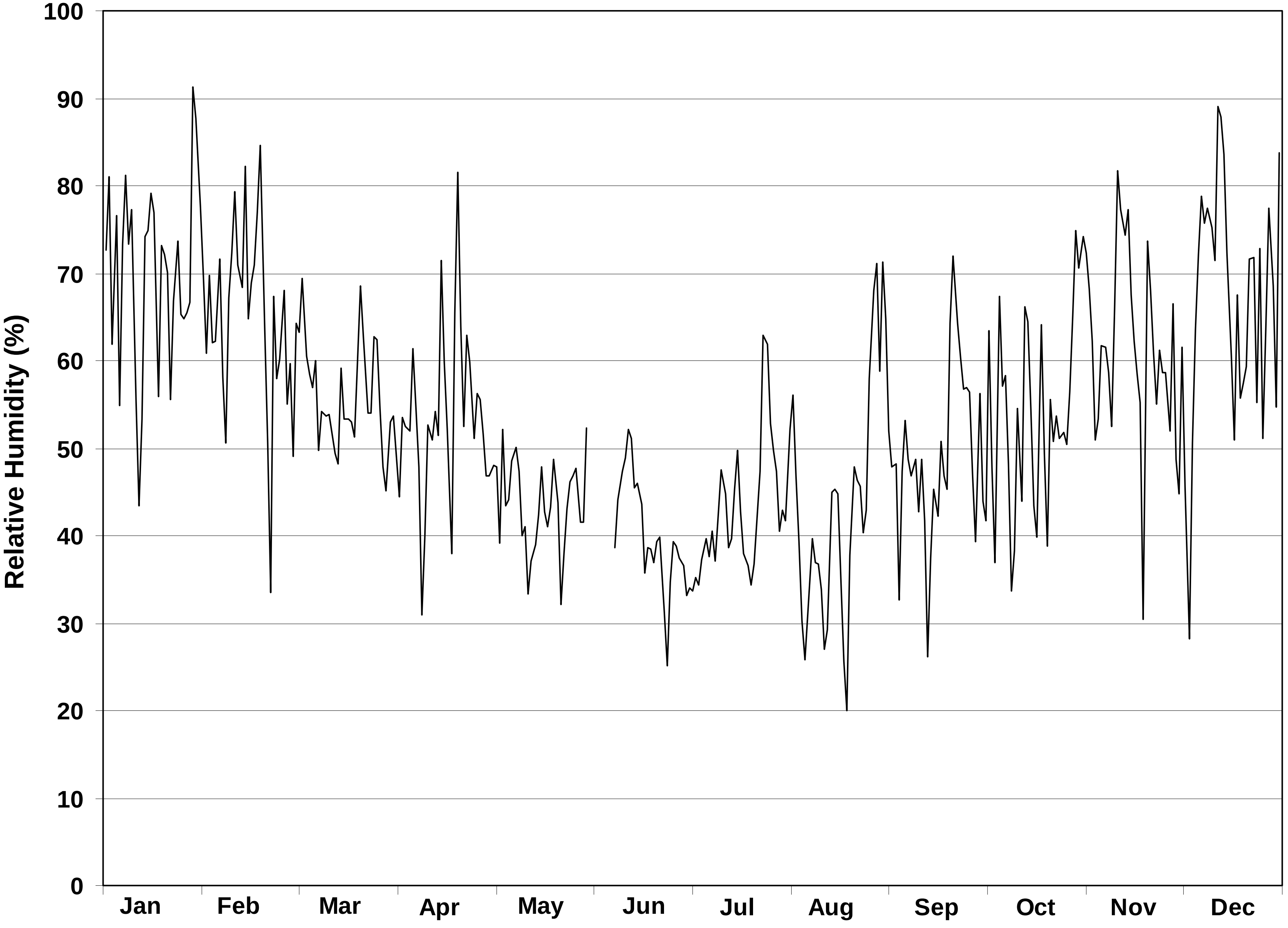

Mean
Minimum
Maximum
35
30
25
20
15
10
5
0
-5
-10
-15
-20
Temperature (°C)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2007 Daily Air Temperature

Figure 3



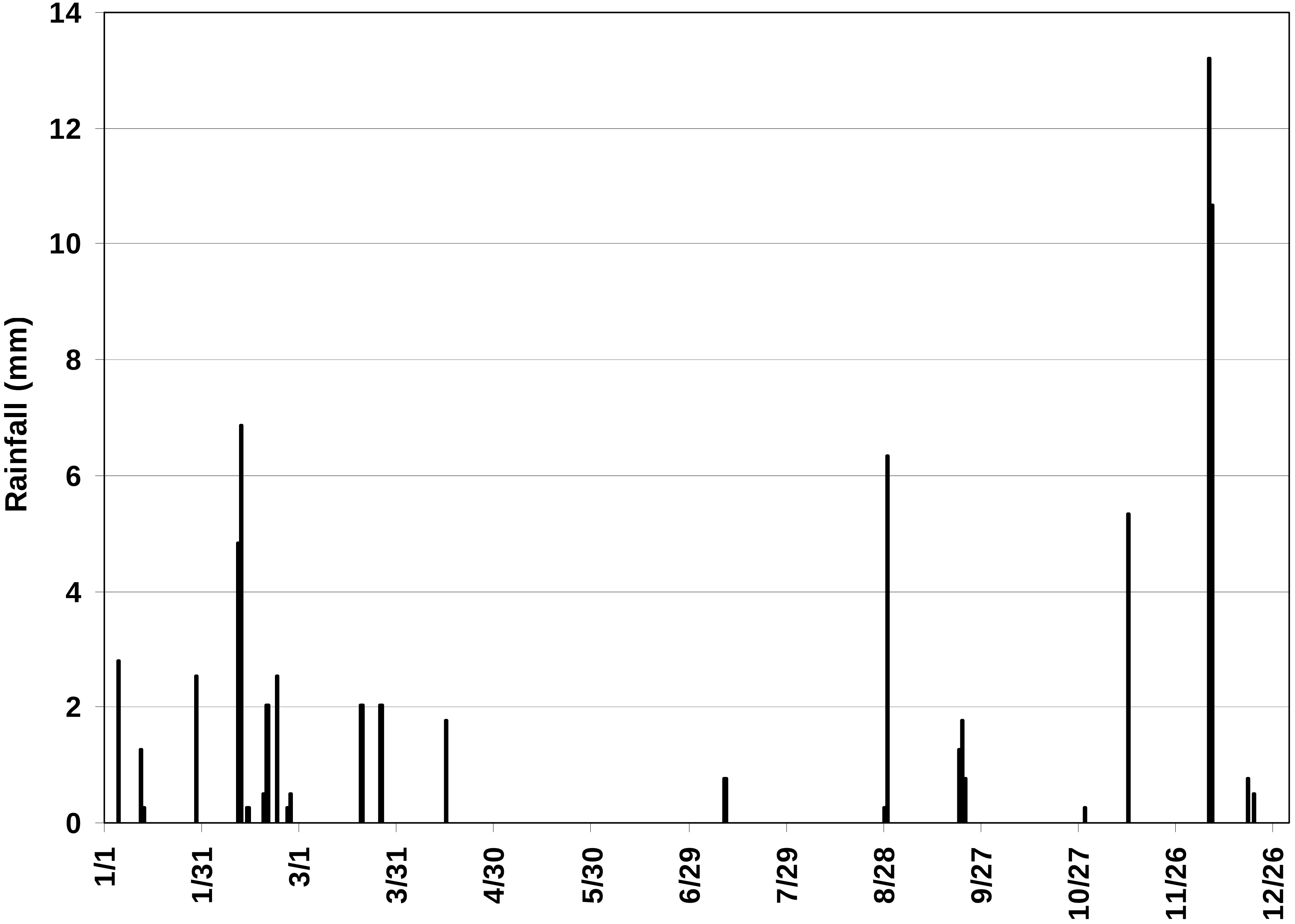
2007 Photosynthetically Available Radiation

Figure 4



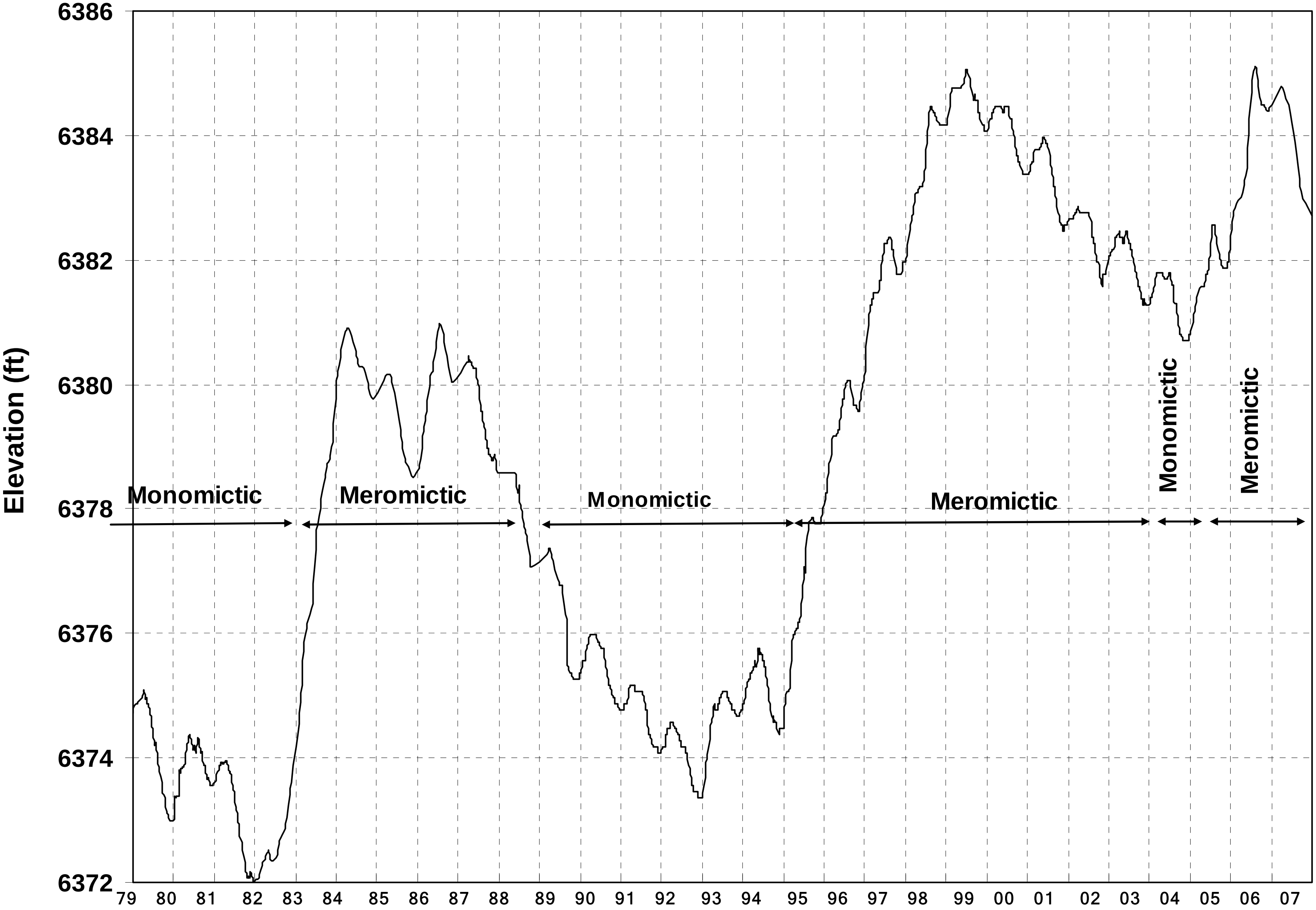
2007 Mean Daily Relative Humidity

Figure 5



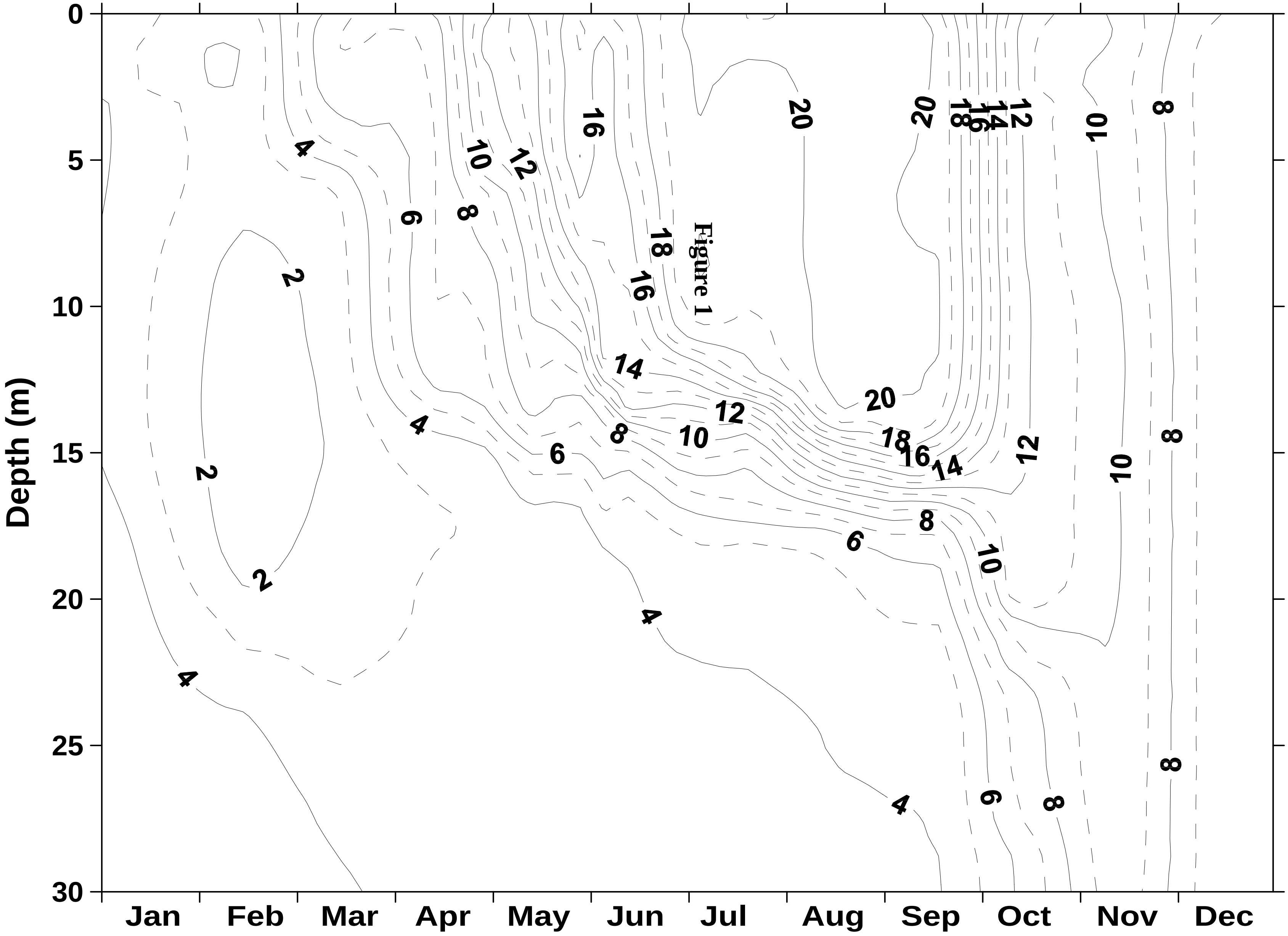
2007 Daily Cain Ranch Precipitation

Figure 6



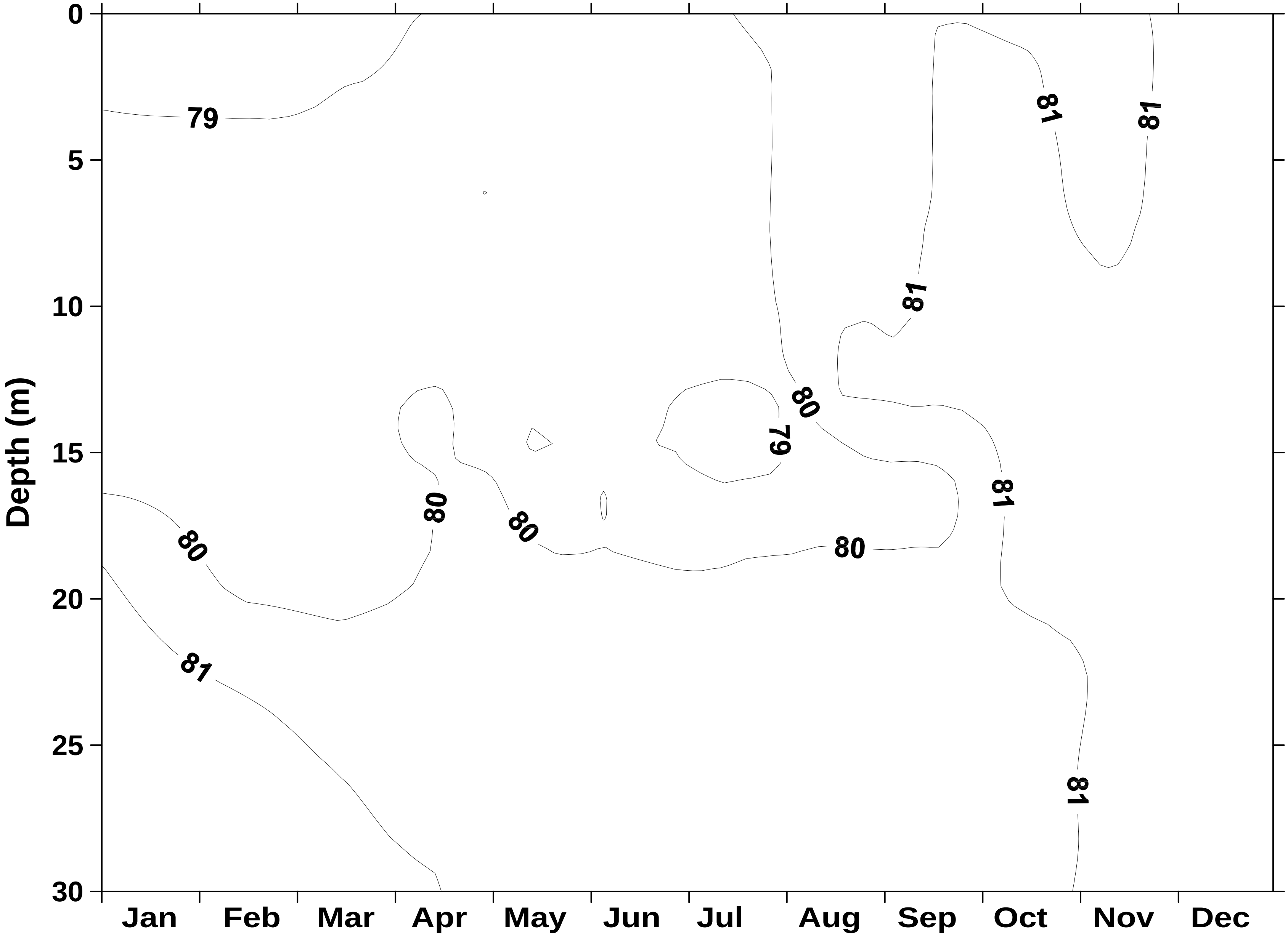
Mono Lake Surface Elevation

Figure 7



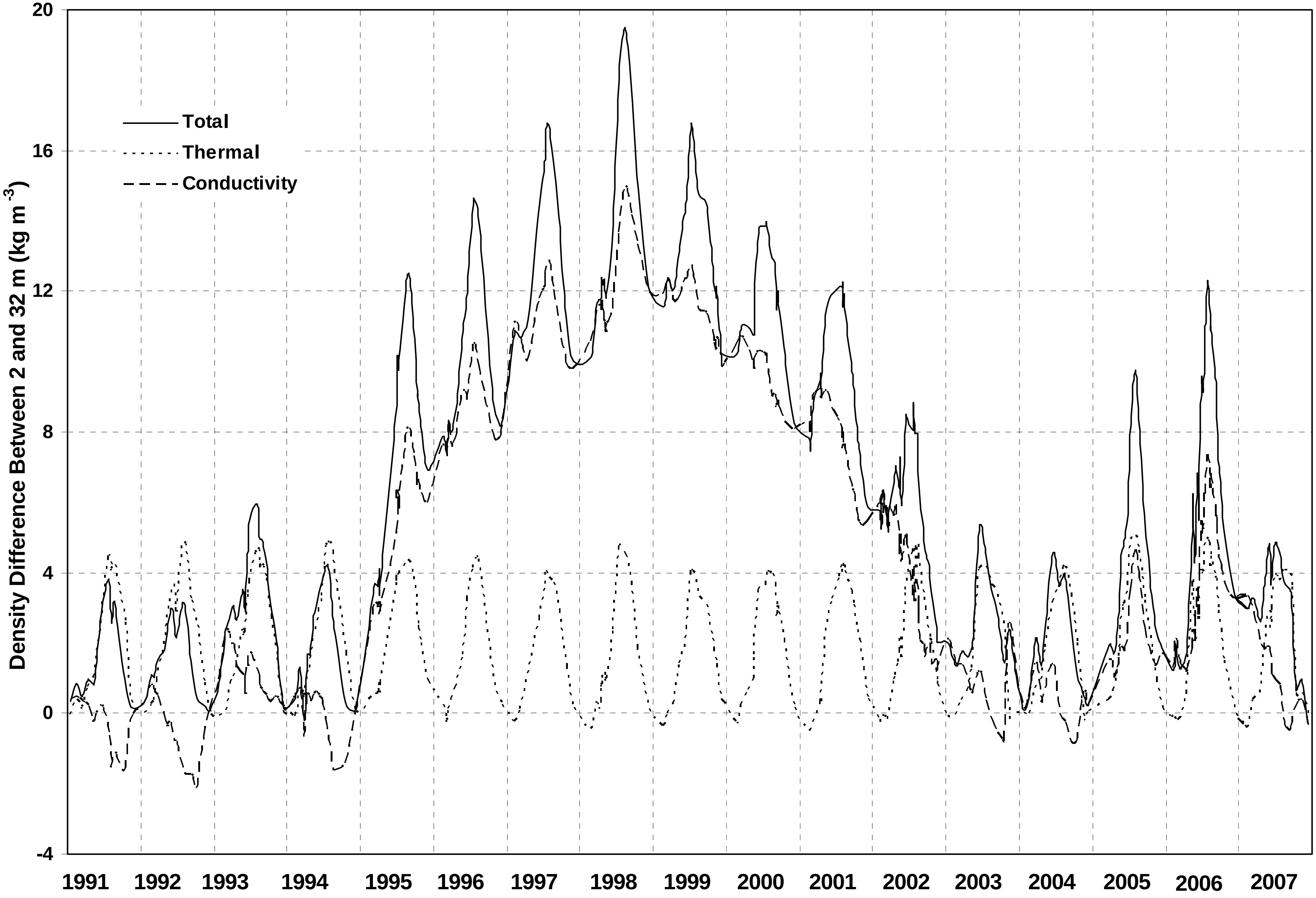
Temperature (°C) at Station 6, 2007

Figure 8



Specific Conductivity (mS/cm) at Station 6, 2007

Figure 9



Density Stratification (2-32 m)

Figure 10

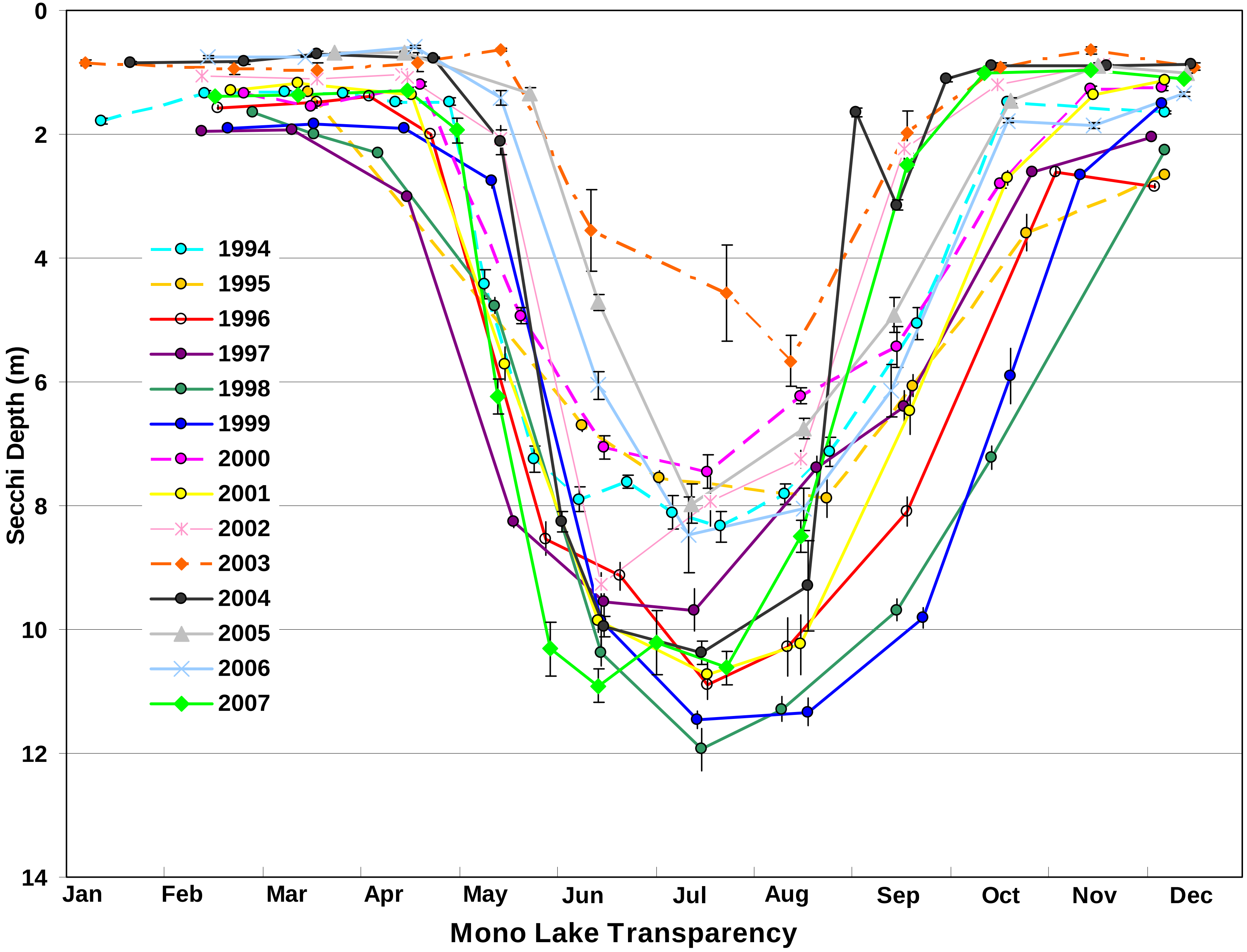
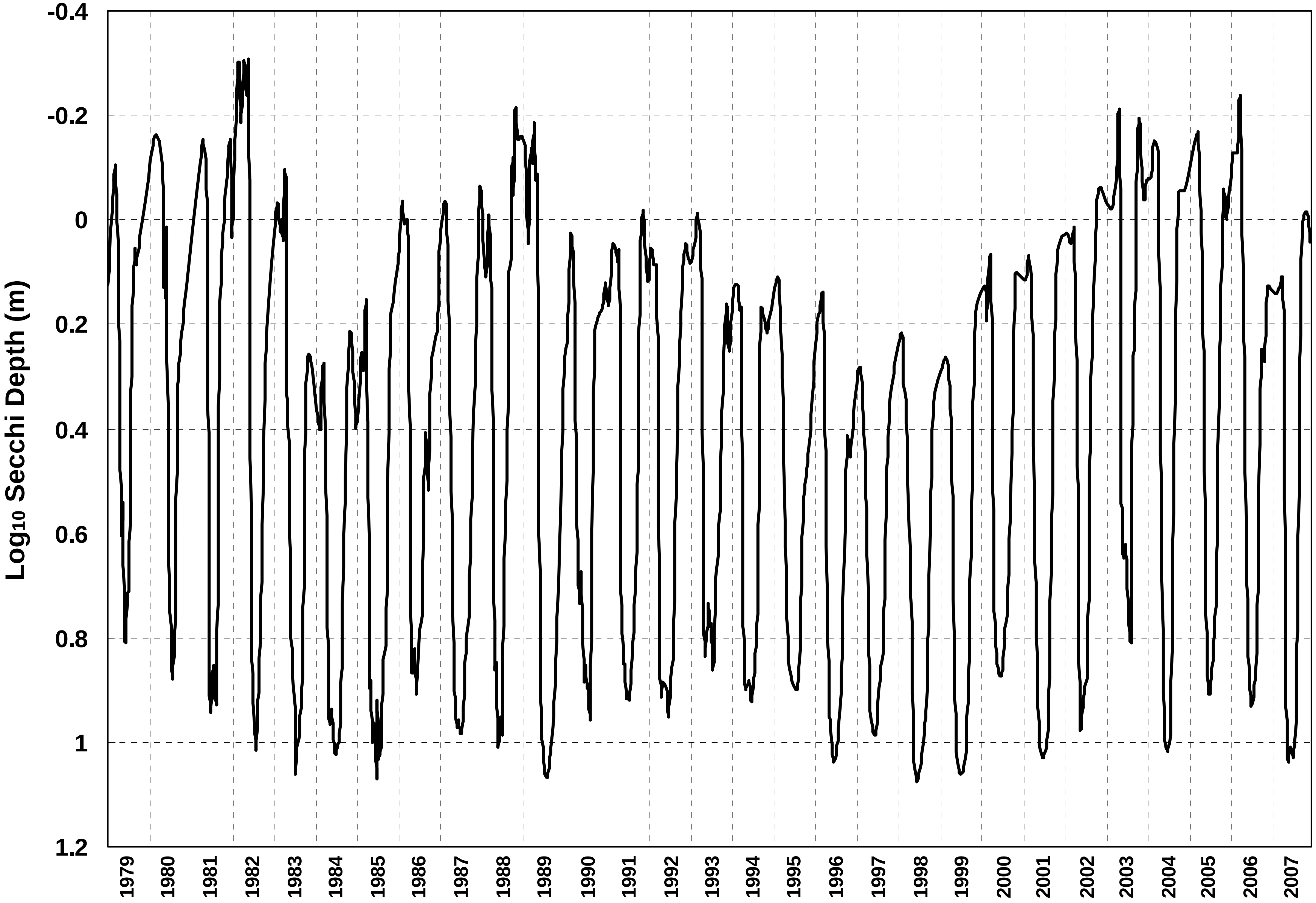
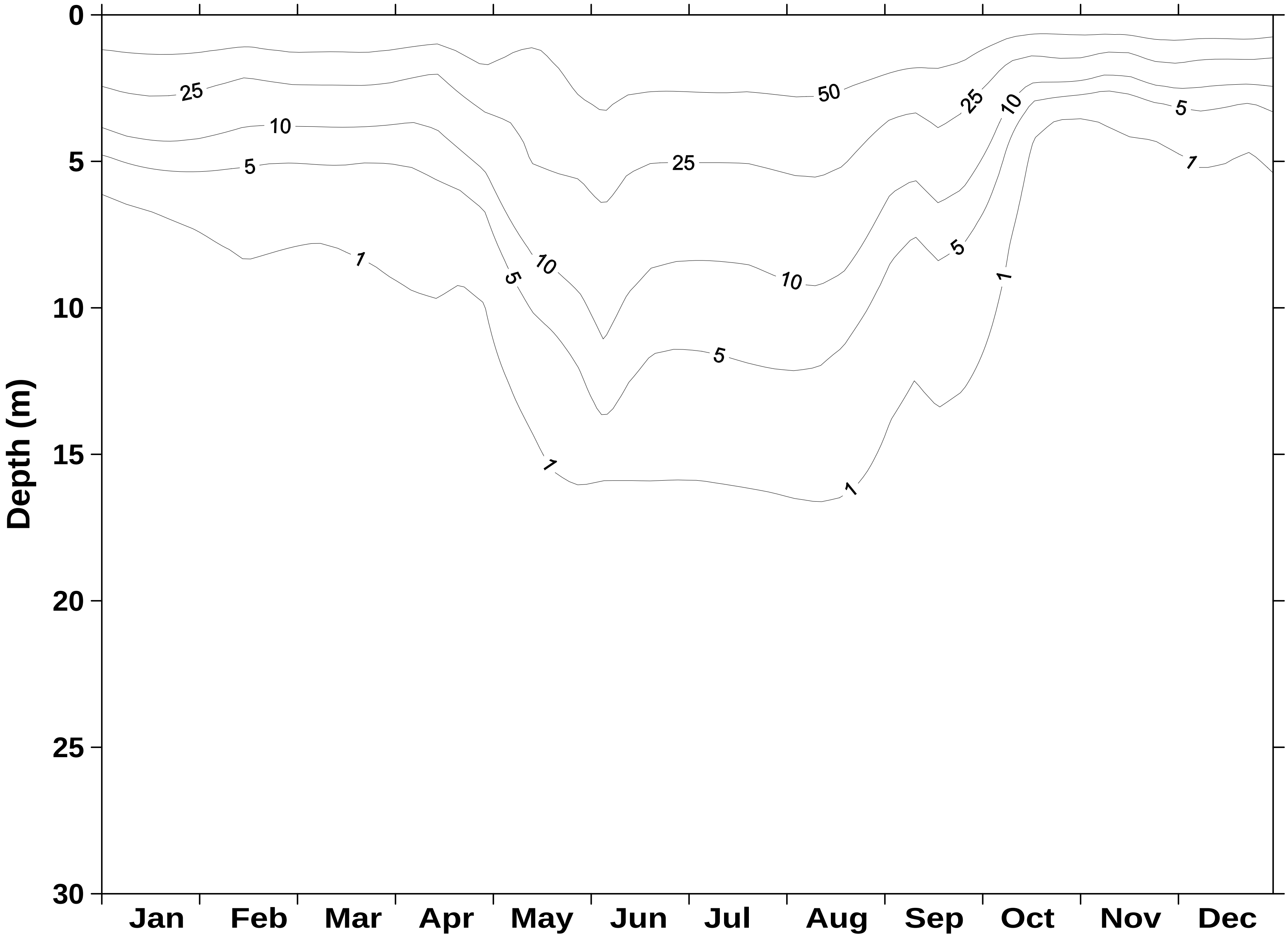

Secchi Depth (m)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Mono Lake Transparency

Figure 11



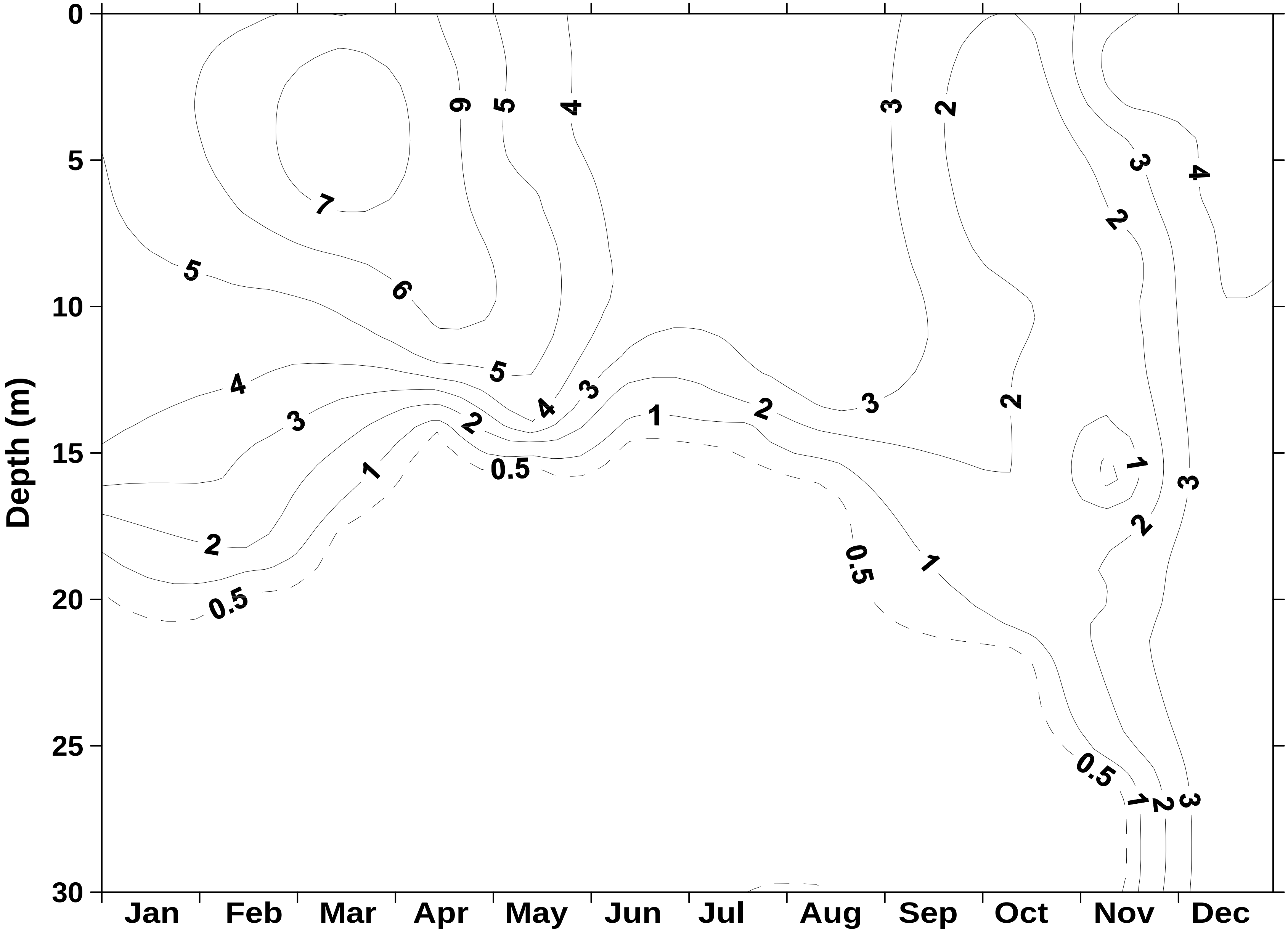
Water Transparency in Mono Lake

Figure 12



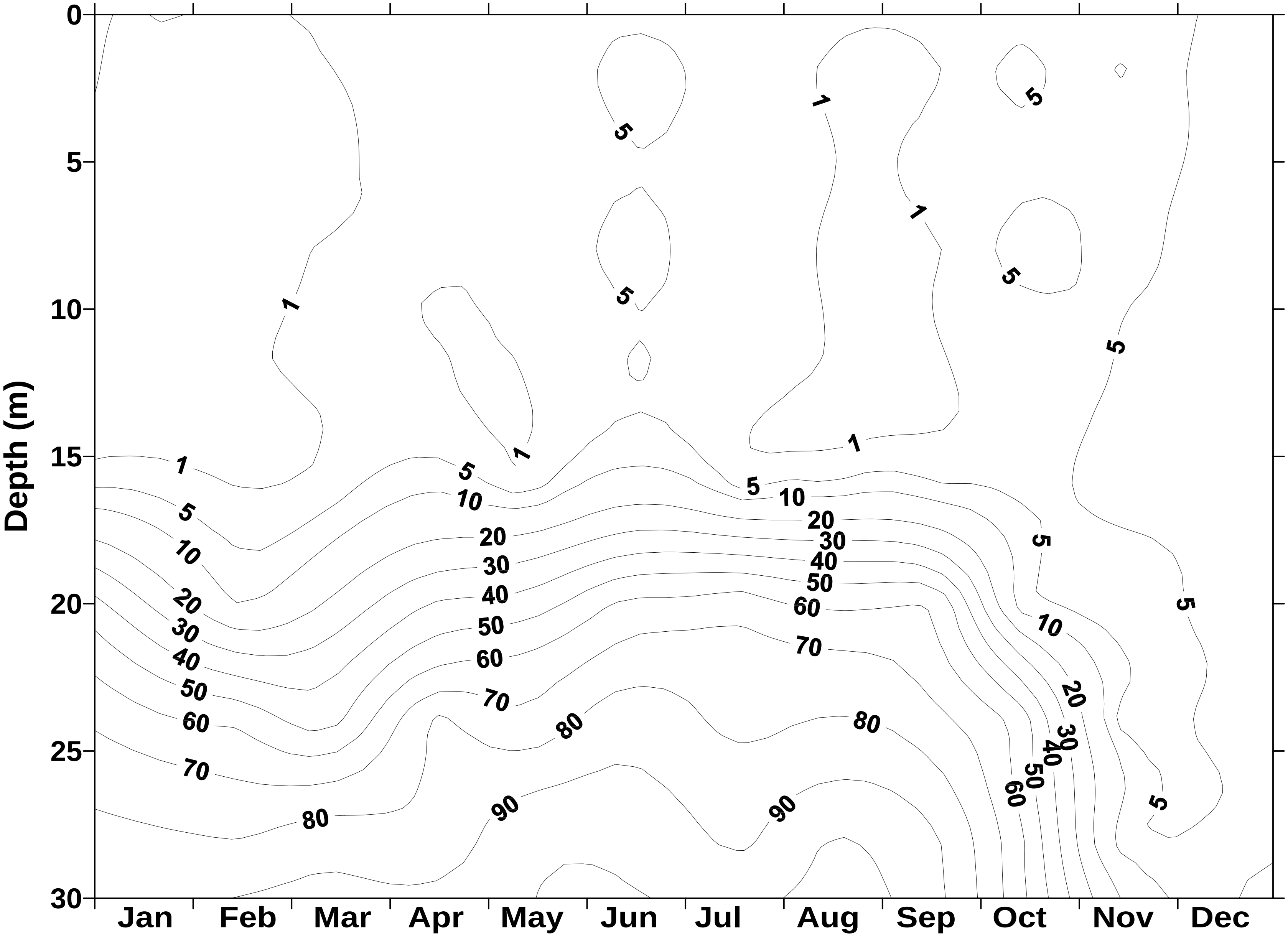
Light Attenuation (% of surface) at Station 6, 2007

Figure 13



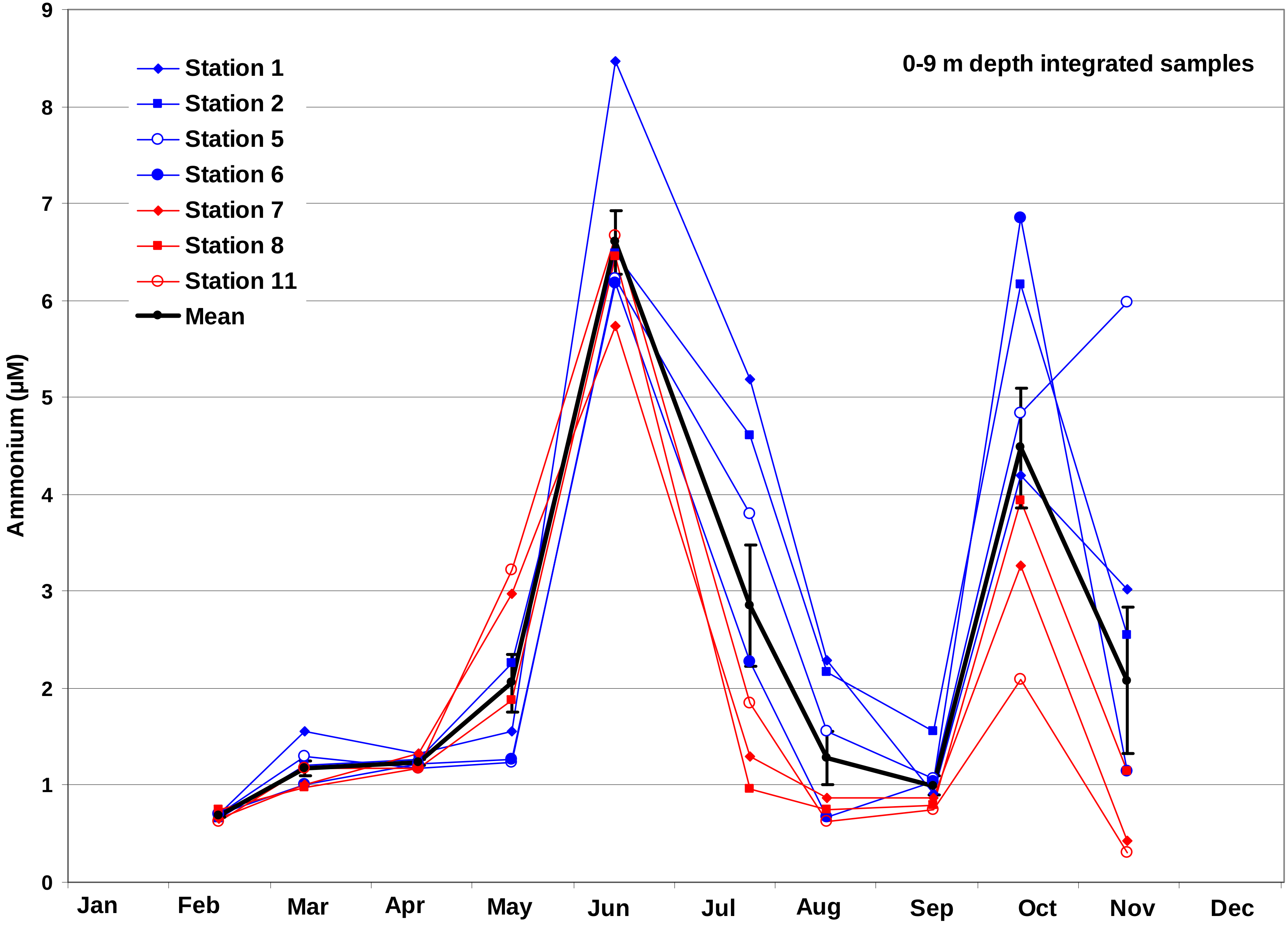
Dissolved oxygen (mg/l) at Station 6, 2006

Figure 14



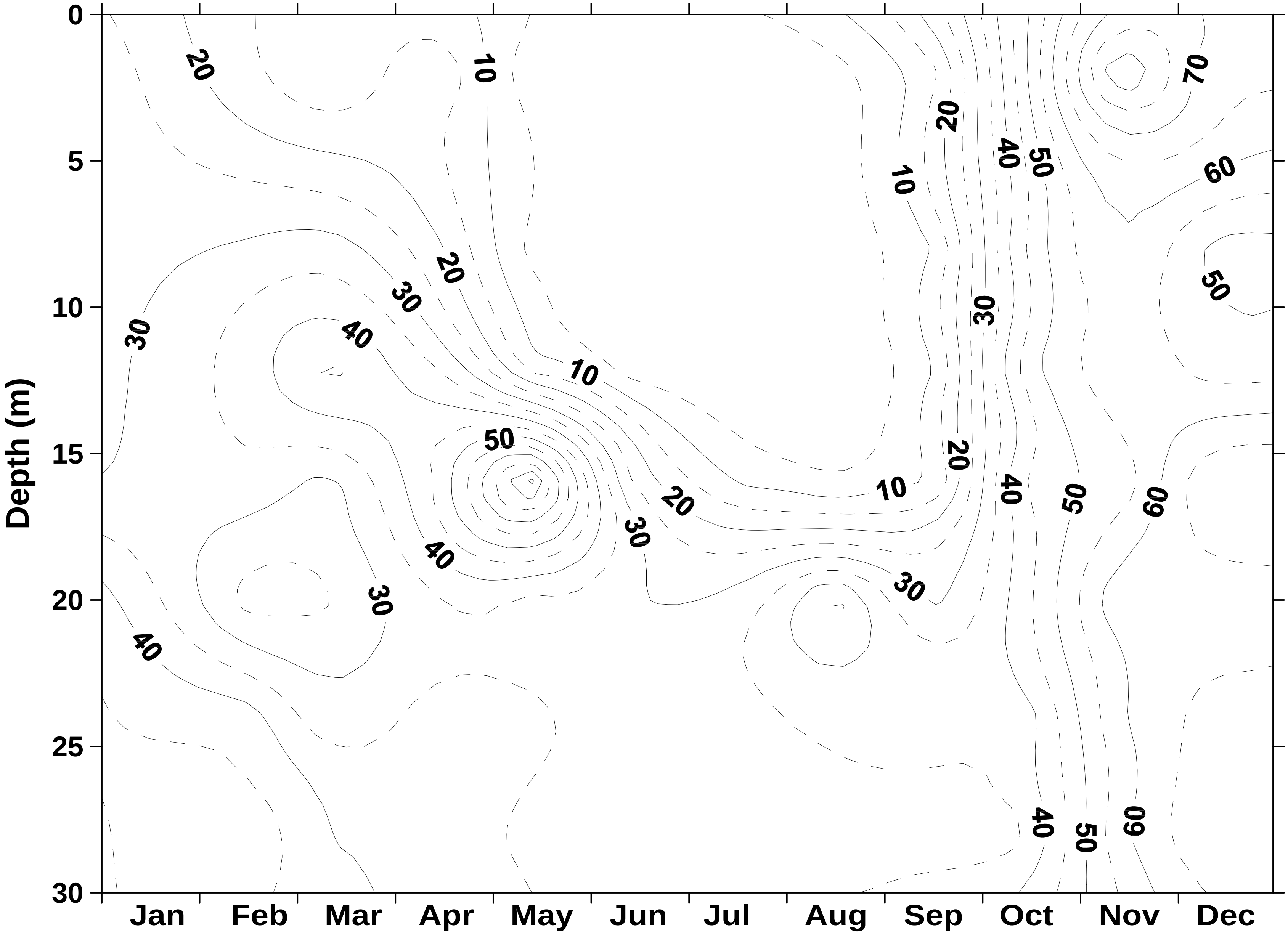
Ammonia (µM) at Station 6, 2007

Figure 15



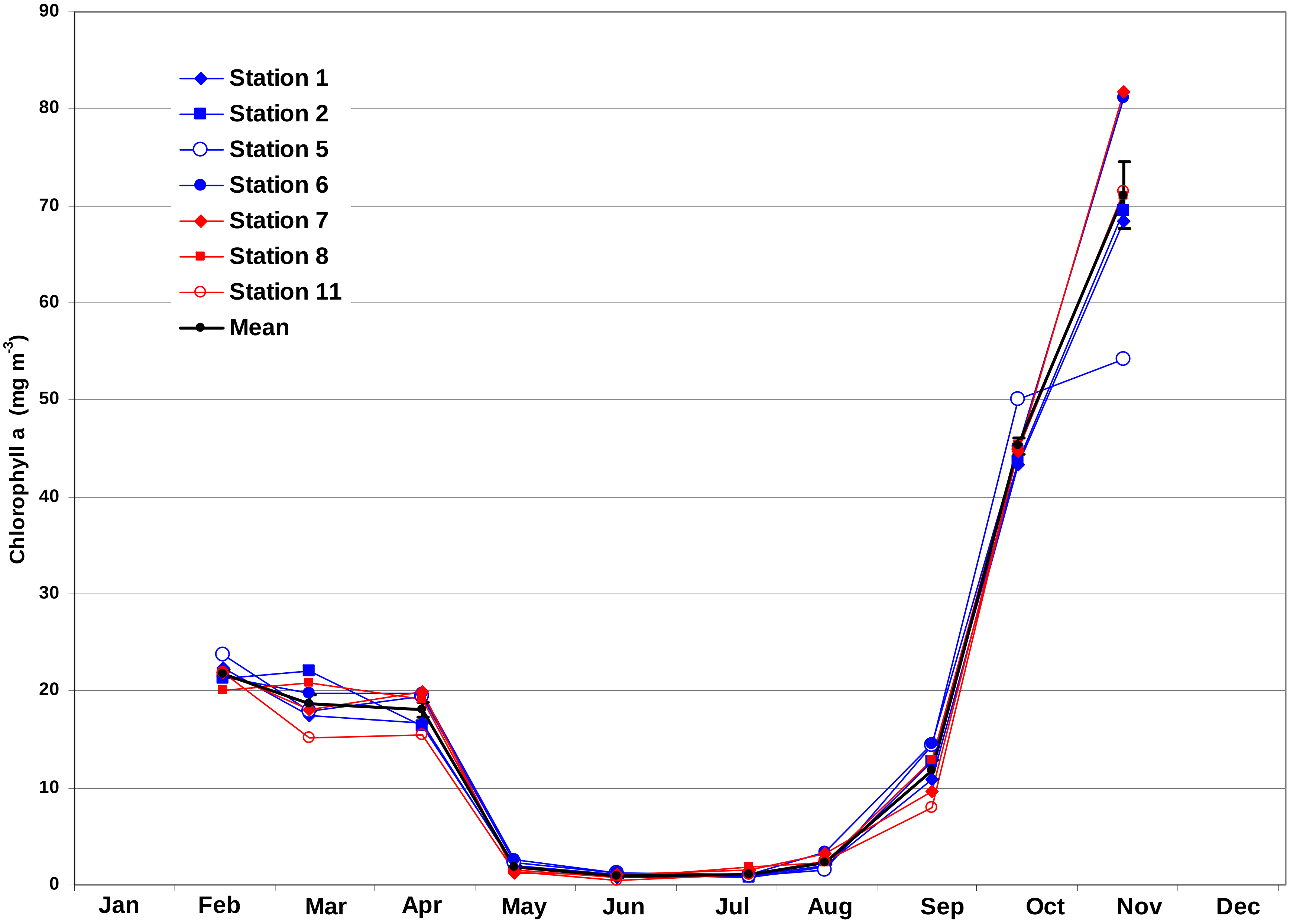
Ammonium Spatial Variability, 2007

Figure 16



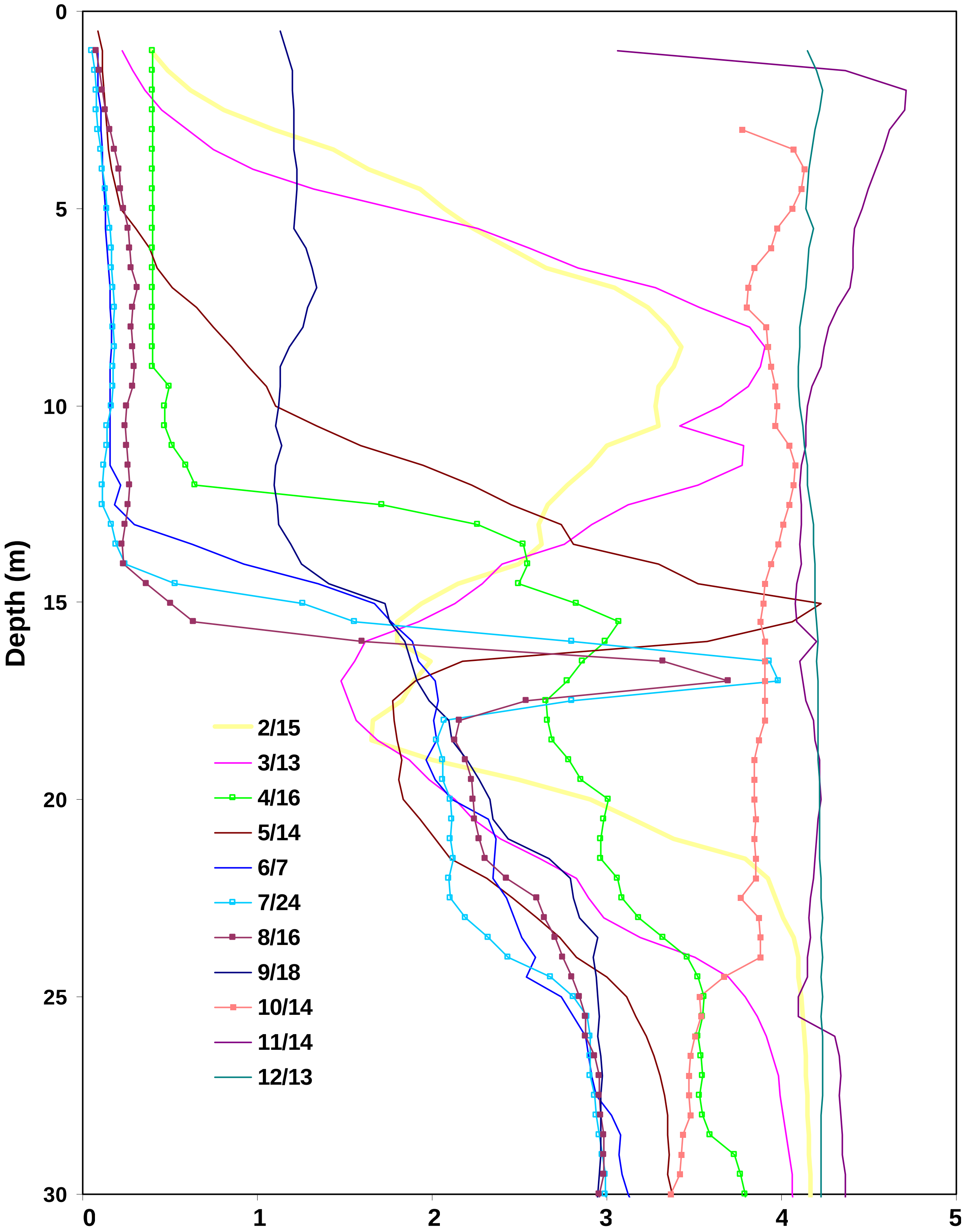
Chlorophyll a (μg/l) at Station 6, 2007

Figure 17

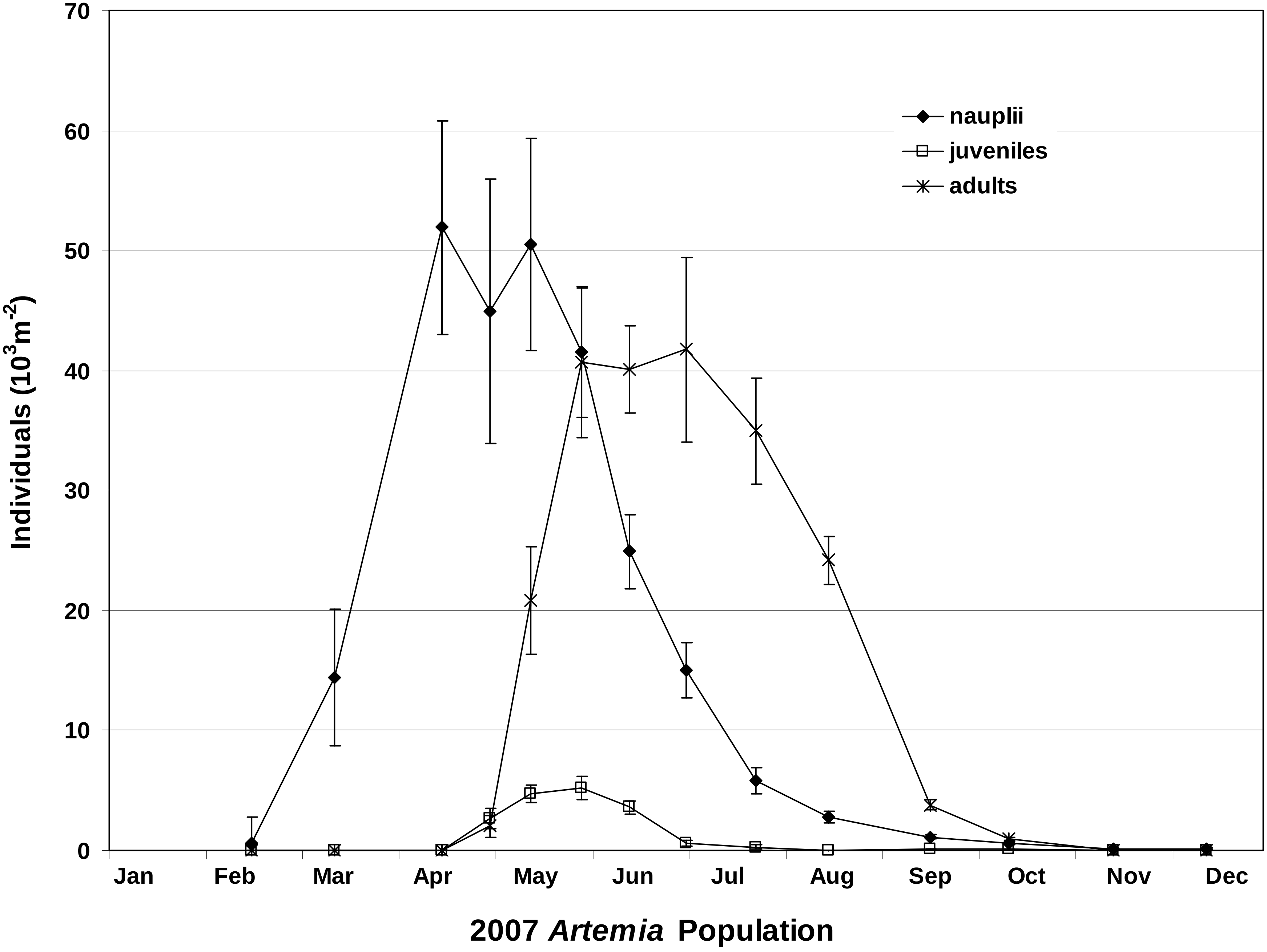


Chlorophyll Spatial Variability, 2007

Figure 18

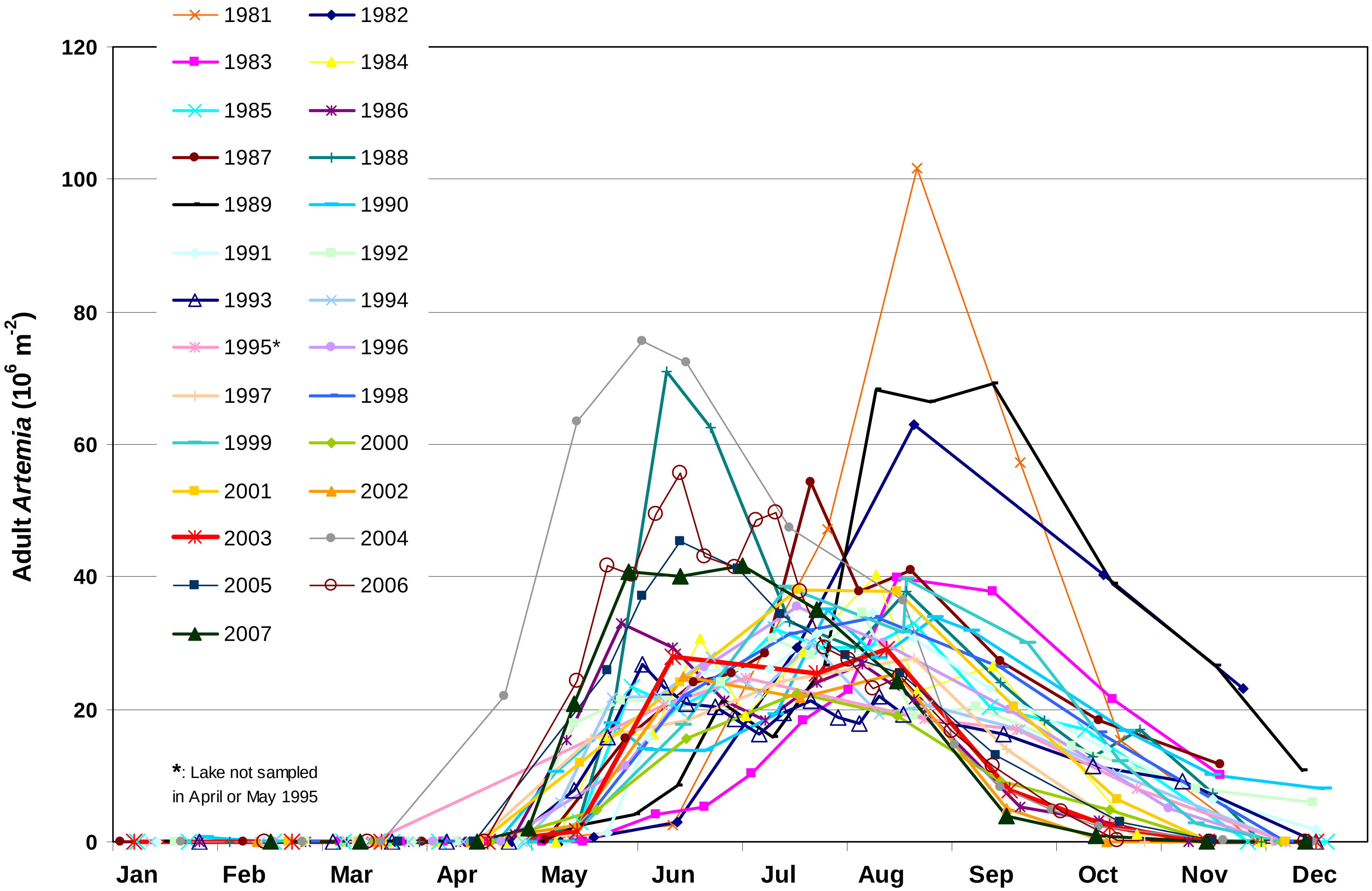


2007 Seasonal fluorescence profiles at Station 6



70
60
50
40
30
20
10
0
Individuals ($10^3 m^{-2}$)
nauplii
juveniles
adults
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2007 *Artemia* Population

Figure 20

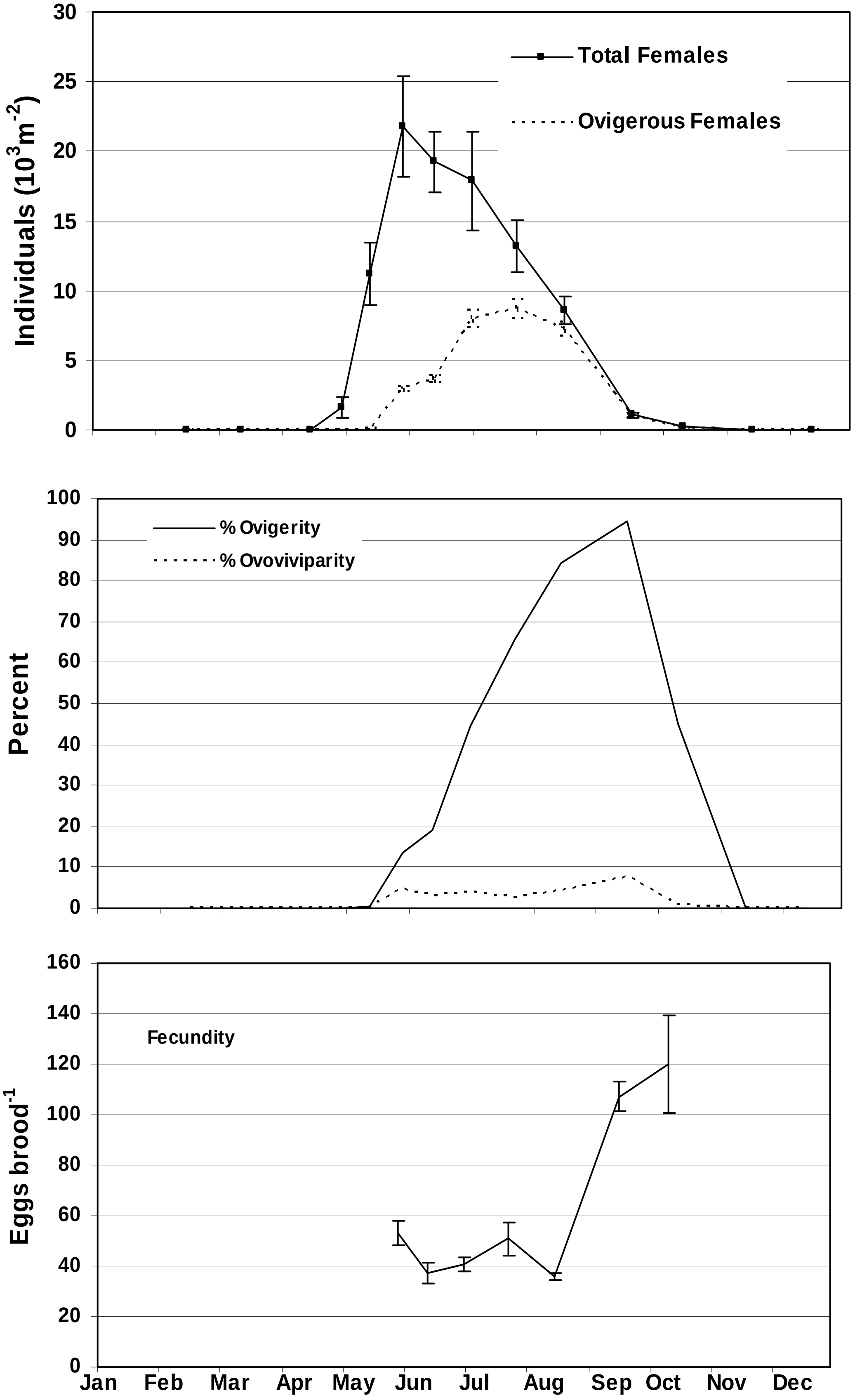


*****: Lake not sampled in April or May 1995

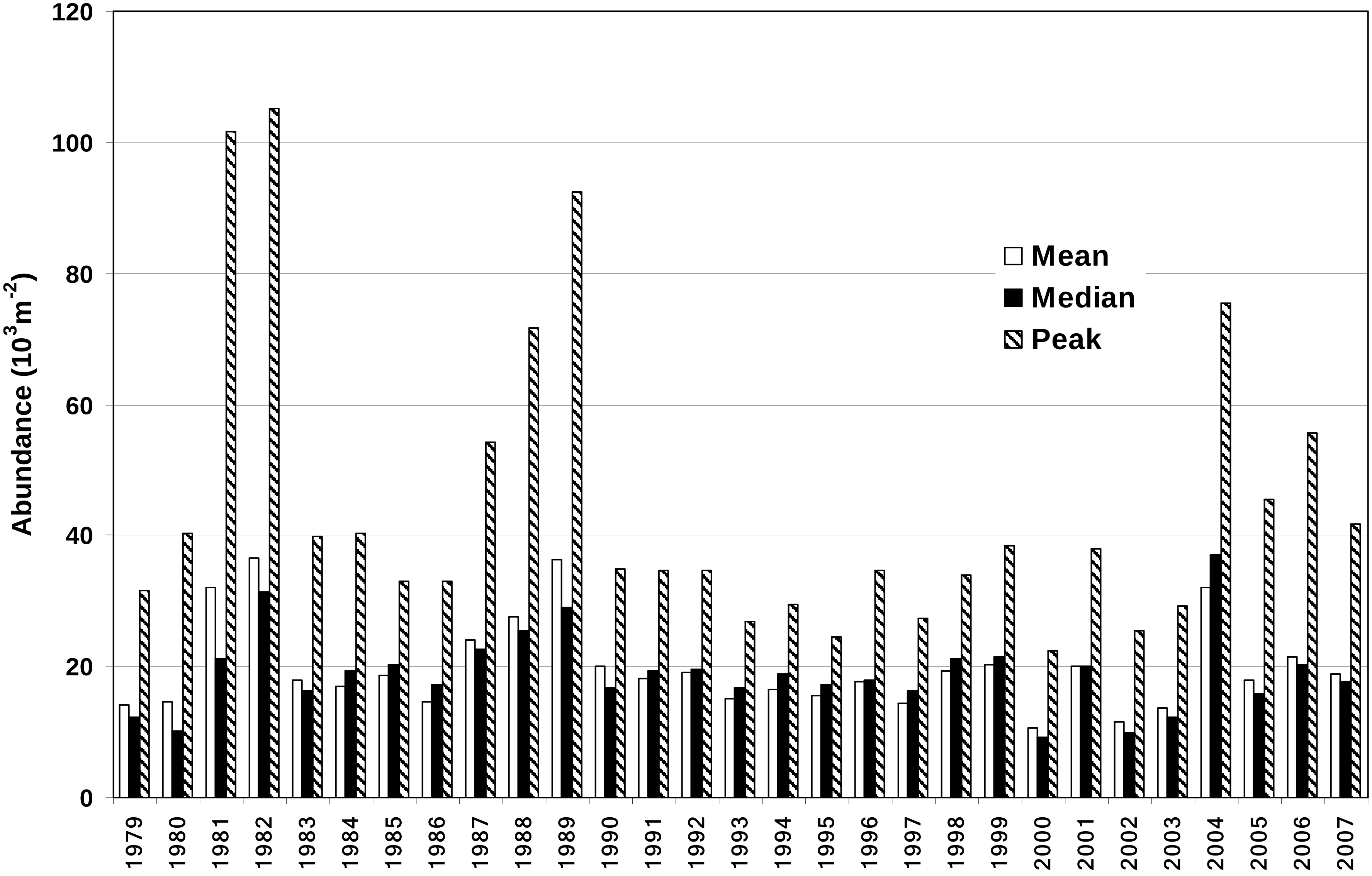
Adult *Artemia* Abundance

Figure 21

Figure 22

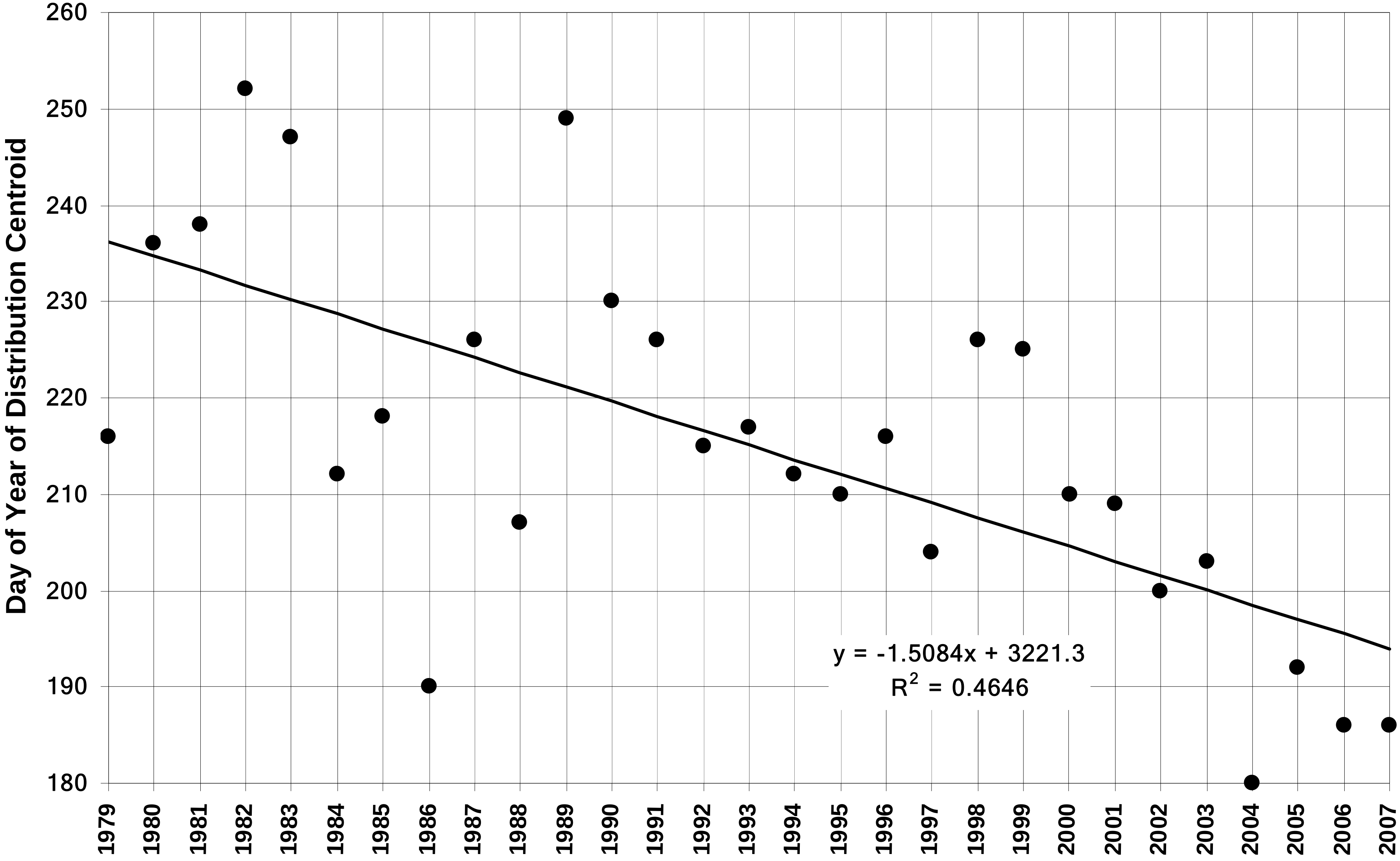


Artemia Reproductive Parameters



Adult *Artemia* Summary

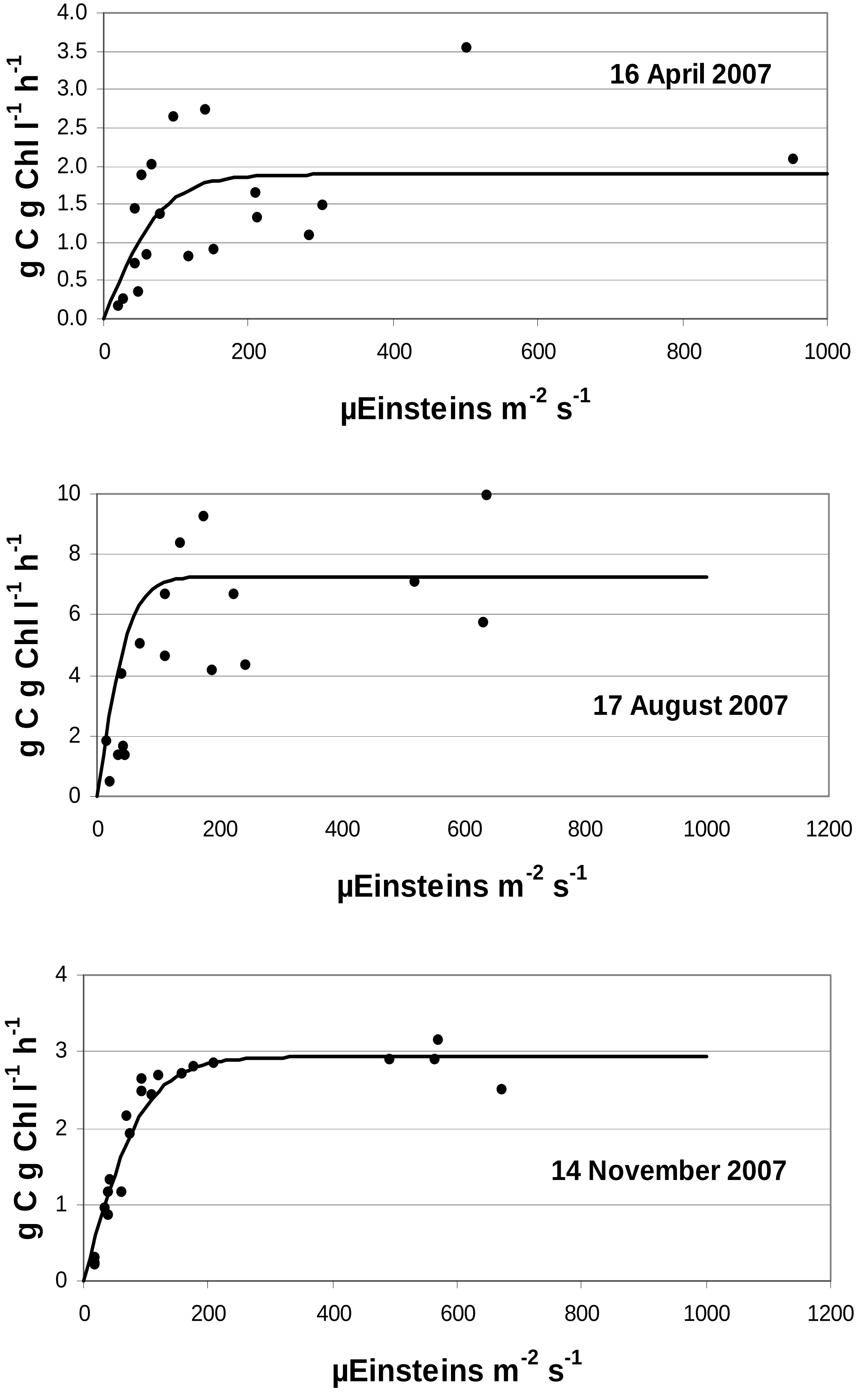
Figure 23



Adult *Artemia* Temporal Distribution

Figure 24

Figure 25



Photosynthetic Rates

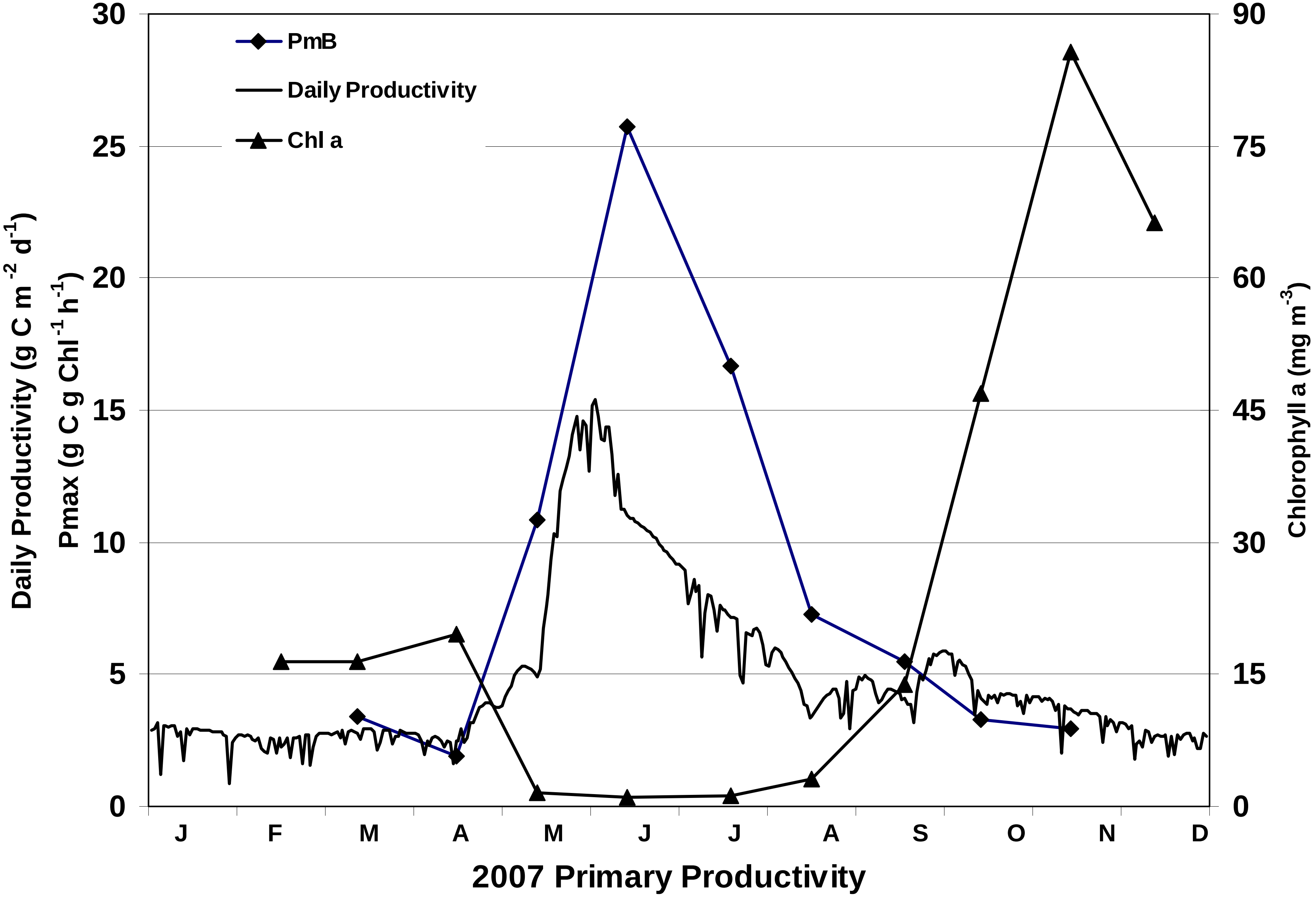
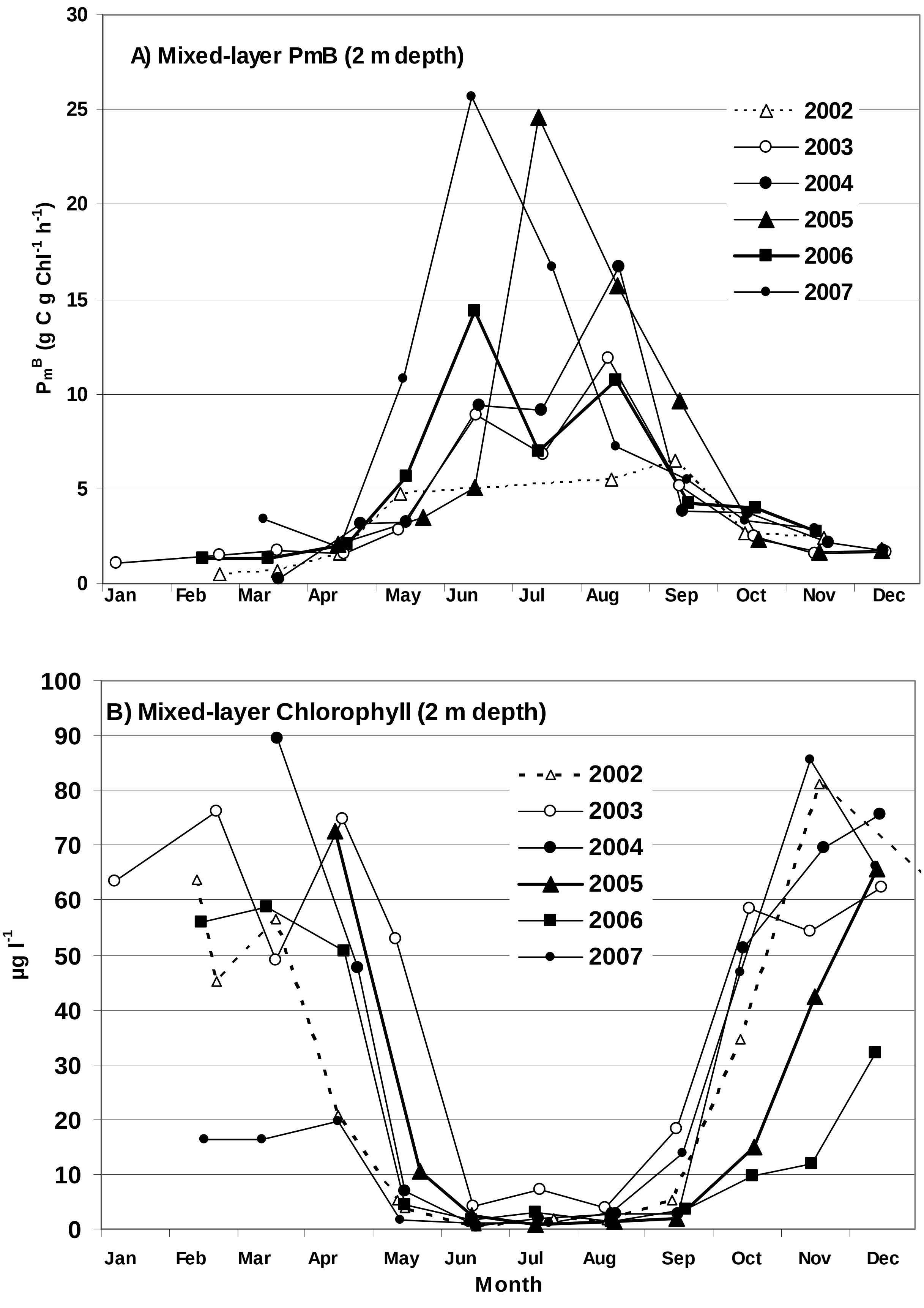

PmB
Daily Productivity
Chl a
30
25
20
15
10
5
0
90
75
60
45
30
15
0
Daily Productivity (g C m $^{-2}$ d^{-1})
Pmax (g C g Chl^{-1} h^{-1})
Chlorophyll a (mg m^{-3})
J
F
M
A
M
J
J
A
S
O
N
D
2007 Primary Productivity

Figure 26

Figure 27


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

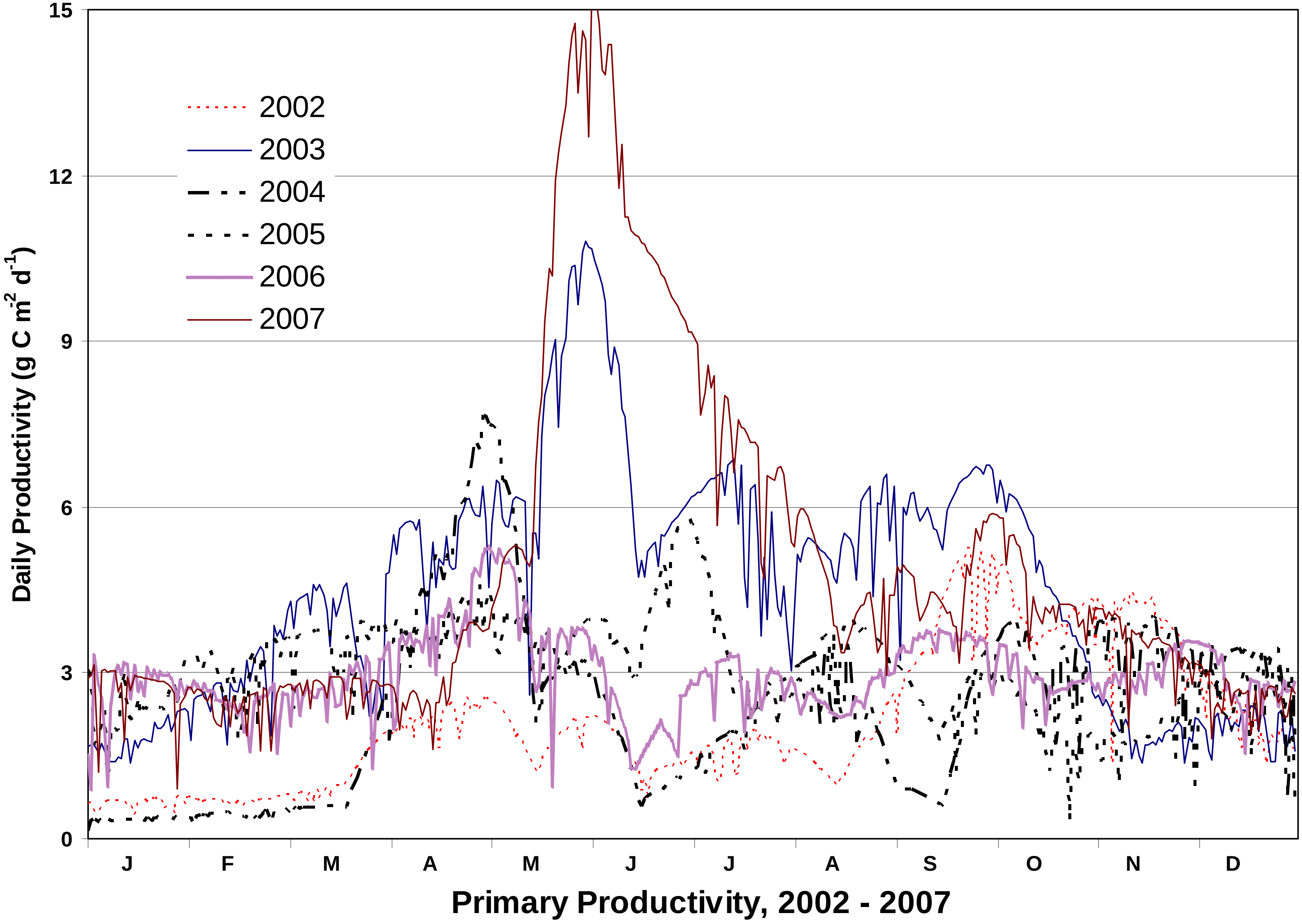

2002
2003
2004
2005
2006
2007
15
12
9
6
3
0
Daily Productivity (g C m^{-2} d^{-1})
J
F
M
A
M
J
J
A
S
O
N
D
Primary Productivity, 2002 - 2007

Figure 28

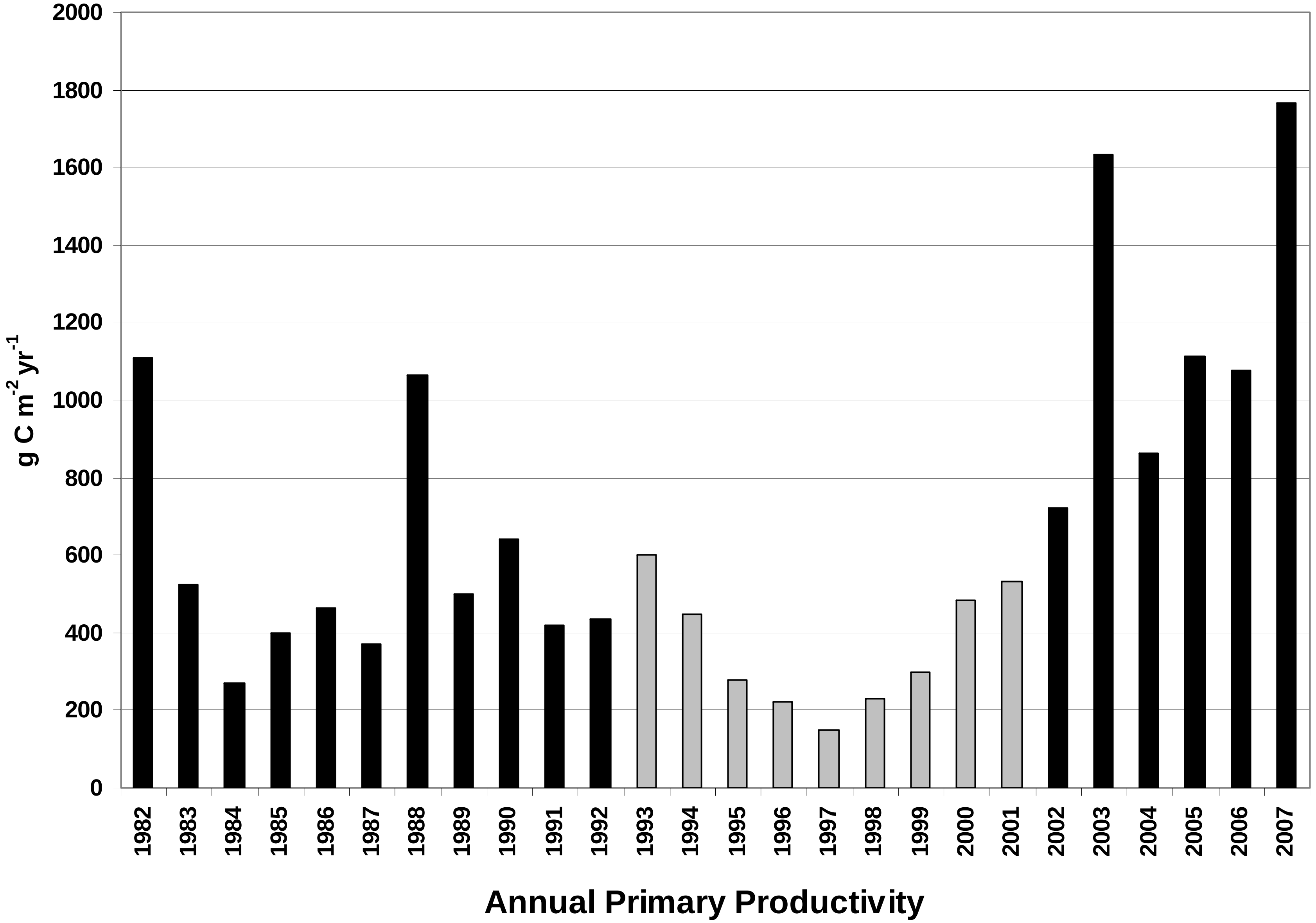

2000
1800
1600
1400
1200
1000
800
600
400
200
0
g C m-2 yr-1
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Annual Primary Productivity

Figure 29

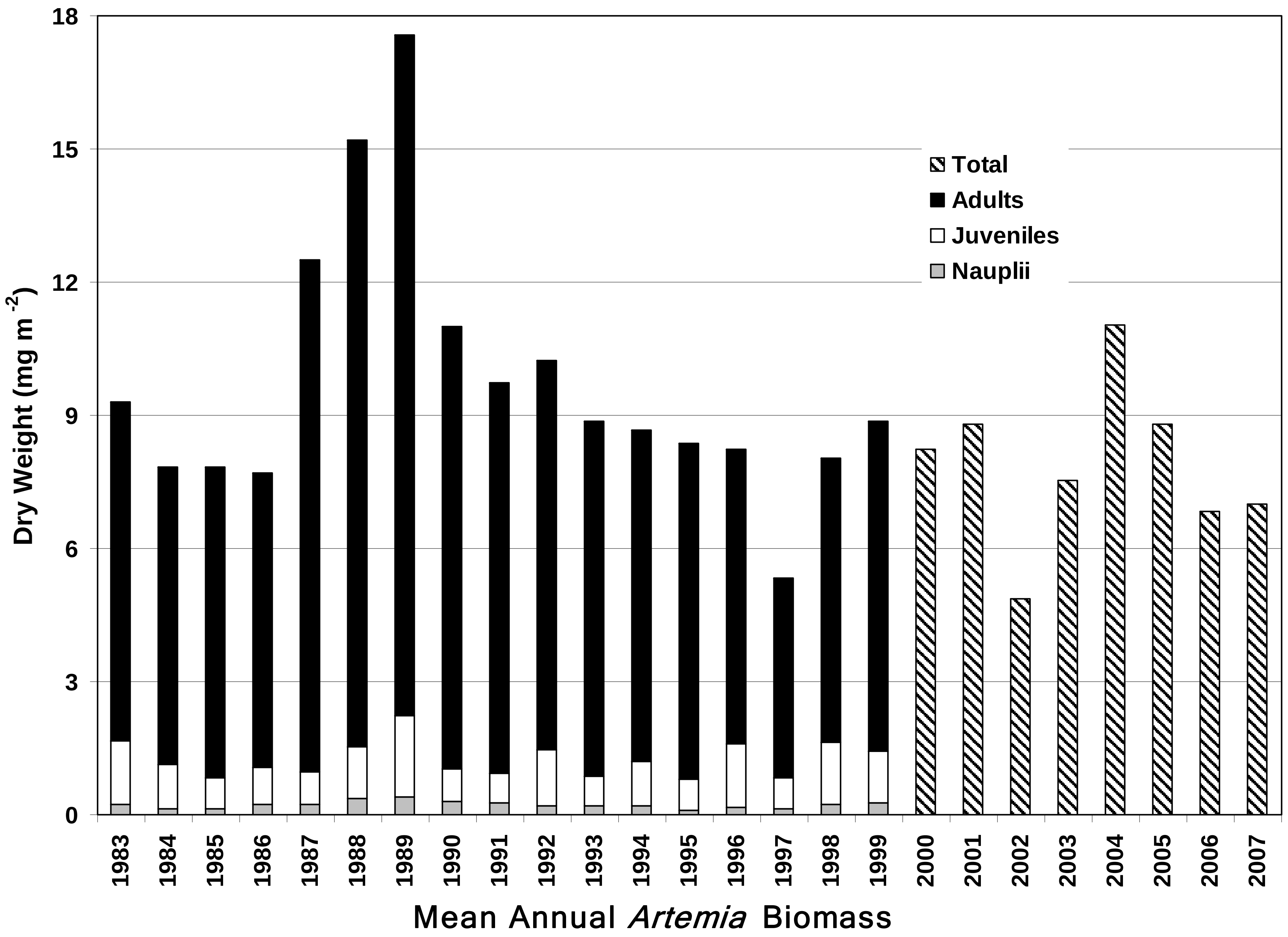

Dry Weight (mg m^{-2})
18
15
12
9
6
3
0
▨ Total
■ Adults
☐ Juveniles
▩ Nauplii
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Mean Annual *Artemia* Biomass

Figure 30

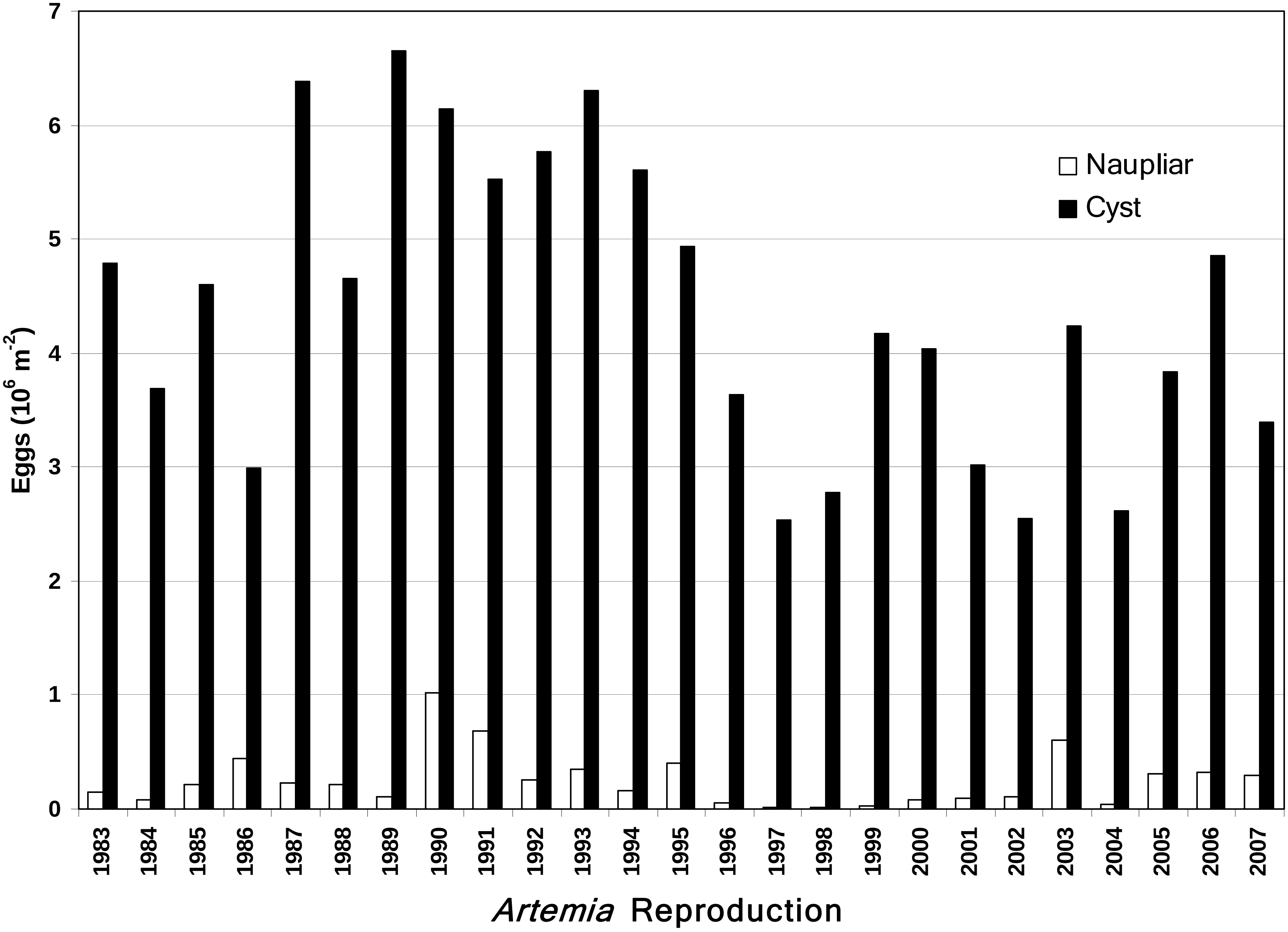

7
6
5
4
3
2
1
0
Eggs (10^6 m^{-2})
☐ Naupliar
■ Cyst
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Artemia Reproduction

Figure 31

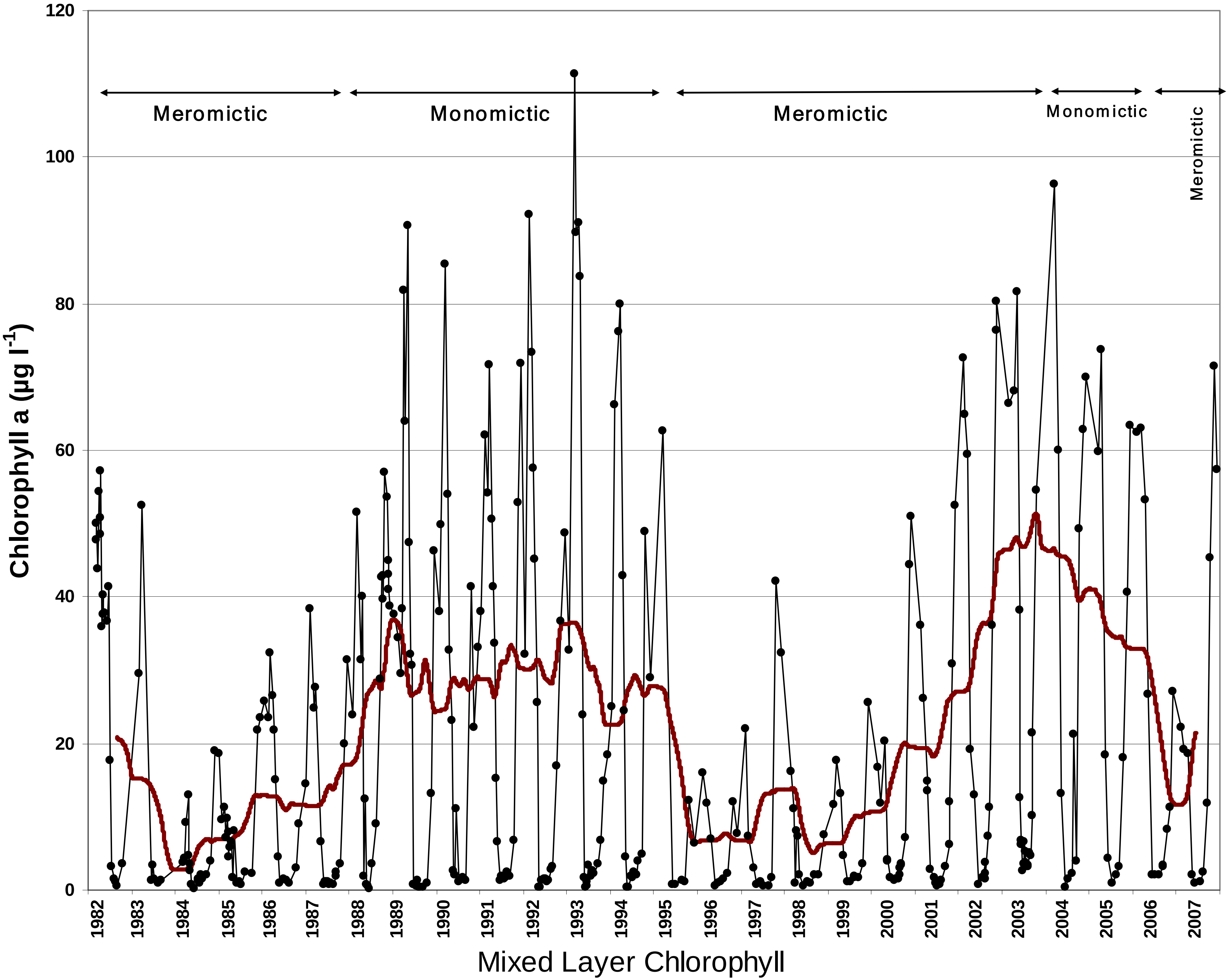
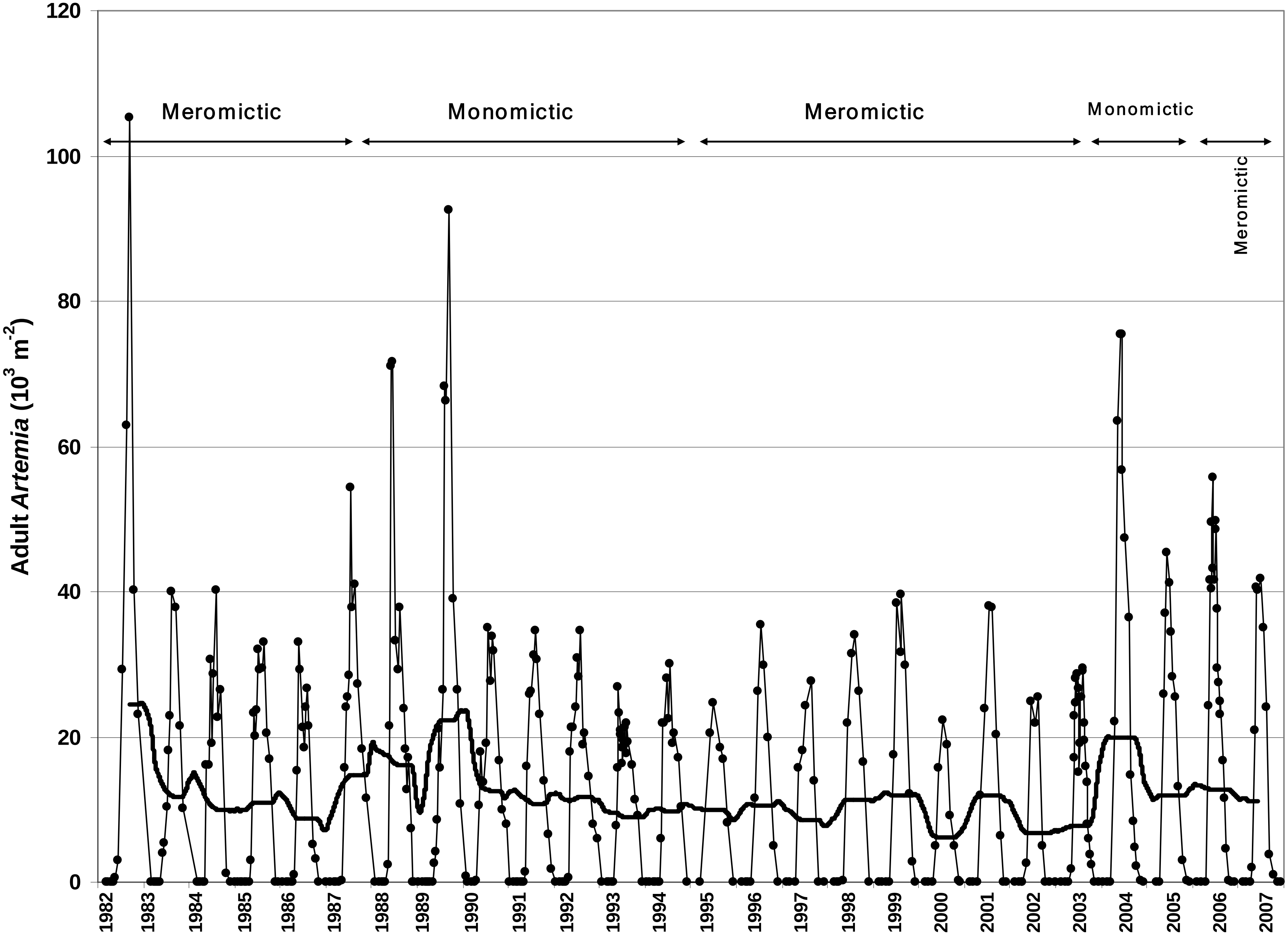

Meromictic
Monomictic
Meromictic
Monomictic
Meromictic
Chlorophyll a (µg l⁻¹)
0
20
40
60
80
100
120
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
Mixed Layer Chlorophyll

Figure 32



Adult *Artemia* Abundance

Figure 33

APPENDIX 2

Ornithology

MONO LAKE WATERFOWL POPULATION MONITORING

2007 Annual Report


10/11/2007

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 2007 at Mono Lake, Bridgeport Reservoir, and Crowley Reservoir, in compliance with State Water Resources Control Board 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.

Summer ground counts indicate an increase in the summer use of Mono Lake by waterfowl, as compared to the previous five years. The number of broods detected along shoreline habitats at Mono Lake (79) in 2007 was comparable to 2006, but Mallard broods comprised a much larger proportion of the breeding population than in previous years. Brackish lagoons and fresh water ponds that formed along the south shore during the rise in lake elevation that occurred in 2006 continued to be used heavily by summering and brooding waterfowl. The seven species that used the Mono Lake shoreline habitats and Restoration Ponds (DeChambeau and County Ponds) for brooding were Canada Goose, Cinnamon Teal, Gadwall, Green-winged Teal, Mallard, Northern Pintail and Ruddy Duck. Gadwall was the most abundant waterfowl species breeding at Mono Lake. Canada Geese were encountered in unvegetated areas or fresh water outflow areas, while the dabbling duck species were typically encountered in brackish lagoons, fresh water ponds, and areas of fresh water outflow.

A total of nine waterfowl species were recorded at Mono Lake during fall aerial surveys. The total number of waterfowl detected in 2007 (23,618) was comparable to 2006. The peak one-day count of 9,926 was approximately 33% higher than occurred in 2006.

A total of 15 waterfowl species were recorded at Bridgeport Reservoir during the fall 2007 aerial surveys. The peak number of waterfowl detected at Bridgeport Reservoir was 11,957 individuals, and occurred during the September 6 survey. A total of 24,693 waterfowl were detected during the six surveys at Bridgeport Reservoir during the fall season. The most abundant species were Gadwall, Northern Shoveler, and Mallard.

A total of 13 waterfowl species were recorded at Crowley Reservoir during the 2007 fall aerial surveys. The peak number detected at Crowley Reservoir was 3,821 which occurred during the September 18 survey. A total of 17,985 waterfowl were detected at Crowley Reservoir over the

six fall season surveys. The most abundant species were Northern Shoveler, Ruddy Duck and Green-winged Teal.

The data from the past six years indicates that brood production has been significantly positively correlated with the level 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. Based on waterfowl data from 1996-2007, total fall detections have been correlated with primary productivity of the lake. However, total fall detections of waterfowl have not been related to mean brine shrimp abundance in the fall. There has been no correlation between the total number of waterfowl detected at Mono Lake, Bridgeport Reservoir, or Crowley Reservoir over the past five years. There has been no significant trend in the peak number of waterfowl, exclusive of Ruddy Ducks, since 1996. No obvious relationship was found between trends in detections of Northern Shoveler or Ruddy Ducks at Mono Lake and the trend in these species based on data from the USFWS breeding estimates and the Pacific Flyway Mid-winter counts.

WATERFOWL MONITORING COMPLIANCE

This report fulfills the Mono Lake waterfowl population survey and study requirement set forth in compliance with the State Water Resources Control Board Order 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 2007. 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 October 11, 2007.

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2007 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 State Water Resources Control Board. 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.

The State Water Resources Control Board 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 how the 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 are conducted in order to determine the size of breeding and/or summering populations, species composition, and spatial distribution of waterfowl during the summer. Habitat use by waterfowl is also documented. Fall aerial surveys are conducted to provide an index of waterfowl numbers using Mono Lake during that time, 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.

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 are generally required to complete each ground survey of Mono Lake, however poor weather conditions combined with scheduling conflicts resulted in surveys being conducted over four-day periods. The time of day that surveys were done in each area around Mono Lake during 2007 are provided in Appendix 1.

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 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. 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. In both areas, birds observed within 100 meters on either side of the deltas were also recorded.

At the DeChambeau Pond complex, observations were taken from a single stationary point at each of the five ponds. Observation points that provide a full view of each pond were selected. At the County Ponds, however, 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 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 broods to an age class 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. 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. 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 and shorebirds. 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. Ms. Debbie House was not available for the October 23 survey. A count was conducted by the secondary observer in order to document overall waterfowl use, but the majority of birds were recorded as unidentified. A summary of the fall survey schedule has been provided as Appendix 4.

Each aerial survey began at Mono Lake at approximately 0900 hrs. 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 hrs 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 opposite side of the plane 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 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. 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, Cinnamon Teal, Gadwall, Mallard, and Northern Pintail. 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 fall aerial survey data was also summed by lakeshore segment for each body of water. In order to provide an index of overall use, waterfowl numbers were summed over all six fall counts to determine total detections of each species and for all waterfowl species at each water body. Single-factor Repeated Measures Analysis of Variance (RM ANOVA) was used to determine if the mean waterfowl detections for the entire fall season differed between lakeshore segments at Mono Lake. The Tukey multiple comparison test (Zar 1996) was used to identify which shoreline segments were different when ANOVA results were significant.

The counts of waterfowl detections at Bridgeport and Crowley were compared with counts of waterfowl at Mono for the all comparison counts conducted from 2002 through 2007. Single-factor RM ANOVA was used to evaluate whether the mean number of waterfowl detected differed between the three bodies of water.

Trend Analysis

Simple linear correlation was used to evaluate the trend in the mean number of waterfowl summering at the lake since 2002. A two-factor RM ANOVA was used to determine if the mean total waterfowl detections differed between lakeshore segments and year. 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 was also used to evaluate the trend in the total fall waterfowl numbers from 1996 to 2007 as a function of primary productivity of the lake in terms of Chlorophyll *a* measurements, and the abundance of brine shrimp (*Artemia monica*) from August thru November of each year (data from limnological monitoring conducted by U.C. Santa Barbara. Pacific Flyway data (Trost et al 2007) for breeding and wintering populations of Northern Shoveler and Ruddy Duck were graphed against data from total and peak counts for these species at Mono Lake from 1996 to 2007. The breeding data used was that from the "traditional survey area" of western Canada and the western prairie states. 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 2007. Photos were taken from a helicopter at all bodies of water on October 11, 2007. These 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

2007 CONDITIONS

Mono Lake

The 2006-2007 water year in the Mono Basin was “Dry” or one in which runoff during 2007 was predicted to be less than 68.5%. Actual predicted runoff was 46% of average. The lake level was initially 0.9 feet higher at 6384.5 feet in early summer (June) than it was in was in June of 2006. The level of Mono Lake, however, gradually dropped through the summer and fall months. During the remainder of the summer survey period of 2007, the level of Mono Lake was between 0.3 feet (at 6384.2 feet) and 1.2 feet lower (at 6383.9 feet) than during the same period in 2006. During the fall survey period, the lake was between 1.3 and (at 6383.5 feet) 1.6 feet lower (at 6382.9 feet) than during the same period in 2006. The decrease in lake elevation resulted in qualitative differences in lake-fringing habitats during the 2007 monitoring period, some of which are discussed below.

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

The increase in lake elevation that occurred in 2006 created many new lagoons in the South Shoreline area. The majority of these lagoons were still present in 2007, and continued to attract waterfowl. Many of the lagoons showed some drying through the summer and fall months. Extensive sand bars formed along the shoreline in this area, isolating spring outflow from lake water. The drop in lake elevation resulted in a great increase in exposed shoreline as compared to 2006.

In the South Tufa area, new lagoons at the east end of the area that had formed in 2006 decreased considerably in size by fall, but attracted waterfowl and shorebirds in the early summer. New areas of emergent vegetation formed behind sand bars, and the drop in lake elevation exposed barren shoreline (Figure 5).

The numerous isolated lagoons that formed along the length of the South Shore Lagoons area in 2006 were still present in 2007. These lagoons continued to attract breeding and migratory waterfowl (Figures 6 and 7). The drop in lake elevation combined with the formation of an extensive littoral bar resulted in the isolation of spring outflow from lake water at some springs, as was the case at Sand Flat Spring (Figure 8). Another result of the drop in elevation was that some fresh water and brackish lagoons in this area, such as those formed by Goose Springs outflow, were no longer inundated by lake water (Figure 9). There was also a large increase in exposed shoreline along much of the area, as compared to 2006.

In the Sammann's Spring area, lake-fringing lagoons that formed in 2006 persisted and continued to attract migratory waterfowl. Lagoons east of the Sammann's Springs tufa continued to attract migratory waterfowl in the fall (Figure 10). The amount of freshwater ponds in the Sammann's Spring area appeared to have increased in 2007 as compared to the last several years. The inundation of lake-fringing lagoons that occurred last year resulted in a die-off of emergent vegetation in some of these lagoons. In 2007, an extensive sandbar system formed in this area. Because of the die-off of emergent vegetation last year, the ponds that reformed behind the littoral bars were more open (Figure 11).

Warm Springs and Northeast Shore

The decrease in lake elevation resulted in the increase in exposed playa and a decrease in the size and extent of lagoons in the Warm Springs and Northeast Shore areas. The "North Lagoon" in the Warm Springs area continued to persist and remain the primary area of waterfowl use on the east side of the lake (Figure 12). The continuous hypersaline lagoon that formed along the shoreline in the Northeast Shore area in 2006 was largely absent by the fall (Figure 13).

Bridgeport Creek to Black Point

Small isolated lagoons continued to persist in the Bridgeport Creek to Black Point area (Figures 14 and 15). These lagoons typically attract small numbers of waterfowl in the fall. The drop in lake elevation resulted in an apparent decrease in the size of many of the lagoons in this area of the lake.

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 meadows continued to be very wet, and the area east of Wilson Creek bay continued to attract most of the waterfowl using the Wilson Creek area. At Mill Creek, a sand bar resulted in the formation of a fresh water pond along the shoreline (Figure 17). In the DeChambeau Creek area (Figure 18), the only notable change was an increase in the amount of exposed shoreline as compared to 2006.

Lee Vining Creek

Lee Vining Creek (Figure 19) did not receive a stream restoration flow in 2007 due to the dry year conditions. A fresh water pond was present behind the sand bar in the north arm of the delta.

Rush Creek

As was the case with Lee Vining Creek, Rush Creek did not receive a stream restoration flow in 2007 due to the dry year conditions. Creek flows at the delta were deflected into the southern part of the bay by a sandbar (Figure 20).

Restoration Ponds

Both County Ponds were flooded in 2007. All of the DeChambeau Ponds were flooded except DeChambeau Pond five, which remained dry all year.

Bridgeport Reservoir

The water level at Bridgeport Reservoir had dropped considerably as compared to 2006. Figure 21 shows the condition of Bridgeport Reservoir in October.

Crowley Reservoir

The water level at Crowley Reservoir was well below that encountered in 2006 (Figures 22-24). The drop in elevation resulted in the exposure of mudflats. The heavy growth of algae that occurred in 2006 was not noted in 2007.

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 10 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 422 to 654 individuals in 2007. The highest proportion of detections was in the South Shore Lagoons area, followed by Sammann's Spring and Warm Springs.

The waterfowl species that brooded in the lake-fringing wetlands and creeks at Mono Lake in 2007 were Canada Goose, Cinnamon Teal, Gadwall, Green-winged teal, Mallard, and Northern Pintail. 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 2007. The number of broods detected in lake-fringing habitats (79) was similar to that seen in 2006. As was the case in 2006, the South Shore Lagoon area was the most heavily used area for brooding as 45 broods were detected in this area. This is the most broods detected in the South Shore Lagoon area, both in terms of number and percent of total broods, since standardized ground surveys began in 2002. The second most heavily used area for brooding in 2007 was the Wilson Creek area. While Gadwall was still the most abundant breeding species, there was a noticeable increase in the number of Mallard broods. In 2007, there were 22 Mallard broods were detected in lake-fringing habitats, whereas the most Mallard broods recorded in all previous years was seven. The majority of Mallard broods in 2007 were in the South Shore Lagoons area, where this species brooded in both brackish and fresh water ponds.

Waterfowl Habitat Use

All four waterfowl species analyzed showed a disproportionate use of the various shoreline habitats in 2007. Table 4 provides the tabulated habitat use data, the chi-squared goodness-of-fit results, and the Bonferonni test results for Canada Goose, Cinnamon Teal, Gadwall, Mallard, and Northern Pintail. Figure 26 is a bar graph depicting the proportional use of habitats by each of these species. Canada Geese were observed using unvegetated areas and ria, with the use of unvegetated more than expected. The four species of dabbling ducks used brackish lagoons significantly more than other habitats. Other habitats these species used frequently were fresh water ponds and ria.

FALL AERIAL SURVEYS

Mono Lake

A total of nine waterfowl species and 23,618 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 9,926 and occurred on the October 2 survey (Table 5, Figure 27). Compared to the 2006 counts, the total number of detections was essentially the same (23,618 vs. 22,198 in 2006) while the one-day peak count in 2007 was approximately 33% greater than that observed in 2006. The peak number of Northern Shoveler occurred on September 6, and the peak number of Ruddy Ducks occurred on October 2. The peak count of 4,171, exclusive of Ruddy Ducks, was 37% lower than the peak count of 5,726 in 2006.

In terms of total detections, Ruddy Ducks and Northern Shovelers were the dominant species during fall migration with Ruddy Ducks accounting for 43.8% (10,360) of all detections, and Northern Shovelers accounting for 38.5% (9,090) of all detections.

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. There was a significant difference in the proportional use of the lakeshore segments and offshore areas by waterfowl during the fall period ($p < 0.001$, $F = 3.953$, $df = 89$). The use of Rush Creek, South Shore Lagoons, Sammann's Spring and Wilson Creek was significantly higher than the use of all other shoreline areas.

Bridgeport Reservoir

A total of 15 waterfowl species and 24,693 individuals were recorded at Bridgeport Reservoir during the 2007 fall aerial surveys (Table 12). The peak number of waterfowl detected on any single count at Bridgeport Reservoir was 11,957 individuals, which occurred on September 6 (Table 12, Figure 27). Compared to the 2006 counts, these numbers represent a 43% decrease in total detections and an approximate 21% decrease in the one-day peak count at Bridgeport. The most abundant species (in terms of total detections) were Gadwall, Northern Shoveler and Mallard. Tables 13-18 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment.

Crowley Reservoir

A total of 13 waterfowl species and 17,985 individuals were detected at Crowley Reservoir during the 2007 fall aerial surveys (Table 19). The peak number of waterfowl detected on any single count at Crowley Reservoir was 3,821 individuals and occurred on September 18 (Table 19, Figure 27). These numbers represent a 30% decrease in total detections and a 51% decrease in the one-day peak count at Crowley as compared to 2006. The most abundant species, in terms of total detections, were Ruddy Ducks, Northern Shovelers and Green-winged Teal. Tables 20-25 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment.

Mono Lake Restoration Ponds

A total of six species and 96 waterfowl were detected at the Restoration Ponds during summer surveys (Table 26). The most abundant species were Gadwall and Cinnamon Teal and Ruddy Ducks. A total of eight broods were seen, including seven Gadwall and one Ruddy Duck brood (Table 27). There were a total of 125 American Coot detections and seven American Coot broods seen.

A total of four waterfowl species and 2850 individuals and 610 American Coots were detected at the DeChambeau and County Pond complexes during fall surveys (Table 28). Large numbers of Northern Shoveler were seen at the County Ponds in September.

COMPARISON OF MONO LAKE WITH BRIDGEPORT AND CROWLEY RESERVOIRS

The total fall detections at each waterbody over the last five years are shown in Figure 28. There has been no correlation between the total number of waterfowl detected at each lake over the past five years. Detections at Bridgeport and Crowley Reservoirs have declined the last two years while no such decline was seen at Mono Lake. Likewise, trends in use of Mono Lake by the two dominant species, Northern Shoveler and Ruddy Ducks have not been mirrored at Bridgeport or Crowley Reservoirs (Figures 29 and 30).

ANALYSIS OF TREND – MONO LAKE

The mean number of waterfowl summering at Mono Lake (592) was significantly higher than all other years since 2002 (Figure 31) ($p = 0.008$, $df = 5$, $F = 3.385$), however there is no established trend in the summering population ($R^2 = 0.72$, $p > 0.05$). The spatial distribution of waterfowl has varied as a function of year ($p<0.001$, $F = 4.348$, $df = 40$). Since 2002, the primary areas of use by summering waterfowl have been South Shore Lagoons, Mill Creek and Wilson Creek. In 2007, the number of waterfowl detected in the South Shore Lagoons area was significantly higher in 2007 as compared to the previous five years, and was significantly higher than all other shoreline areas. Figure 32 shows how the distribution of broods has varied as a function of lake elevation since 2002. Based on survey data from the last six years, the number of broods at Mono Lake has been positively correlated with lake elevation ($r = 0.9$, $p<0.05$) (Figure 33).

The total number of fall detections has varied independently of lake elevation based on waterfowl counts conducted since 1996 ($r = - 0.46$, $p > 0.05$), Figure 34. Total fall detections from 1996-2007 have been positively correlated with productivity of the lake as measured by Chlorophyll *a* concentrations ($r = 0.716$, $p= 0.049$) with variation in Chlorophyll *a* concentrations explaining 51.3% of the variation in total waterfowl numbers (Figure 35). Total fall detections of waterfowl have not shown any relationship to mean brine shrimp abundance in the fall ($r = 0.077$, $p = 0.812$) (Figure 36). The numbers of Northern Shovelers and Ruddy Ducks using Mono Lake in the fall has not shown any direct relationship to trends in the breeding populations or mid-winter counts (Figures 37 and 38).

Figure 39 illustrates the trend in the peak number of waterfowl detected at Mono Lake from 1996-2007. There has been no significant trend in the peak number of waterfowl, exclusive of Ruddy Ducks ($r^2 = 0.215$, $p = 0.12$, $F = 2.733$, $df = 11$).

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 slight decline in 2007. Overall, the lake has experienced a net increase of 1.7 feet in elevation, as measured during the breeding season for waterfowl (June) for the period of 2002-2007. The main effect this increase in elevation appeared to have is that lake-fringing lagoons along the south shore increased 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. Field measurements of salinity indicated that many of these lagoons were brackish (greater than 500 ppm salinity). The response of the breeding population of waterfowl at Mono Lake to these changes has been 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. With the exception of 2007, the breeding population of ducks has remained fairly constant both in terms of population size and species composition. Accompanying the shift in distribution was a notable increase in the number of broods in the last two years. Also of note was the presence of an increased number of Mallard broods in 2007 (22 broods versus an average of five to eight over the previous five years). This apparent increase in the number and diversity of broods is likely related to the habitat conditions at the lake during the last two years, providing more diverse and abundant potential breeding areas around the lake, particularly along the south shore. When the bulk of waterfowl are nesting in the northwest shore areas, they would likely be highly congregated, while nesting along the south shoreline would lead to much greater spacing of nesting birds. Factors that influence reproductive success in waterfowl include the spatial heterogeneity of habitats, which influences predator search efficiency (Bowman and Harris 1980 in Baldassarre and Bolen 1994), weather events that influence habitat condition before and during the nesting period (Greenwood et al., 1995), and predation.

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. Based on waterfowl data from 1996-2007, the total fall detections has been correlated with primary productivity of the lake. Total fall detections of waterfowl have not shown any relationship to mean brine shrimp abundance in the fall.

Since 2003, Mono Lake has supported between 13.7% and 35.6% of all waterfowl counted at the three bodies of water during the fall census period. There has been no correlation between the total number of waterfowl detected at each lake over the past five years. Detections at Bridgeport and Crowley Reservoirs have declined the last two years while no such decline was seen at Mono Lake. Likewise, no correlation was found between use of each lake by Northern Shoveler or Ruddy Duck in terms of the total number of detections.

No obvious relationship was found between trends in detections of Northern Shoveler or Ruddy Ducks at Mono Lake and the trend in these species based on data from the USFWS breeding estimates and the Pacific Flyway Mid-winter counts.

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Table 1. 2007 Summer Ground Count Data

Survey 1	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Canada Goose	52				1				4	57
Cinnamon Teal					7		34	8		49
Gadwall	16	5	28	14	34	19	172	64	25	377
Green-winged Teal		2				4	2			8
Mallard	4	6	1	3	49	2	33	9	11	118
Northern Pintail					9	1	11	9	1	31
Northern Shoveler								4		4
Redhead						1	3			4
Ruddy Duck			3							3
Wood Duck							3			3
Total Waterfowl by Area	72	13	32	17	100	27	258	94	41	654

Survey 2	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Canada Goose	20		4							24
Cinnamon Teal	4				23		7	5		39
Gadwall	12	10	30	11	5		201	35	24	328
Green-winged Teal		2			15	2	4			23
Mallard	6	2	4	2	27		60	28	3	132
Northern Pintail					1	14	34	6		55
Redhead							1			1
Ruddy Duck							2			2
Wood Duck							2			2
Total Waterfowl by Area	42	14	38	13	71	16	311	74	27	606

Survey 3	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Canada Goose	10				17				75	102
Cinnamon Teal					5		70			75
Gadwall	7	5	21	3	2		79		15	132
Green-winged Teal				3			8			11
Mallard		2	1	15	13	1	49			81
Northern Pintail							13		2	15
Ruddy Duck							3			3
Wood Duck				3						3
Total Waterfowl by Area	17	7	22	24	37	1	222	0	92	422

Table 2. Summary of 2007 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	82	0	4	0	18	0	0	0	79	183
Cinnamon Teal	4	0	0	0	35	0	111	13	0	163
Gadwall	35	20	79	28	41	19	452	99	64	837
Green-winged Teal	0	4	0	3	15	6	14	0	0	42
Mallard	10	10	6	20	89	3	142	37	14	331
Northern Pintail	0	0	0	0	10	15	58	15	3	101
Northern Shoveler	0	0	0	0	0	0	0	4	0	4
Redhead	0	0	0	0	0	1	4	0	0	5
Ruddy Duck	0	0	3	0	0	0	5	0	0	8
Wood Duck	0	0	0	3	0	0	5	0	0	8
Total Waterfowl by Area	131	34	92	54	208	44	791	168	160	1682

Total Waterfowl Detections	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR
Number of Waterfowl	131	34	92	54	208	44	791	168	160
% of Detections	7.8%	2.0%	5.5%	3.2%	12.4%	2.6%	47.0%	10.0%	9.5%

Table 3. 2007 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	2								1	3
	Cinnamon Teal										0
	Gadwall				1						1
	Green-winged Teal										0
	Mallard				1			3		1	5
	Northern Pintail										0
	Total broods	2	0	0	2	0	0	3	0	2	9
Survey 2	Canada Goose			2							2
	Cinnamon Teal							1			1
	Gadwall	1			2			7		2	12
	Green-winged Teal										0
	Mallard		2		1	1		6		1	11
	Northern Pintail										0
	Total broods	1	2	2	3	1	0	14	0	3	26
Survey 3	Canada Goose										0
	Cinnamon Teal										0
	Gadwall	3	1	1				21		7	33
	Green-winged Teal				2						2
	Mallard				1	1		4			6
	Northern Pintail							3			3
	Total broods	3	1	1	3	1	0	28	0	7	44

Total	Shoreline Segment	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total Broods
	Canada Goose	2		2						1	5
	Cinnamon Teal							1			1
	Gadwall	4	1	1	3			28		9	46
	Green-winged Teal				2						2
	Mallard		2		3	2		13		2	22
	Northern Pintail							3			3
	Total broods per area	**6**	**3**	**3**	**8**	**2**	**0**	**45**	**0**	**12**	**79**

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				Cinnamon Teal				Gadwall				Mallard				Northern Pintail			
Habitat	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign
Marsh									2	34.8	30.9	-	2	17.7	13.9	-				
Wet Meadow									1	34.8	32.9	-								
Alkali Wet Meadow									2	34.8	30.9	-								
Riparian Scrub									7	34.8	22.2	-								
Freshwater Stream									2	34.8	31.0	-	3	17.7	12.2	-				
Ria	4	28.5	21	-					40	34.8	0.8	NS	17	17.7	0.1	NS	1	11.0	9.1	-
Fresh Water Pond					18	31.5	5.8	-	46	34.8	3.6	NS	27	17.7	4.9	NS	2	11.0	7.4	-
Brackish Lagoon					45	31.5	5.8	+	247	34.8	1293.1	+	68	17.7	142.8	+	30	11.0	32.8	+
Hypersaline Lagoon									12	34.8	15.0	-	5	17.7	9.1	-				
Unvegetated	53	28.5	21.1	+					17	34.8	9.1	-	2	17.7	14.0	-				
Open Water									7	34.8	22.3	-								
Total	57		42.1		63		11.6		383		1491.6		124		196.9		33		49.3	

Table 5. Summary of 2007 Mono Lake Fall Aerial Survey Counts

Species	6-Sep	18-Sep	2-Oct	17-Oct	30-Oct	13-Nov	**Total Detections**	**%Total**
Bufflehead					1		1	0.00
Canada Goose			2	46	112	85	245	1.04
Cinnamon Teal	6	48					54	0.23
Gadwall	9	14	19		2		44	0.19
Green-winged Teal	105	86	50	99	326	79	745	3.15
Mallard	169	143	415	81	182	117	1107	4.69
Northern Pintail		2	146		20	198	366	1.55
Northern Shoveler	3867	3003	2109		78	33	9090	38.49
Ruddy Duck	431	1405	6855	399	914	356	10360	43.86
Unidentified *Anas*	15	264	330	923	67	7	1606	6.80
Total waterfowl	4602	4965	9926	1548	1702	875	23618	

Table 6. Mono Lake - Fall Aerial Survey, September 6, 2007

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			
Cinnamon Teal			6													6		6
Gadwall	2				7											9		9
Green-winged Teal			42	57										6		105		105
Mallard			88	40							6			35		169		169
Northern Shoveler	556		1239	420	2		18	18	300	958	325	25	6			3867		3867
Ruddy Duck											20				11	31	400	431
Anas spp.												15				15		15
Total Waterfowl	558	0	1375	517	9	0	18	18	300	958	351	40	6	41	11	4202	400	4602

Table 7. Mono Lake - Fall Aerial Survey, September 18, 2007

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			
Cinnamon Teal				16	25								7			48		48
Gadwall	2			5									3			10	4	14
Green-winged Teal		6	40	12					8	20						86		86
Mallard			60	25	10					3				45		143		143
Northern Pintail			2													2		2
Northern Shoveler	453			90					470	1300	400	275	15			3003		3003
Ruddy Duck								25	165		178				2	370	1035	1405
Anas spp.			74	75	35						40	20		20		264		264
Total Waterfowl	455	6	176	223	70	0	0	25	643	1323	618	295	25	65	2	3926	1039	4965

Table 8. Mono Lake - Fall Aerial Survey, October 2, 2007

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												2				2		2
Gadwall	10											1			4	15	4	19
Green-winged Teal					12					6		2		30		50		50
Mallard	5		208	107								10		85		415		415
Northern Pintail	20		6		2					80		38				146		146
Northern Shoveler	620	7	1	8			1		3	1308	6	88	67			2109		2109
Ruddy Duck	11	53		2		131	40	136		20	118	131	151	15	90	898	5957	6855
Anas spp.			180	150												330		330
Total Waterfowl	666	60	395	267	14	131	41	136	3	1414	124	272	218	130	94	3965	5961	9926

Table 9. Mono Lake - Fall Aerial Survey, October 23, 2007

Waterfowl Count	**Lakeshore segment**															Shoreline	Offshore	Lakewide
Species	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO	Total	Total	Total
Canada Goose				6				40								46		46
Green-winged Teal			14	75											10	99		99
Mallard	51		23				7									81		81
Ruddy Duck								37			73					110	289	399
Anas spp.	153	135	49	18	45			42		198	95	75	45	68		923		923
Total Waterfowl	204	135	86	99	45	0	7	119	0	198	168	75	45	68	10	1259	289	1548

Table 10. Mono Lake - Fall Aerial Survey, October 30, 2007

Waterfowl Count	**Lakeshore segment**															Shoreline	Offshore	Lakewide
Species	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO	Total	Total	Total
Bufflehead								1								1		1
Canada Goose				95								17				112		112
Gadwall													2			2		2
Green-winged Teal				80	143									78	25	326		326
Mallard			3	70	40			69								182		182
Northern Pintail					20											20		20
Northern Shoveler	55		15	3				5								78		78
Ruddy Duck	18					2	1			4	2	10	113		9	159	755	914
Anas spp.			2	30	33						2					67		67
Total Waterfowl	73	0	20	278	236	2	1	75	0	4	4	27	115	78	34	947	755	1702

Table 11. Mono Lake - Fall Aerial Survey, November 13, 2007

Waterfowl Count	**Lakeshore segment**															Shoreline	Offshore	Lakewide
Species	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO	Total	Total	Total
Canada Goose			39	12					17			17				85		85
Green-winged Teal	45			27				3		4						79		79
Mallard			64			3		33				17				117		117
Northern Pintail			87	111												198		198
Northern Shoveler										17		12		4		33		33
Ruddy Duck		1		21			4		8			24	45	19	6	128	228	356
Anas spp.													7			7		7
Total Waterfowl	45	1	190	171	0	3	4	36	25	21	0	70	52	23	6	647	228	875

Table 12. Summary of 2007 Fall Aerial Survey Counts - Bridgeport Reservoir

Species	6-Sep	18-Sep	2-Oct	23-Oct	30-Oct	13-Nov	**Total Detections**	**%Total**
American Wigeon					20		20	0.08
Bufflehead			7		105	28	140	0.57
Canada Goose	278	93	408			85	864	3.50
Cinnamon Teal	569	30					599	2.43
Common Merganser			2		7	1	10	0.04
Gadwall	2755	870	212		181	385	4403	17.83
Green-winged Teal	451	312	79		192	150	1184	4.79
Lesser Scaup					3		3	0.01
Mallard	592	1356	221		400	120	2689	10.89
Northern Pintail	202	1100	472		54		1828	7.40
Northern Shoveler	3270	200	50		33		3553	14.39
Redhead		50			3		53	0.21
Ring-necked Duck		1	1		8	2	12	0.05
Ruddy Duck	100		40		275	1100	1515	6.14
Snow Goose						2	2	0.01
Anas spp.	3740	2350	202	1013	420	93	7818	31.66
Total Waterfowl	11957	6362	1694	1013	1701	1966	24693	

Table 13. Bridgeport Reservoir Fall Survey, September 6, 2007

Species	Lakeshore segment			**Total**
	NOAR	WEBA	EASH	
Canada Goose		250	28	278
Cinnamon Teal	4	500	65	569
Gadwall	5	2600	150	2755
Green-winged Teal	6	400	45	451
Mallard	17	535	40	592
Northern Pintail	1	200	1	202
Northern Shoveler	20	3250		3270
Ruddy Duck		100		100
Anas spp.		3260	480	3740
Total waterfowl	53	11095	809	11957

Table 14. Bridgeport Reservoir Fall Aerial Survey, September 18, 2007

Species	Lakeshore segment			**Total**
	NOAR	WEBA	EASH	
Canada Goose		93		93
Cinnamon Teal		30		30
Gadwall	20	600	250	870
Green-winged Teal	2	150	160	312
Mallard	6	1250	100	1356
Northern Pintail		1100		1100
Northern Shoveler		200		200
Redhead		50		50
Ring-necked Duck	1			1
Anas spp.		2300	50	2350
Total waterfowl	29	5773	560	6362

Table 15. Bridgeport Reservoir Fall Aerial Survey , October 2, 2007

Species	Lakeshore segment			**Total**
	NOAR	WEBA	EASH	
Bufflehead		1	6	7
Canada Goose		396	12	408
Common Merganser	2			2
Gadwall	10	114	88	212
Green-winged Teal	3	40	36	79
Mallard		200	21	221
Northern Pintail		472		472
Northern Shoveler		40	10	50
Ring-necked Duck	1			1
Ruddy Duck		40		40
Anas spp.		141	61	202
Total waterfowl	16	1444	234	1694

Table 16. Bridgeport Reservoir Fall Aerial Survey, October 23, 2007

Species	Lakeshore segment			Total
	NOAR	WEBA	EASH	
Anas spp.	135	745	133	1013
Total waterfowl	135	745	133	1013

Table 17. Bridgeport Reservoir Fall Aerial Survey, October 30, 2007

Species	Lakeshore segment			Total
	NOAR	WEBA	EASH	
American Wigeon		20		20
Bufflehead	12	56	37	105
Common Mergenser	2	5		7
Gadwall	3	150	28	181
Green-winged Teal	7	180	5	192
Lesser Scaup	2		1	3
Mallard		400		400
Northern Pintail	4	50		54
Northern Shoveler	3	30		33
Redhead	1		2	3
Ring-necked Duck	8			8
Ruddy Duck		200	75	275
Anas spp.		400	20	420
Total waterfowl	42	1491	168	1701

Table 18. Bridgeport Reservoir Fall Aerial Survey, November 13, 2007

Species	Lakeshore segment			Total
	NOAR	WEBA	EASH	
Bufflehead	7	4	17	28
Canada Goose		85		85
Common Mergenser	1			1
Gadwall		385		385
Green-winged Teal		150		150
Mallard		120		120
Ring-necked Duck	2			2
Ruddy Duck		1100		1100
Snow Goose		2		2
Anas spp.	6	87		93
Total waterfowl	16	1933	17	1966

Table 19. Summary of 2007 Fall Aerial Survey Counts - Crowley Reservoir

Species	6-Sep	18-Sep	2-Oct	23-Oct	30-Oct	13-Nov	**Total Detections**	**%Total**
American Wigeon					12		12	0.07
Bufflehead			2		95	93	190	1.06
Canada Goose	14	74	2	4	73	25	192	1.07
Cinnamon Teal	128	25	1				154	0.86
Gadwall	164	254	159		239	104	920	5.12
Green-winged Teal	280	216	619		354	220	1689	9.39
Lesser Scaup						8	8	0.04
Mallard	59	474	112		87	179	911	5.07
Northern Pintail	71	386	998		179	6	1640	9.12
Northern Shoveler	1140	924	449		20	4	2537	14.11
Redhead		6					6	0.03
Ring-necked Duck			41		46		87	0.48
Ruddy Duck	30	110	302		2566	2066	5074	28.21
Anas spp.	950	1352	545	1444	85	189	4565	25.38
Total Waterfowl	2836	3821	3230	1448	3756	2894	17985	

Table 20. Crowley Reservoir Fall Aerial Survey, September 6, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Canada Goose				14				14
Cinnamon Teal	30	8		60	30			128
Gadwall	6	12	6				140	164
Green-winged Teal	80			180			20	280
Mallard	5			40	4		10	59
Northern Pintail	10			40	1		20	71
Northern Shoveler	180			880			80	1140
Ruddy Duck				5			25	30
Anas spp.	90			860				950
Total waterfowl	401	20	6	2079	35	0	295	2836

Table 21. Crowley Reservoir Fall Aerial Survey, September 18, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Canada Goose				72			2	74
Cinnamon Teal				15	10			25
Gadwall	75	23		32	4		120	254
Green-winged Teal				160	25		31	216
Mallard	2			55	12		405	474
Northern Pintail	50	4		180	2		150	386
Northern Shoveler	525			300			99	924
Redhead				6				6
Ruddy Duck	80			30				110
Anas spp.	400	2		920			30	1352
Total waterfowl	1132	29	0	1770	53	0	837	3821

Table 22. Crowley Reservoir Fall Aerial Survey, October 2, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Bufflehead							2	2
Canada Goose				2				2
Cinnamon Teal							1	1
Gadwall	22			50			87	159
Green-winged Teal	100			110			409	619
Mallard	36			60	12		4	112
Northern Pintail	100			820			78	998
Northern Shoveler	7		2	440				449
Ring-necked Duck	1			40				41
Ruddy Duck				300			2	302
Anas spp.	50			390	20		85	545
Total waterfowl	316	0	2	2212	32	0	668	3230

Table 23. Crowley Reservoir Fall Aerial Survey, October 23, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Canada Goose	4							4
Anas spp.	510	30	10	550	210	40	94	1444
Total waterfowl	514	30	10	550	210	40	94	1448

Table 24. Crowley Reservoir Fall Aerial Survey, October 30, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
American Wigeon							12	12
Bufflehead	2	18	23	15	5	22	10	95
Canada Goose				8			65	73
Gadwall	47	5	3	100		4	80	239
Green-winged Teal	55			124		35	140	354
Mallard				51		34	2	87
Northern Pintail	30			80		20	49	179
Northern Shoveler				20				20
Ring-necked Duck				46				46
Ruddy Duck	1300	19		1200	35		12	2566
Anas spp.				30		55		85
Total waterfowl	1434	42	26	1674	40	170	370	3756

Table 25. Crowley Reservoir Fall Aerial Survey, November 13, 2007

Species	Lakeshore segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Bufflehead	6	6	11	37	11	14	8	93
Canada Goose	25							25
Gadwall	6		5	75		10	8	104
Green-winged Teal				180	40			220
Lesser Scaup		2		6				8
Mallard				4	6	165	4	179
Northern Pintail							6	6
Northern Shoveler				4				4
Ruddy Duck	802	2	6	1028	27	115	86	2066
Anas spp.	34			40		115		189
Total waterfowl	873	10	22	1374	84	419	112	2894

Table 26. Mono Lake Restoration Ponds - Total Summer Detection

Waterfowl Totals	COPO	DEPO	Total
Cinnamon Teal	11	13	24
Gadwall	19	8	27
Green-winged Teal	1	4	5
Mallard	15	0	15
Northern Pintail	2	0	2
Ruddy Duck	15	8	23
Total Waterfowl by Area	63	33	96

Table 27. Mono Lake Restoration Ponds - Total Waterfowl Broods

	COPO	DEPO
Gadwall	4	3
Ruddy Duck		1
Total broods	4	4

Table 28. Mono Lake Restoration Ponds - 2007 Fall Survey Counts

DeChambeau Ponds	6-Sep	18-Sep	2-Oct	23-Oct	30-Oct	13-Nov	**Total Fall Detections**
Gadwall			10				10
Northern Shoveler					10		10
Anas spp.	10	47	112	286	5	6	466
Total Waterfowl	10	47	122	286	15	6	486
American Coot	28	18	45	208	145	70	514

County Ponds	6-Sep	18-Sep	2-Oct	23-Oct	30-Oct	13-Nov	**Total Fall Detections**
Green-winged Teal		30					30
Northern Shoveler	1250	850	15				2115
Ruddy Duck						10	10
Anas spp.			39	85	85		209
Total Waterfowl	1250	880	54	85	85	10	2364
American Coot	0	6	42	0	30	18	96

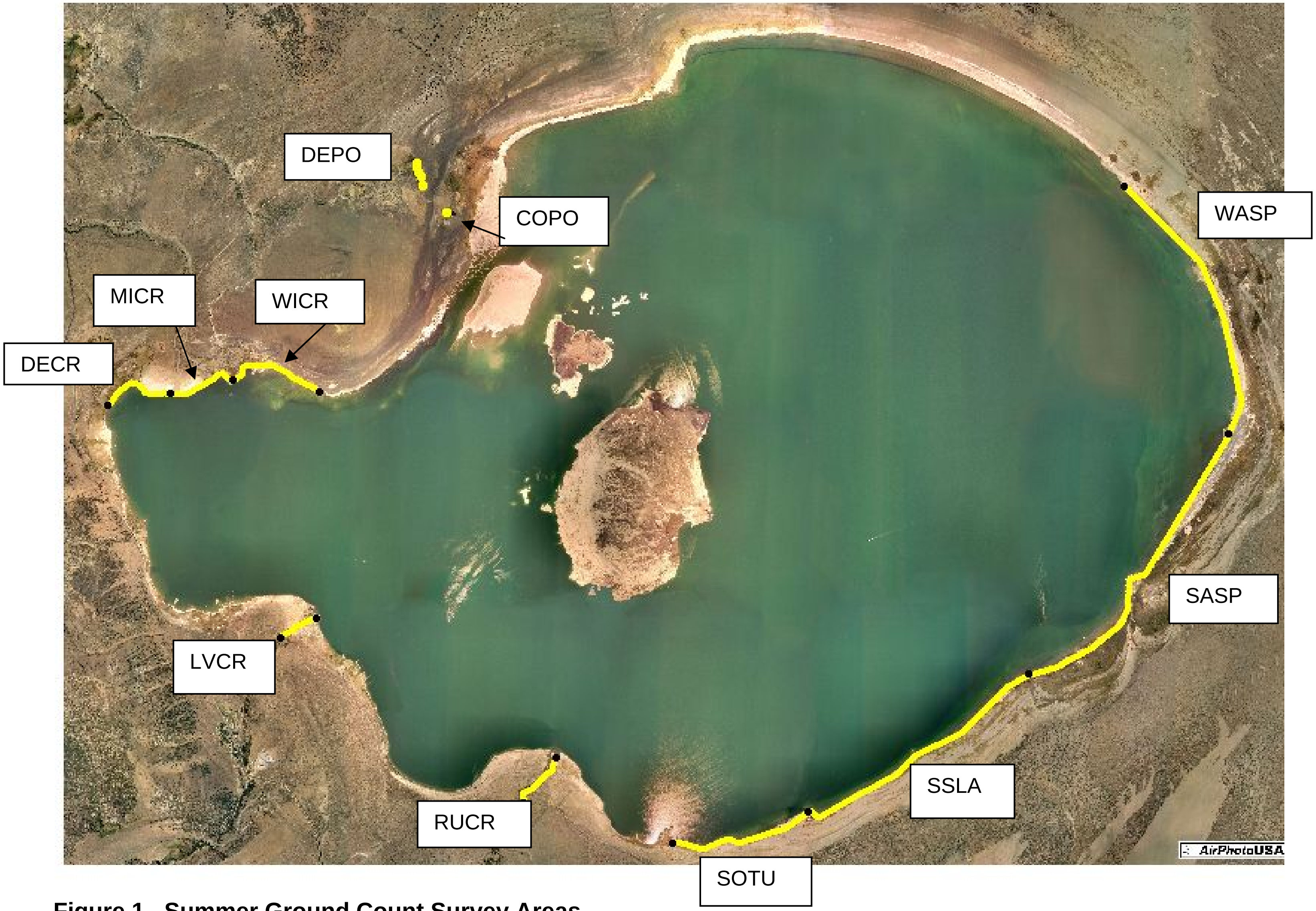


Figure 1. Summer Ground Count Survey Areas

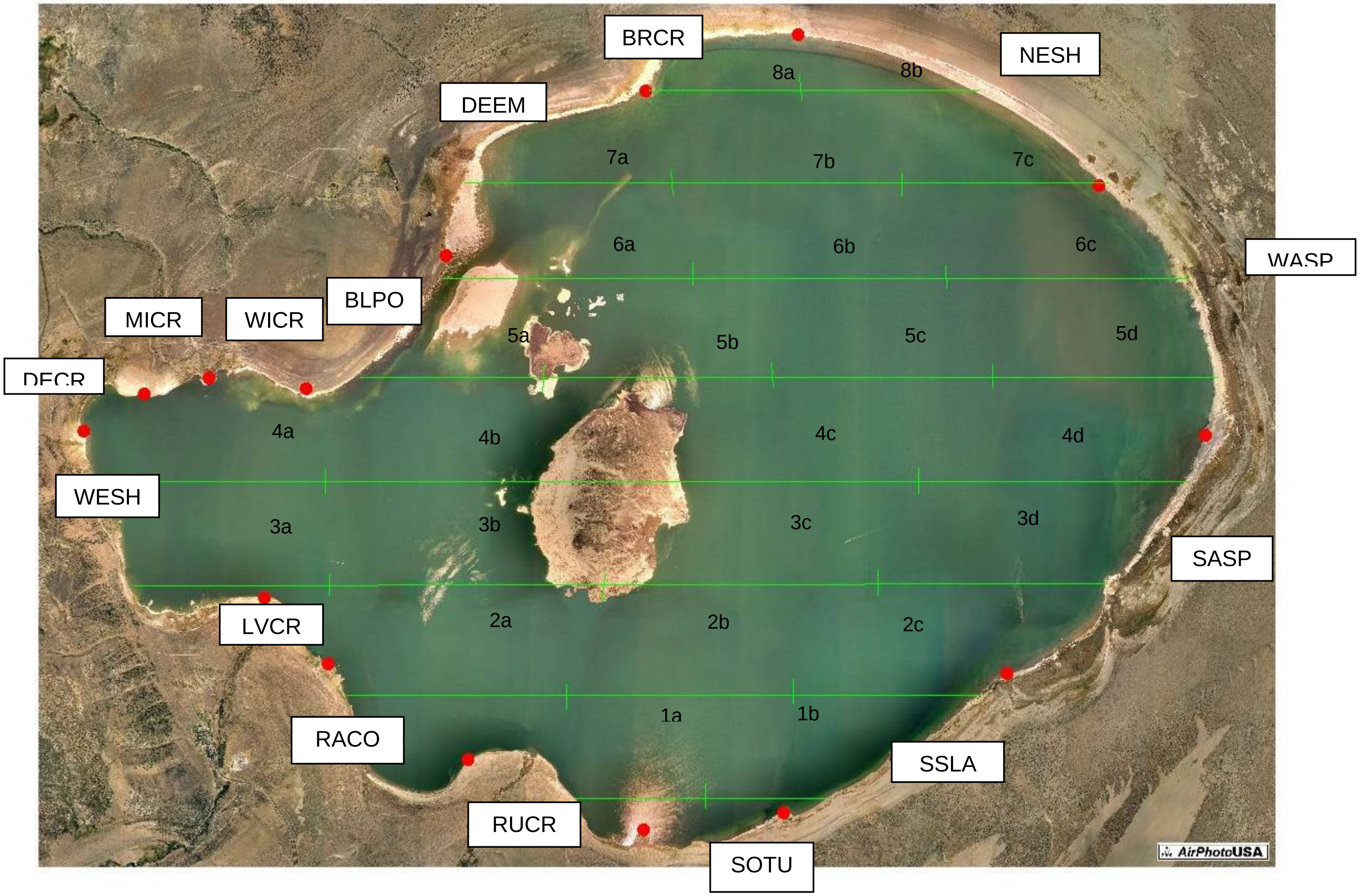


Figure 2. Lakeshore Segment, Segment Boundaries, and Cross-Lake Transects for Fall Aerial Surveys of Mono Lake

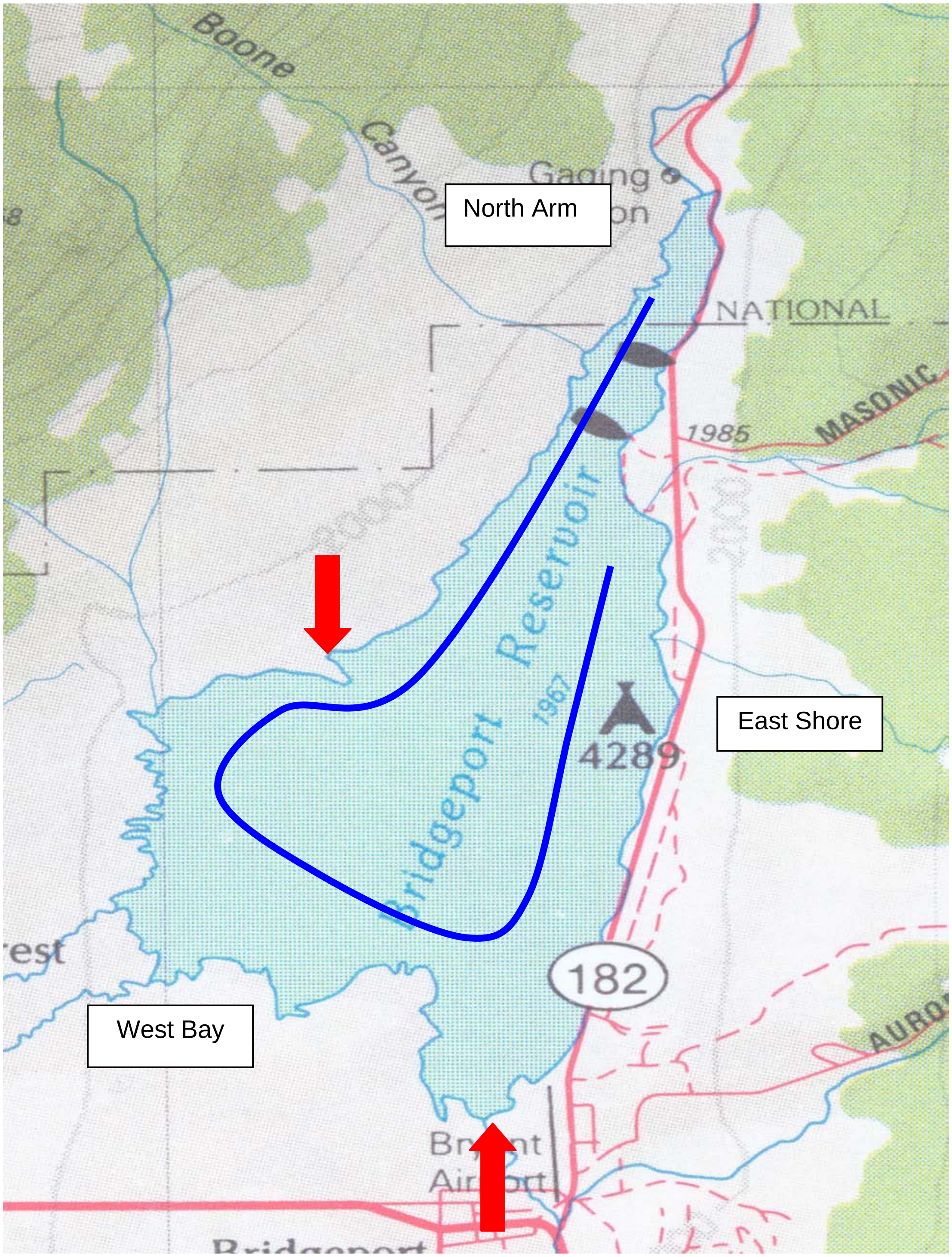


Figure 3. Lakeshore Segments and Segment Boundaries Used for Fall Aerial Surveys of Bridgeport Reservoir

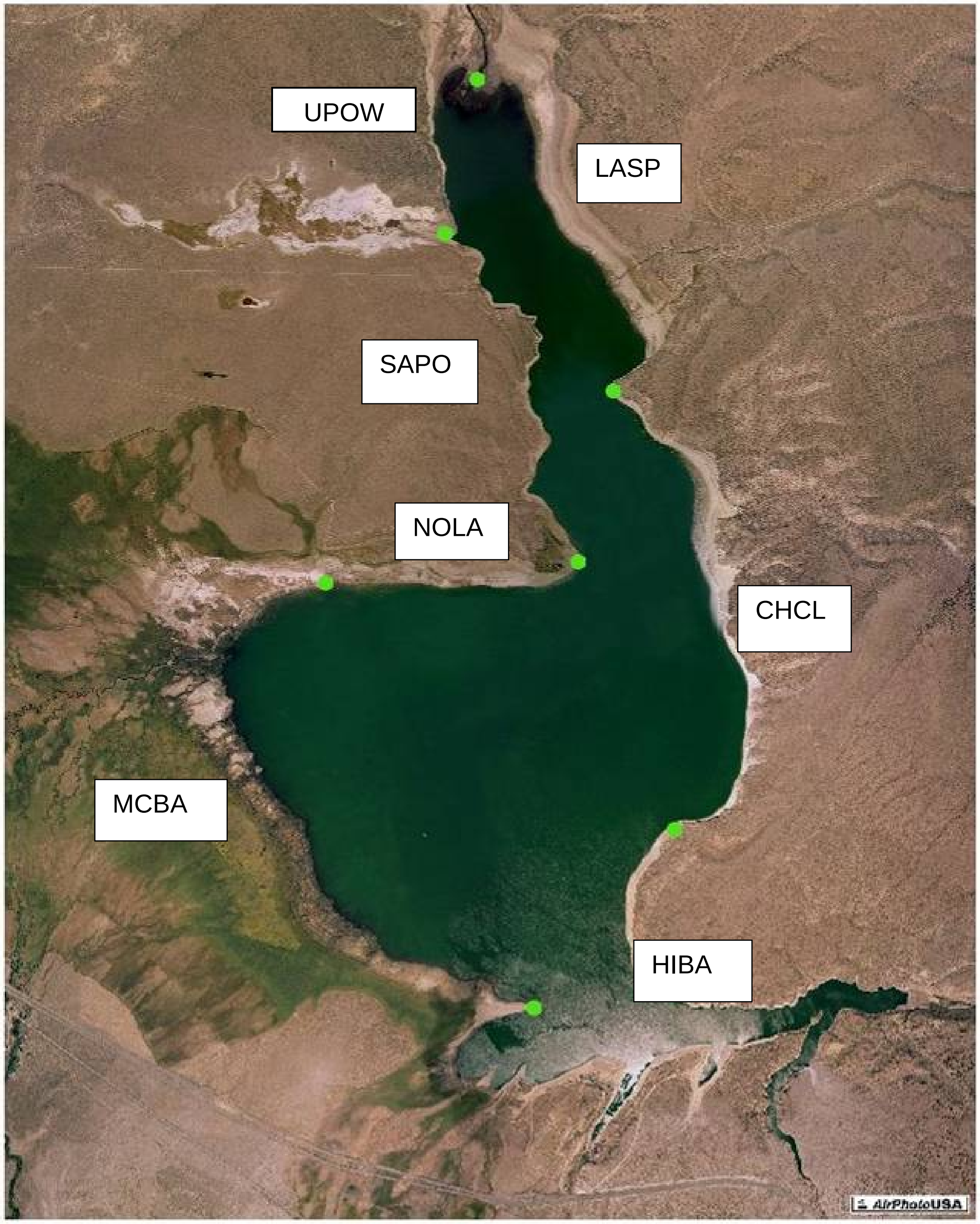


Figure 4. Lakeshore Segments and Segment Boundaries Used for Aerial Surveys of Crowley Reservoir

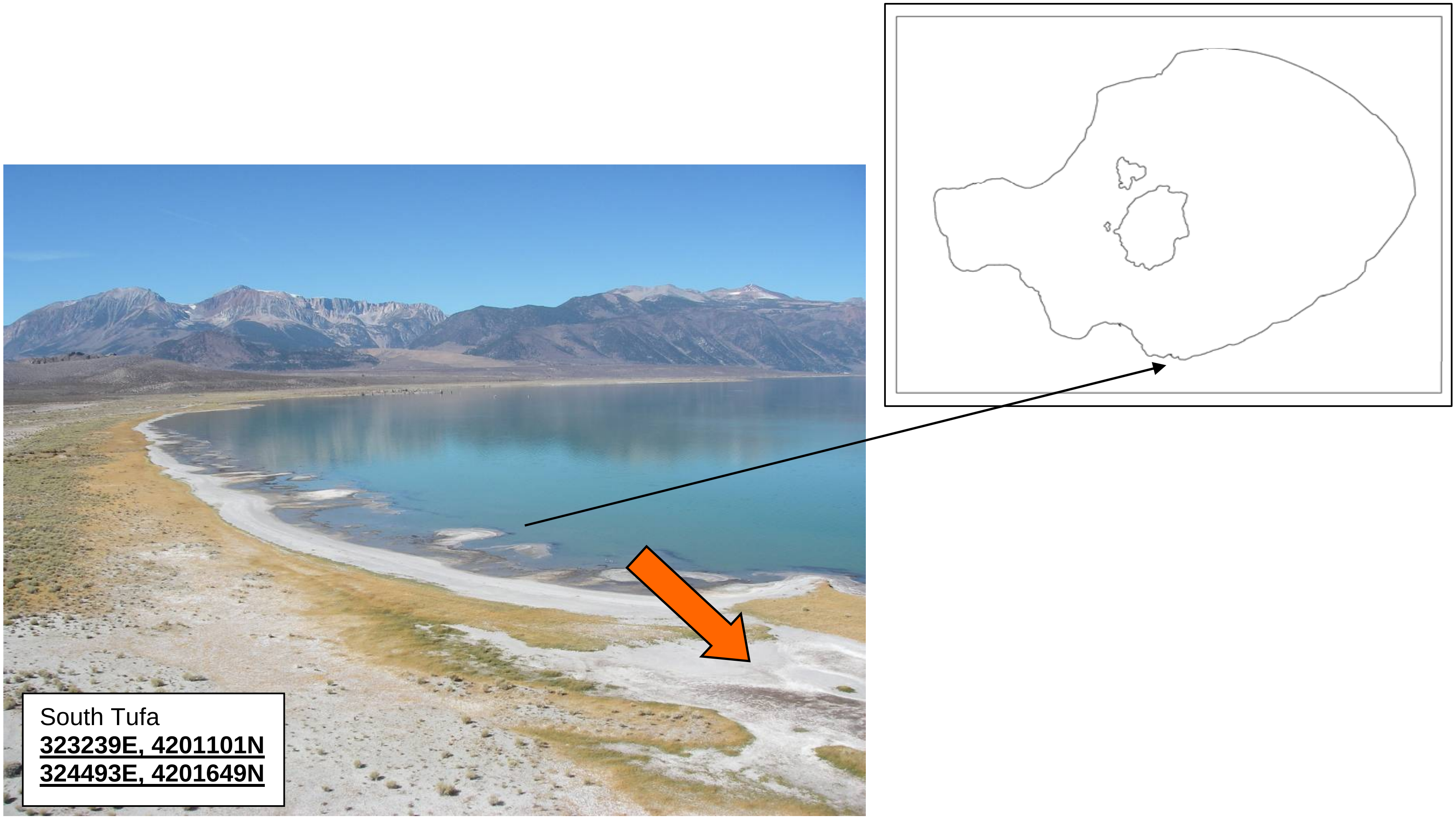


Figure 5. South Tufa Shoreline Area – East End. The photo shows the increased amount of exposed shoreline and retraction of lagoons present in 2006. The red arrow points to an area that supported a brackish lagoon in 2006 and throughout the summer of 2007, but was dry by fall.

Figure 6. South Shore Lagoons Area – West End. This first lagoon at the west end of the South Shore Lagoons shoreline area attracted breeding and migratory waterfowl.

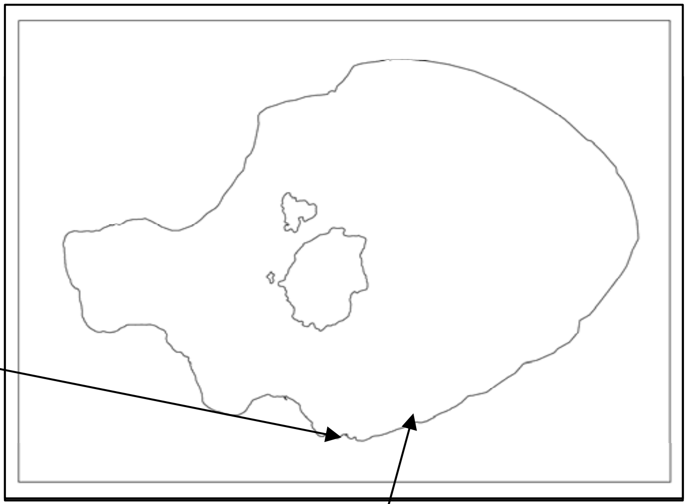
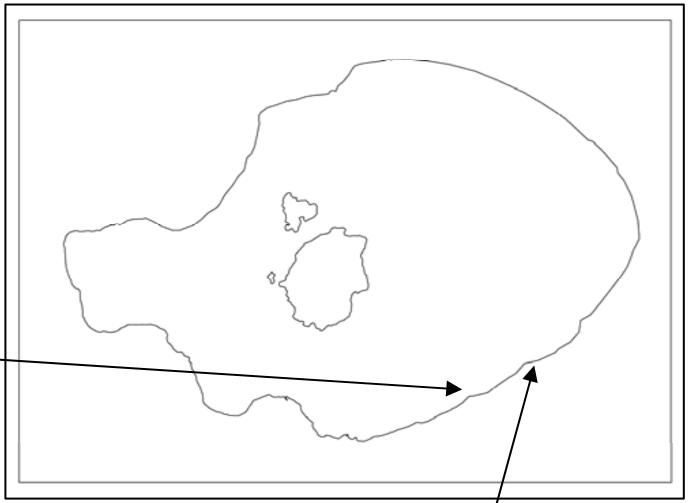


Figure 7. South Shore Lagoons Area. This brackish lagoon attracts breeding and migratory waterfowl and supports several broods.

Figure 8. South Shore Lagoons – Sand Flat Spring
Shoreline dynamics resulted in the isolation of spring flow from lake water at this spring as well as several other lake-fringing springs in 2007.



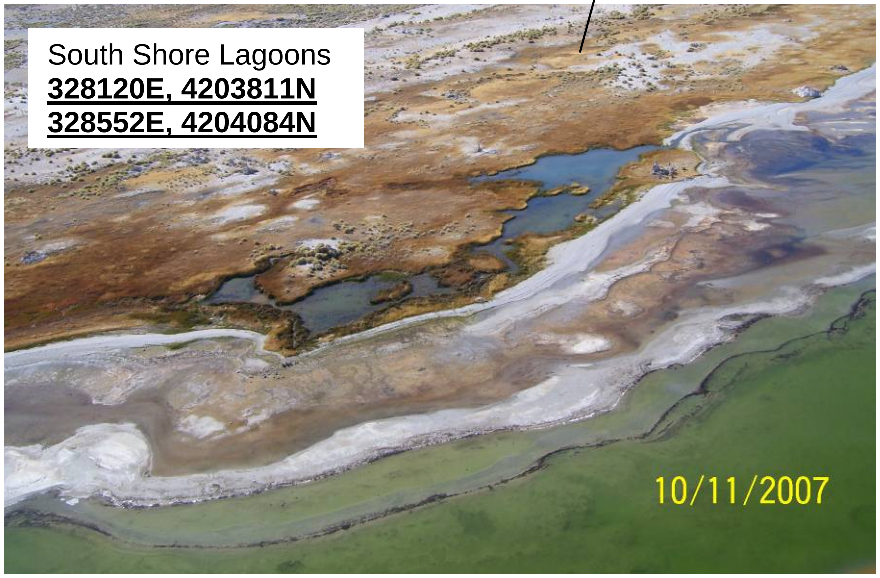
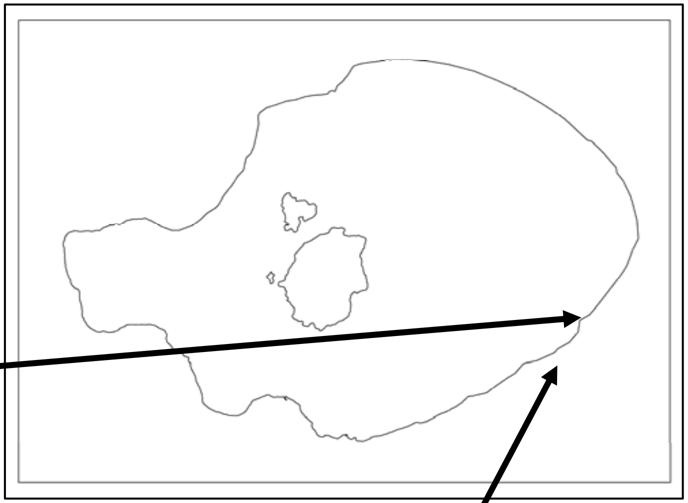
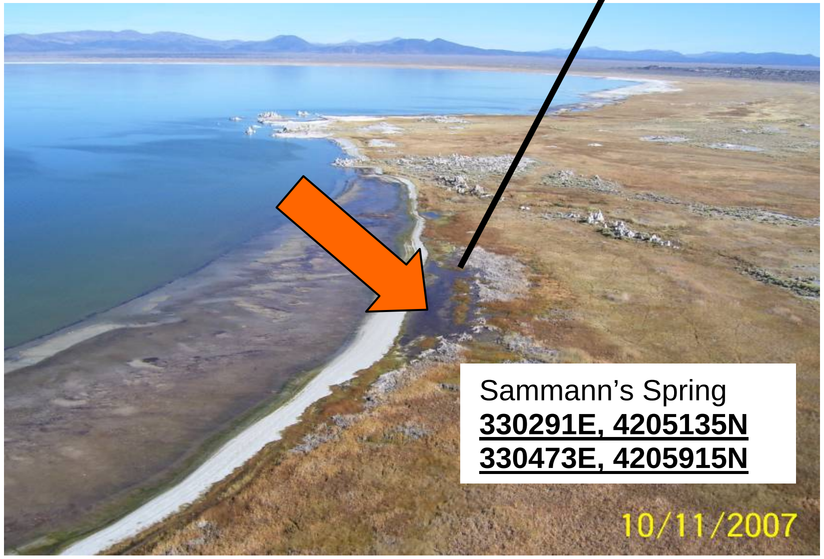

South Shore Lagoons
328120E, 4203811N
328552E, 4204084N

Figure 9. South Shore Lagoons Area - Goose Springs

Figure 10. Sammann's Spring Area, East of Sammann's Spring
Extensive lagoons were still present east of Sammann's Springs. These lagoons were used mainly by migratory waterfowl in the fall.





Sammann's Spring
330291E, 4205135N
330473E, 4205915N

Figure 11. Sammann's Spring Area, West of Sammann's Spring
There was an increase in the amount of freshwater ponds in the western portion of the Sammann's Springs area. The inundation of lake-fringing lagoons that occurred last year resulted in a die-off of emergent vegetation in some of these lagoons. In 2007, a large sand bar formed along shore, isolating spring outflow water from lake water. Because of the die-off of emergent vegetation last year the ponds that reformed behind the sand berms contained some open water. The red arrow points to one of the open fresh water ponds present at Sammann's Springs in 2007.

Figure 12. Warm Springs Shoreline Area
As compared to 2006, the amount of exposed shoreline increased.

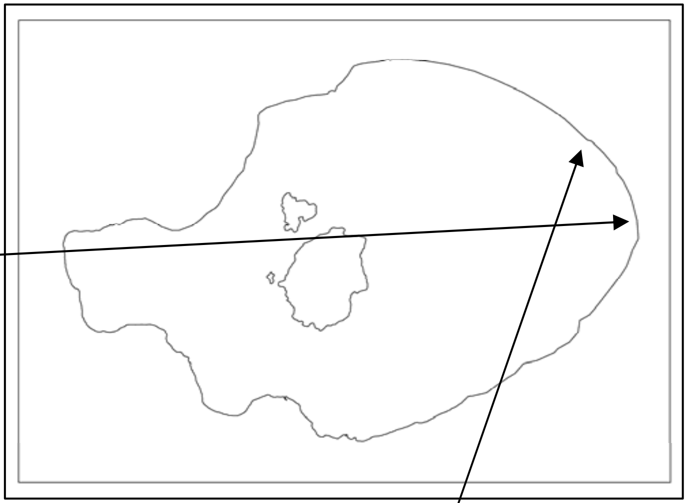
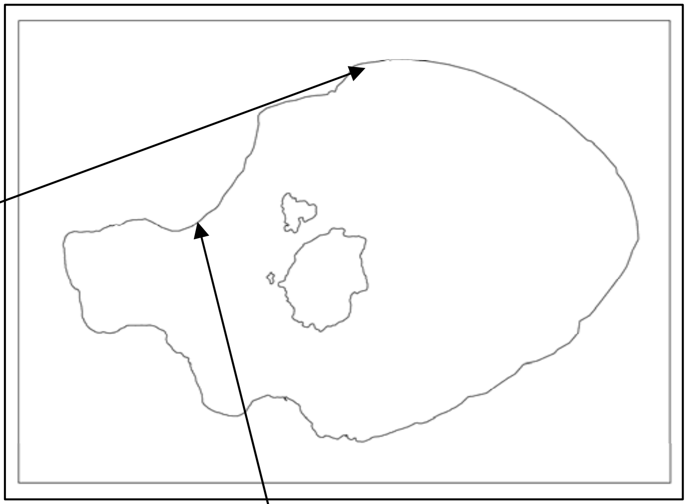


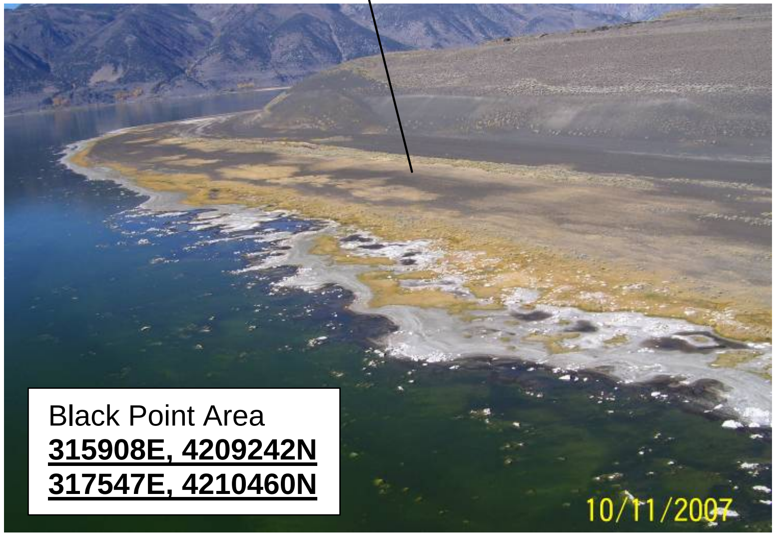
Figure 13. Northeast Shore Area The hypersaline lagoons present in 2006 had dried by fall of 2007.

Bridgeport Creek Area
323135E, 4215789N
324272E, 4215830N

10/11/2007

Figure 14. Bridgeport Creek Shoreline Area





Black Point Area
315908E, 4209242N
317547E, 4210460N

10/11/2007

Figure 15. Black Point Shoreline Area
Shoreline lagoons present in 2006 had receded somewhat, and received less use in 2007.

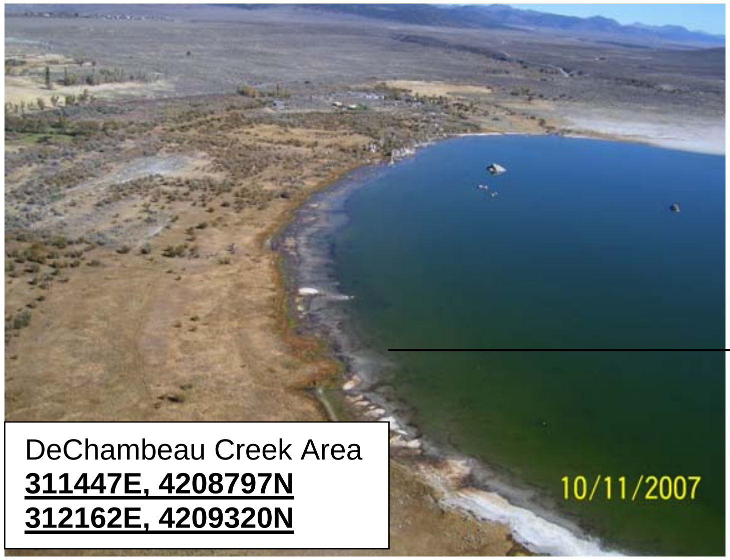

Wilson Creek Area
313944E, 4209661N
314382E, 4209675N

10/11/2007

Figure 16. Wilson Creek Area.

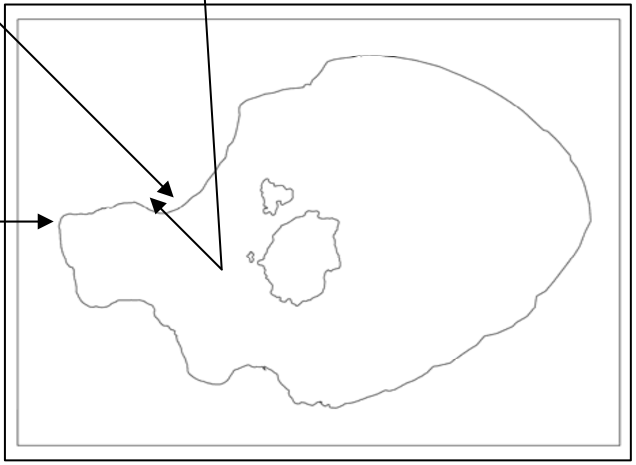

Mill Creek Area
313481E, 4209525N
313618E, 4209628N

Figure 17. Mill Creek Delta. Photo shows the new freshwater pond that formed along the shore in 2007


DeChambeau Creek Area
311447E, 4208797N
312162E, 4209320N

10/11/2007

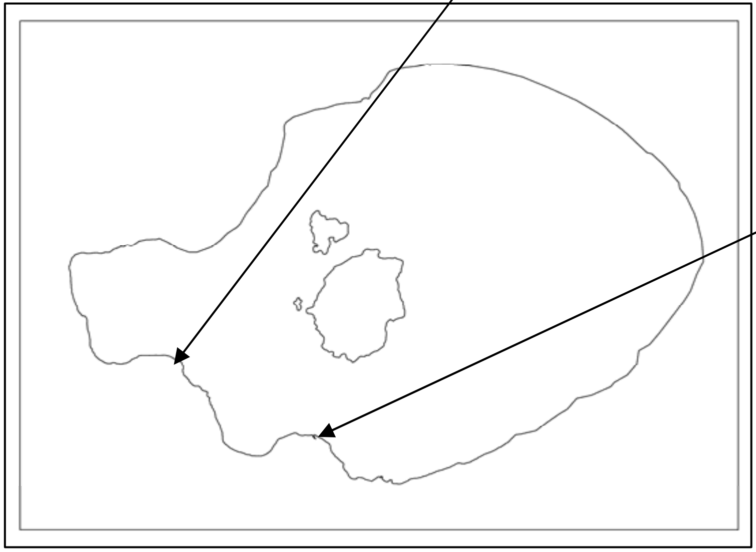
Figure 18. DeChambeau Creek Shoreline Area



Lee Vining Creek Delta
315417E, 4205093N
315341E. 4205354N

10/11/2007

Figure 19. Lee Vining Creek Delta



Rush Creek Delta
319968E, 4202698N
319577E, 4202773N

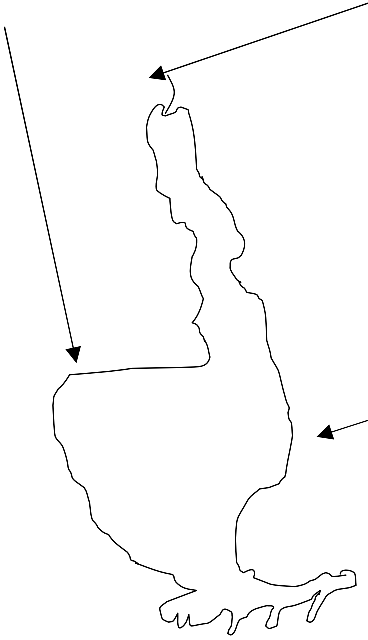
10/11/2007

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. Owens River – Crowley Reservoir

Figure 23. McGee Bay Area - Crowley Reservoir



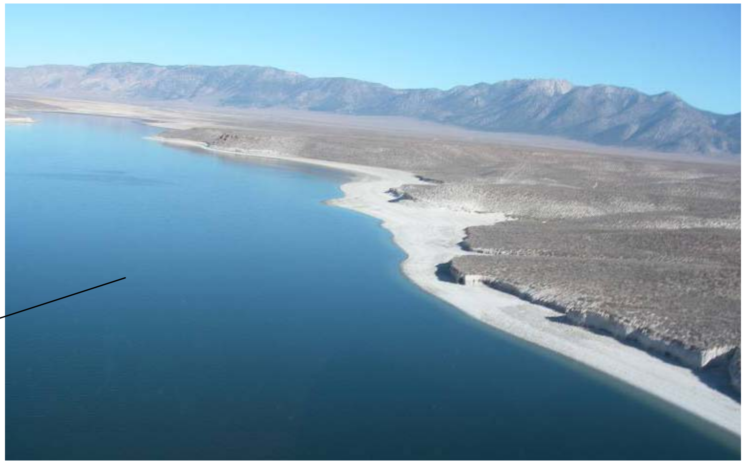


Figure 24. Chalk Cliffs Area of Crowley. This area is typically only used by waterfowl late in fall, after hunting season opens.

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

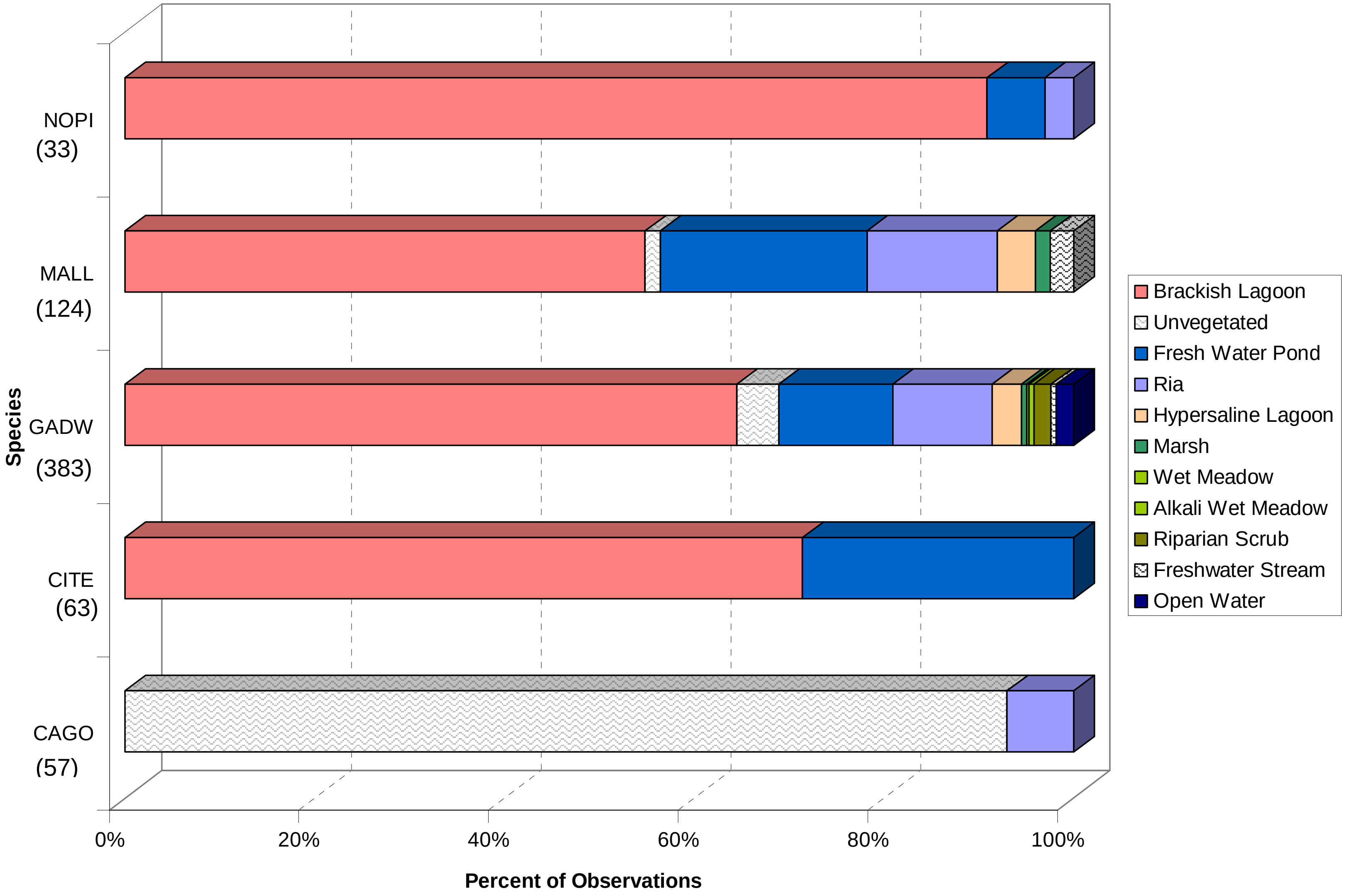


Figure 26. Habitat Use from Summer Waterfowl Species. The numbers in parentheses indicate sample size. The bars represent the percent of the total observations.

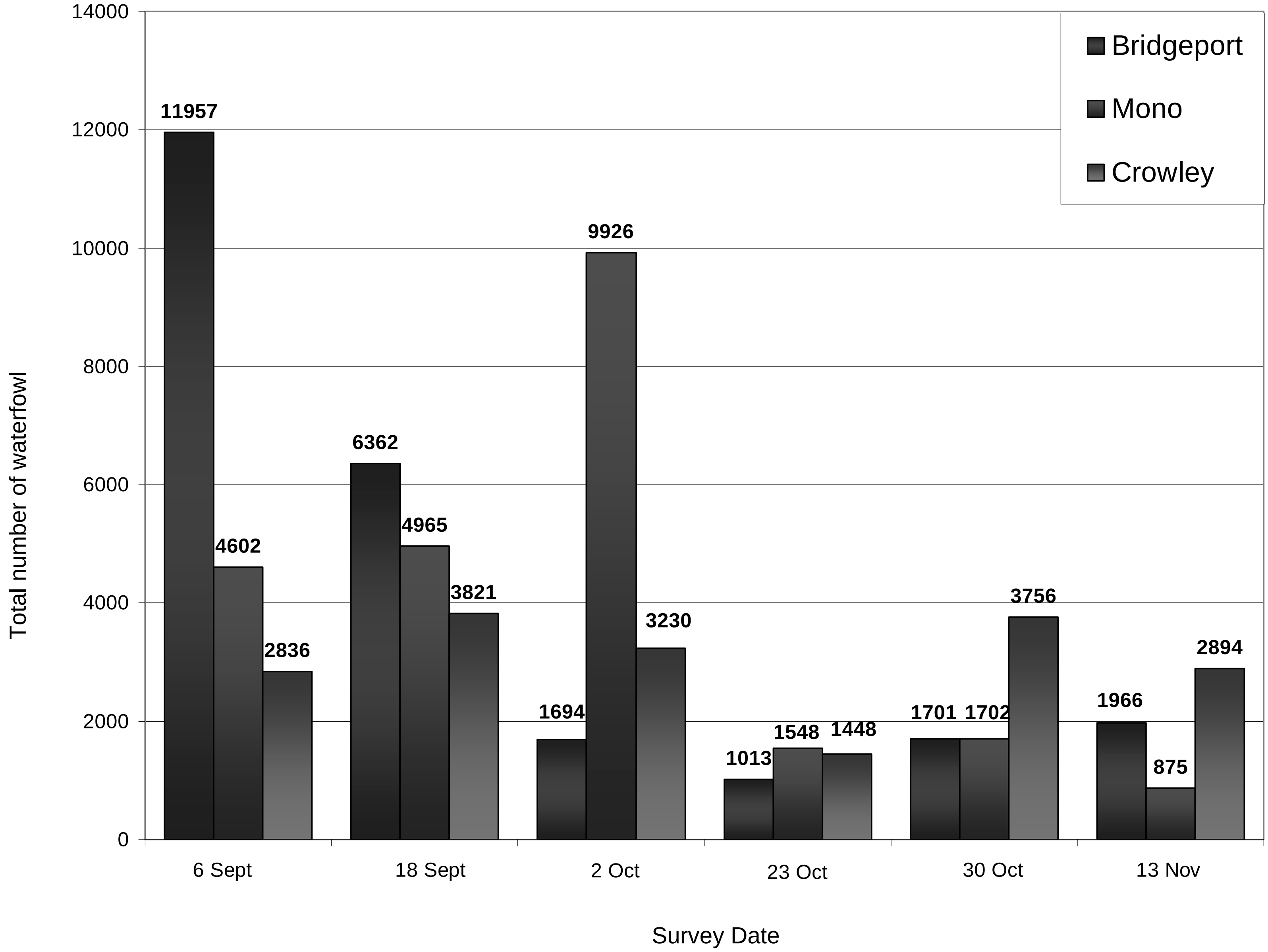


Figure 27. Total Waterfowl Detected from Fall Aerial Surveys

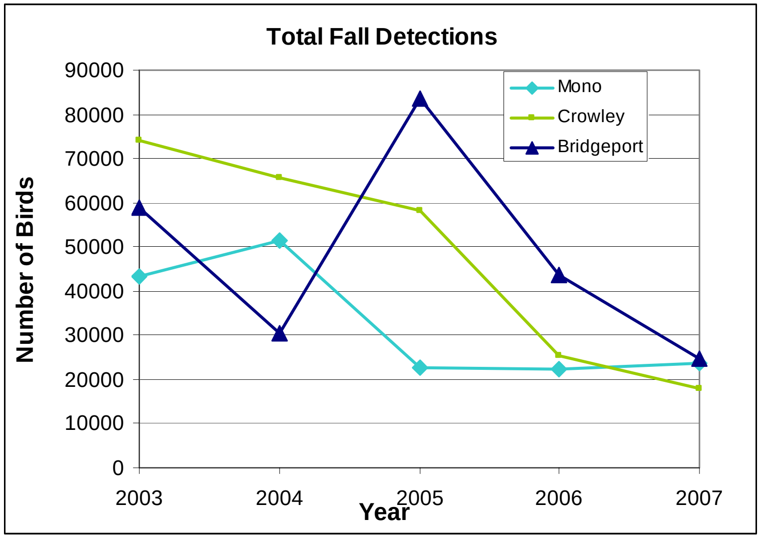


Figure 28. Total Fall Detections in all Waterbodies 2003-2007

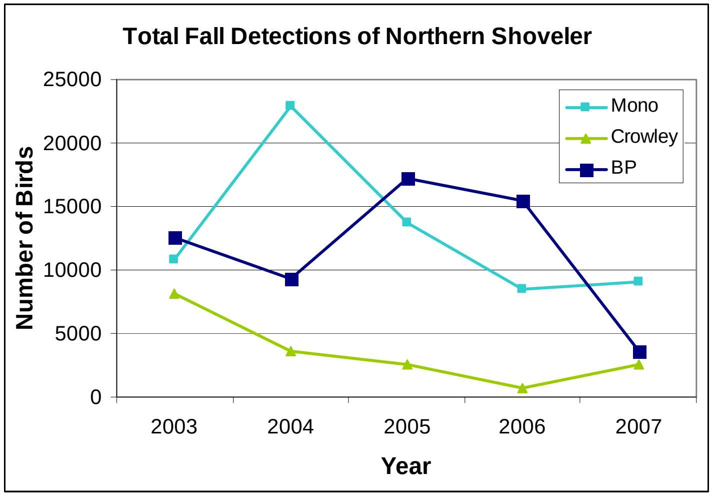


Figure 29. Northern Shovelers 2003-2007

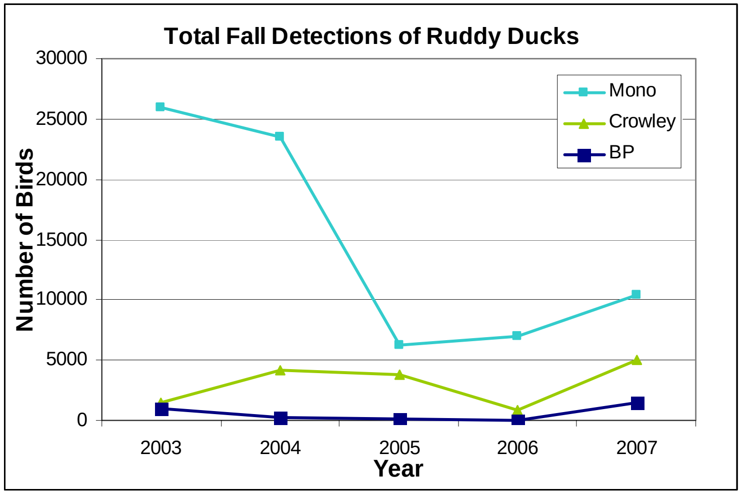


Figure 30. Ruddy Ducks 2003

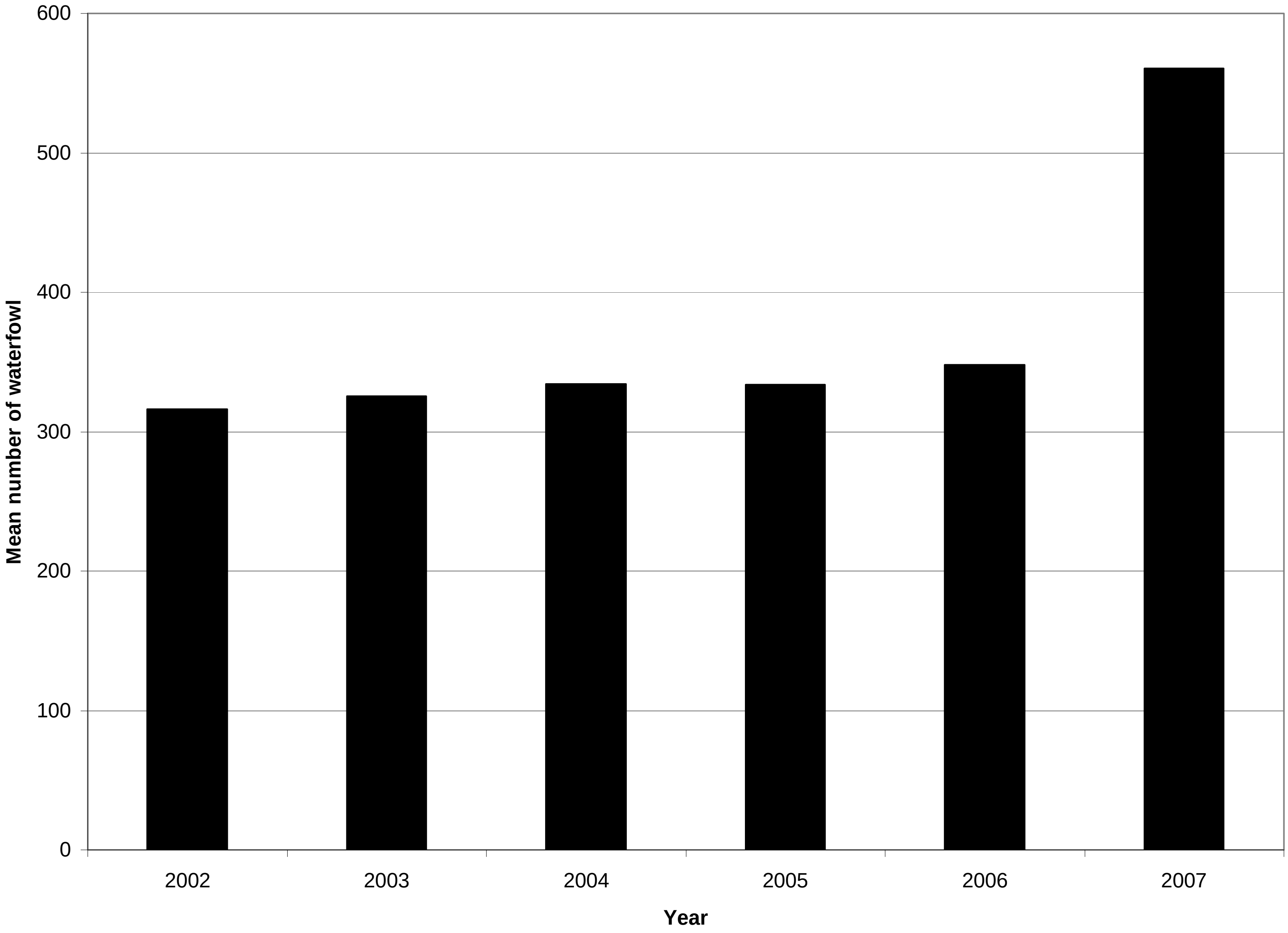


Figure 31. Mean Number of Summering Waterfowl at Mono Lake 2002-2007

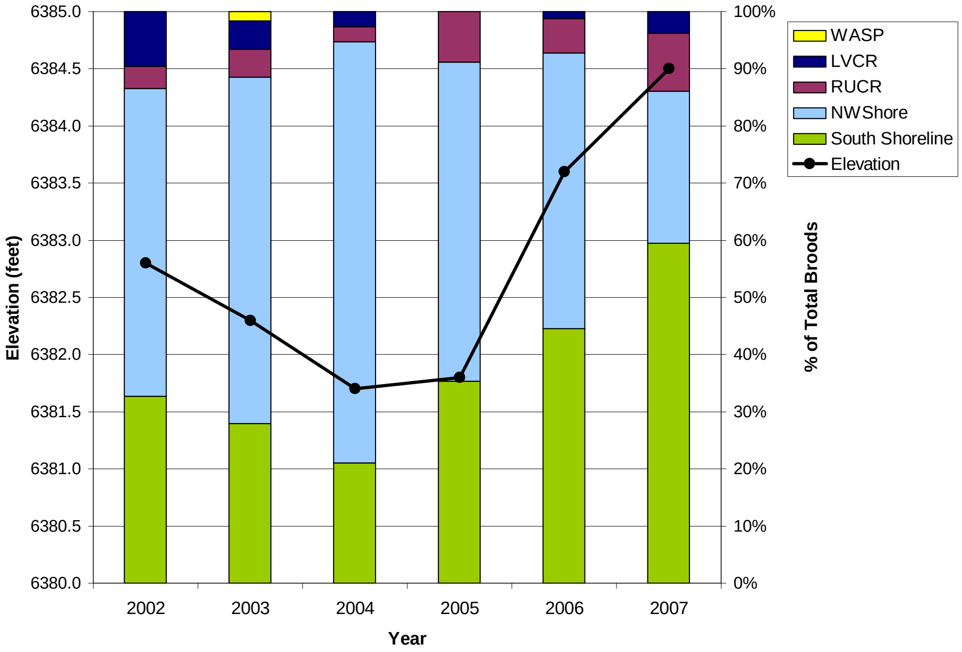


Figure 32. Proportional Use of Mono Lake Shoreline Areas for Brooding 2002-2007

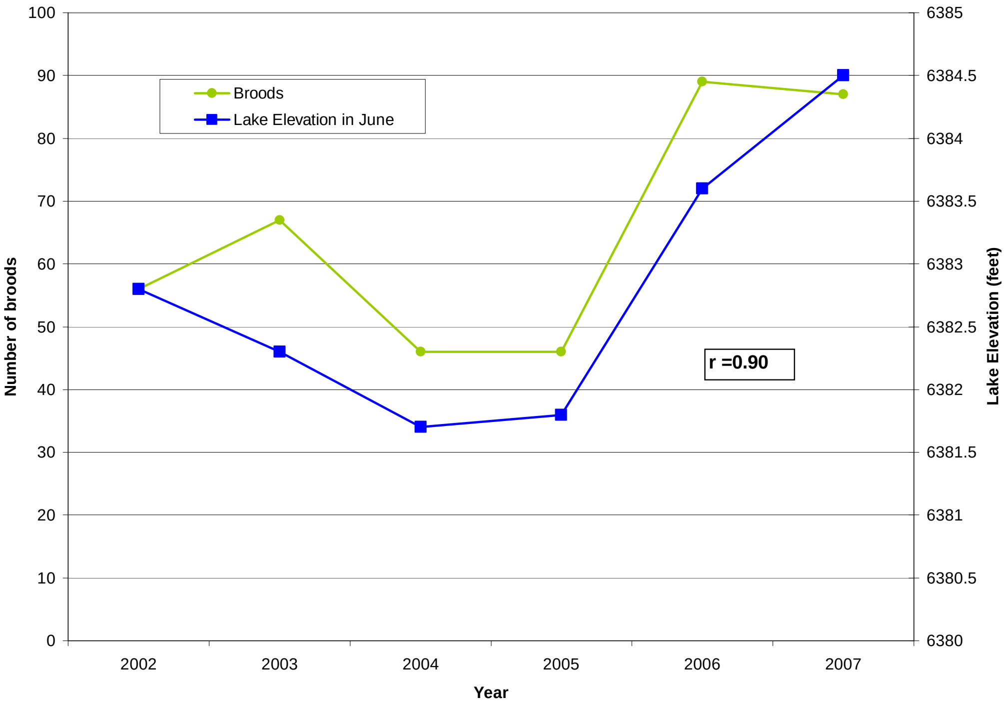


Figure 33. Number of Broods at Mono Lake vs. Lake Elevations

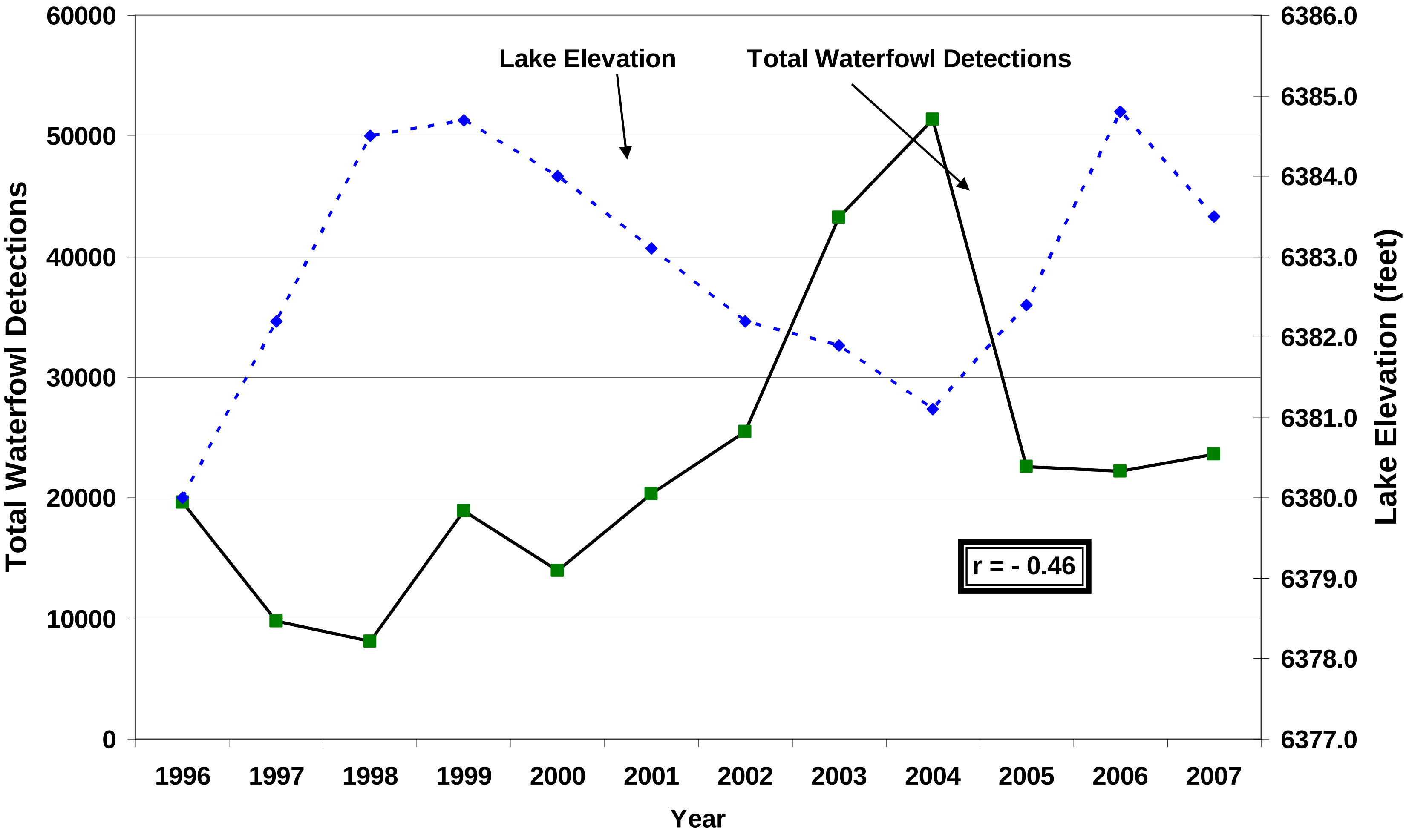


Figure 34. Total Waterfowl Detections vs. Lake Elevations

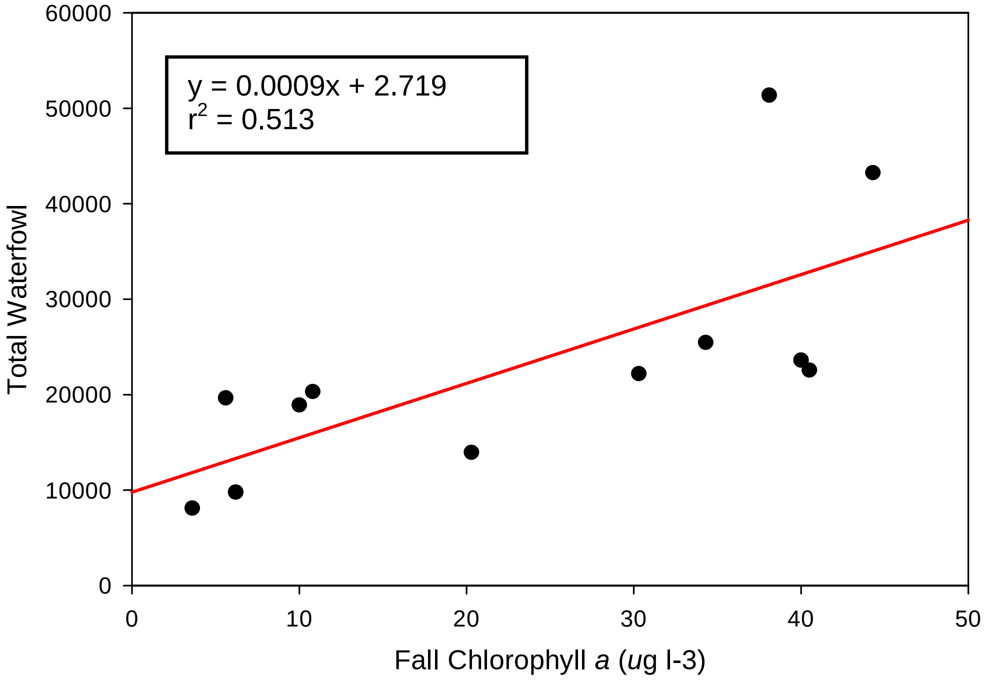


Figure 35. Total Waterfowl Detections vs. Fall Chorophyll *a* Concentration at Mono Lake - 1996-2007

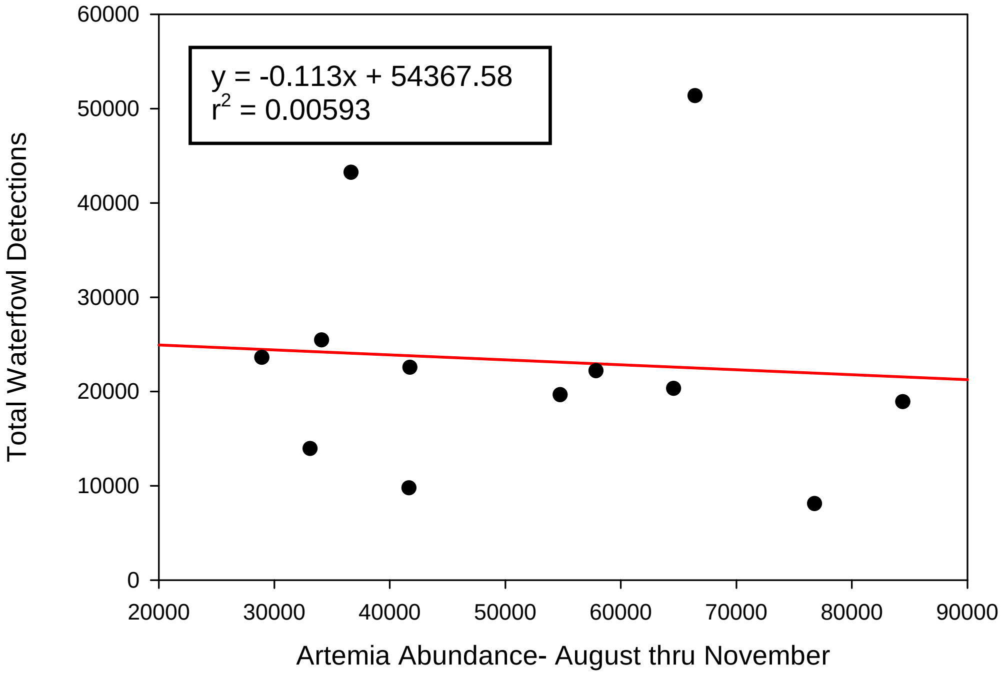


Figure 36. Total Waterfowl Detections vs. Fall Brine Shrimp Abundance at Mono Lake - 1996-2007

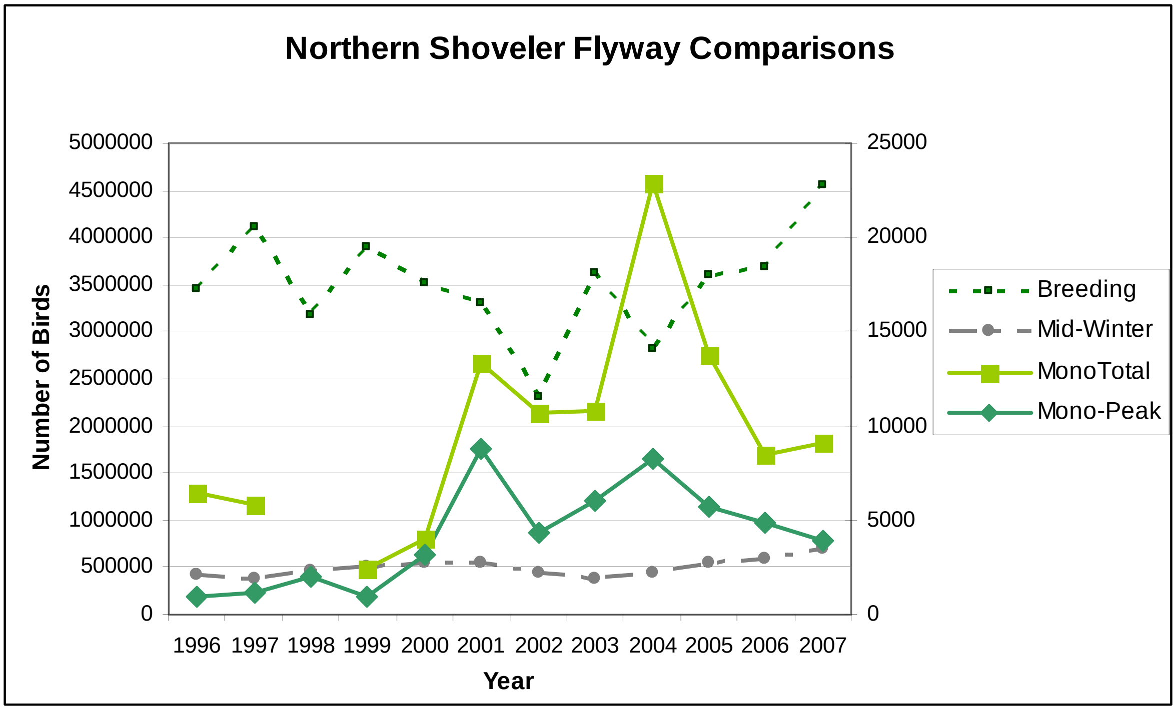


Figure 37. 2007 Northern Shoveler - Mono Lake vs. Breeding and Mid-winter Pacific Flyway Populations

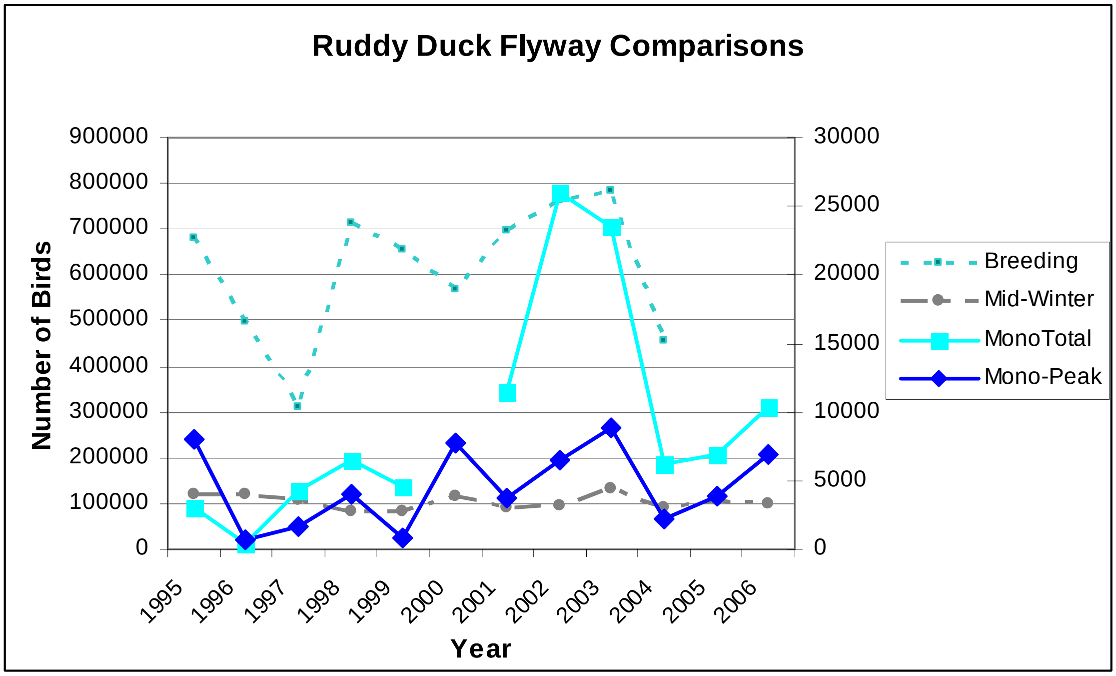


Figure 38. Ruddy Duck - Mono Lake vs. Mid-Winter Pacific Flyway Populations

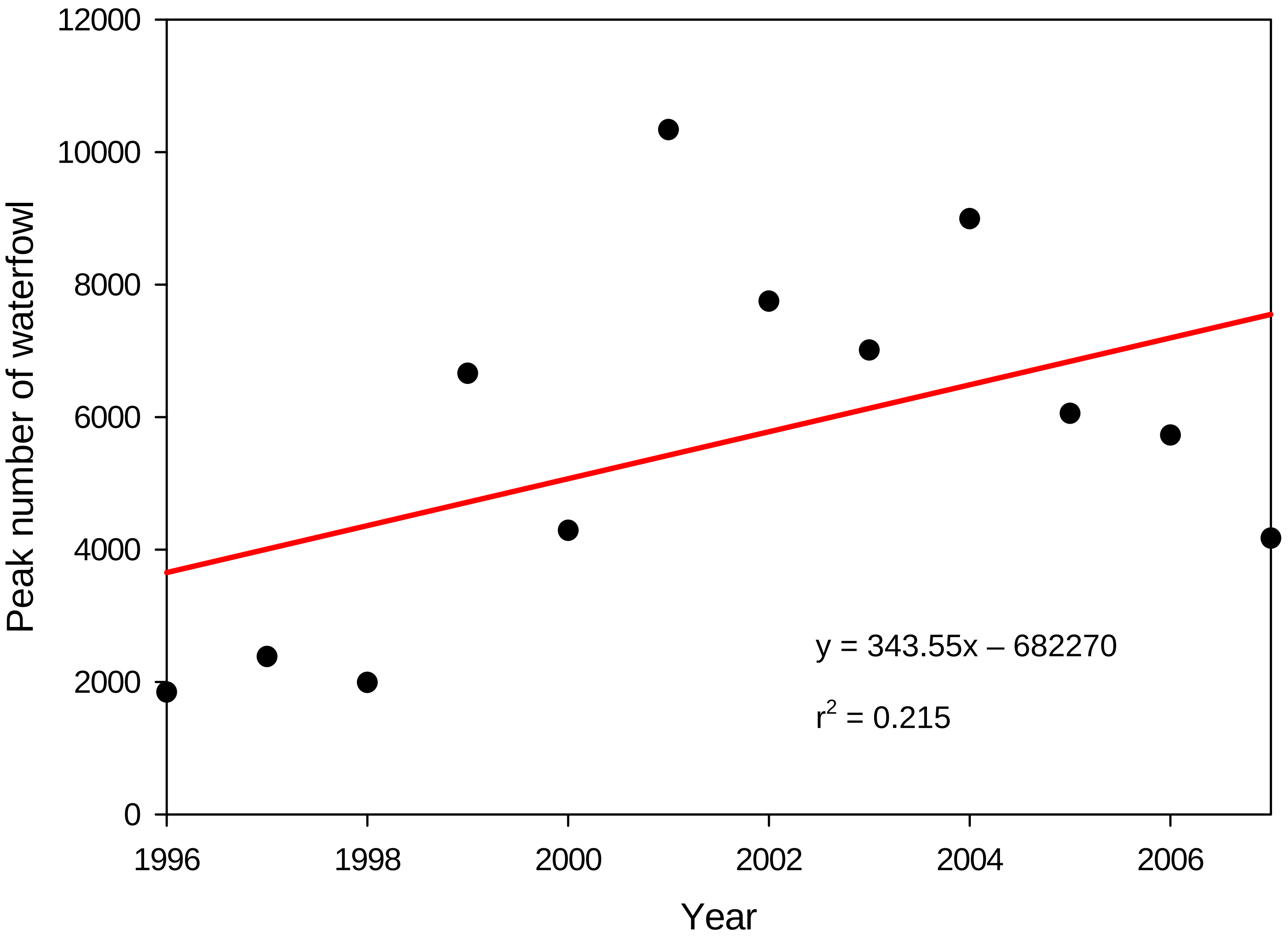


Figure 39. Trend in Peak Waterfowl Numbers (not including Ruddy Ducks) at Mono Lake 1996-2007

APPENDICES

Appendix 1. 2007 Ground Count Surveys - Dates and Times that Surveys were Conducted at Each Survey Area.

Survey 1

Survey area	Survey Date and Time			
	4-Jun	5-Jun	6-Jun	7-Jun
RUCR	1247 - 1400 hrs			
SOTU	0554 - 0708 hrs			
SSLA	0708 - 1020 hrs			
SASP			0548 - 0910 hrs	
WASP				0700 - 0832 hrs
WICR		0802 - 0845 hrs		
MICR		0658 - 0802 hrs		
DECR		0602 - 0657 hrs		
LVCR		0948 - 1040 hrs		
DEPO		1115 - 1137 hrs		
COPO		1145-1200 hrs		

Survey 2

Survey area	Survey Date and Time			
	25-Jun	26-Jun	28-Jun	29-Jun
RUCR	0553 - 0641 hrs			
SOTU	0725 - 0821 hrs			
SSLA	0823 - 1200 hrs			
SASP				0830 - 1115 hrs
WASP				0648 - 0821 hrs
WICR		0812 - 0906 hrs		
MICR		0705 - 0812 hrs		
DECR		0558 - 0705 hrs		
LVCR			0700 - 0810 hrs	0700 - 0810 hrs
DEPO		0905 - 0935 hrs		
COPO		0940 - 0955 hrs		

Appendix 1. Continued. 2007 Ground Count Surveys - Dates and Times that Surveys were Conducted at Each Summer Survey Area.

Survey 3

Survey area	**Survey Date and Time**			
	16-Jul	17-Jul	18-Jul	19-Jul
RUCR				0551 - 0648 hrs
SOTU	0548 - 0640 hrs			
SSLA	0640 - 1040 hrs			
SASP			0634 - 0913 hrs	
WASP			0915 - 1050 hrs	
WICR		0809 - 0920 hrs		
MICR		0707 - 0809 hrs		
DECR		0554 - 0707 hrs		
LVCR		1158 - 1250 hrs		
DEPO		1110 - 1135 hrs		
COPO		1035 - 1056 hrs		

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

Common Name	Scientific Name	Code
American Coot	*Fulica americana*	AMCO
American Wigeon	*Anas americanus*	AMWI
Bufflehead	*Bucephala albeola*	BUFF
Canada Goose	*Branta canadensis*	CAGO
Cinnamon Teal	*Anas cyanoptera*	CITE
Common Merganser	*Mergus merganser*	COME
Lesser Scaup	*Aythya affinis*	LESC
Gadwall	*Anas strepera*	GADW
Green-winged Teal	*Anas crecca*	GWTE
Mallard	*Anas platyrhynchos*	MALL
Northern Pintail	*Anas acuta*	NOPI
Northern Shoveler	*Anas clypeata*	NSHO
Redhead	*Aythya americana*	REDH
Ring-necked Duck	*Aythya collaris*	RNDU
Ruddy Duck	*Oxyura jamaicensis*	RUDU
Snow Goose	*Chen caerulescens*	SNGO
Wood Duck	*Aix sponsa*	WODU
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. 2006 Fall Aerial Survey Dates

Survey Number	1	2	3	4	5	6
Mono Lake	6 Sept	21 Sept	3 Oct	17 Oct	31 Oct	15 Nov
Bridgeport Reservoir	6 Sept	21 Sept	3 Oct	17 Oct	31 Oct	15 Nov
Crowley Reservoir	6 Sept	21 Sept	3 Oct	17 Oct	31 Oct	15 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”

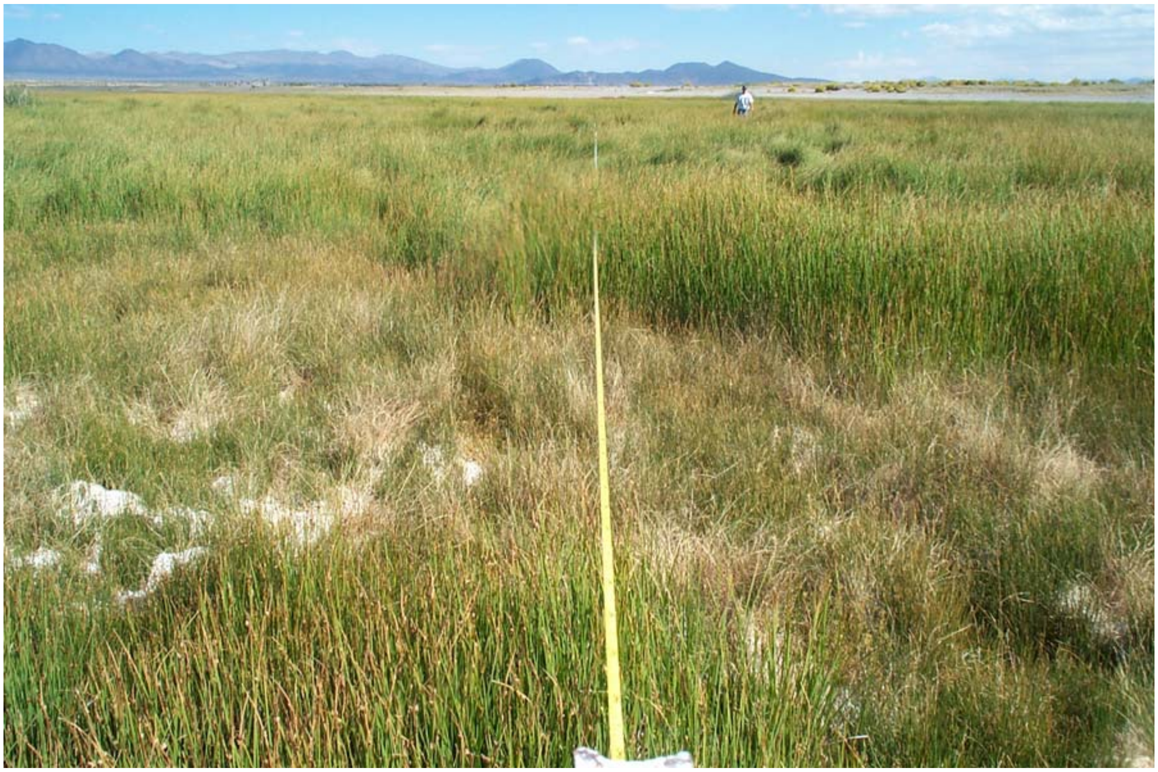
APPENDIX 3

Vegetation

2007

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

2007 was not a monitoring year for Mono Basin riparian or lake fringing wetland.

Channel opening revegetation

2007 was the fifth year following the completion of the 3D Floodplain Project. Surveys conducted in 2005 indicated that sites suitable for the establishment of herbaceous and woody riparian vegetation were being colonized. Field visits conducted in 2007 indicated that the site was continuing to progress. No further work will be required at this site.

Visits conducted at the former Marzano site on the west bank across from the 3D indicated that this site is also progressing 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 first 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 2007, large woody debris was placed in the channels of both Lee Vining and Rush Creeks.

Salt Cedar Control

Personnel from LADWP conducted surveys of the delta areas of both Rush and Lee Vining Creeks several times during the 2007 growing season. No plants were observed during these surveys and no treatment occurred.

Grazing Moratorium

The grazing moratorium will continue in 2008.