Section 5

Mono Basin Waterfowl
Habitat and Population Monitoring
2009-2010

Mono Lake Waterfowl Restoration Project
Compliance Checklist
2009

Hydrology †	**Section 2**
Mono Lake Elevation	☑
Walker Creek Flows	☑
Parker Creek Flows	☑
Lee Vining Creek Flows	☑
Rush Creek Flows	☑
Mono Basin Exports	☑
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APPENDIX 1

Limnology

2009 ANNUAL REPORT

MIXING AND PLANKTON DYNAMICS IN MONO LAKE, CALIFORNIA

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EXECUTIVE SUMMARY

Limnological monitoring of Mono Lake was conducted during 2009 as part of a long-term monitoring program begun in 1982. Chapter 1 describes the seasonal plankton dynamics observed from 1979 through 2008, a period which encompassed a wide range of varying hydrologic and annual vertical mixing regimes including three periods of persistent chemical stratification or meromixis (1983–1988, 1995–2003, 2005–2007). In brief, long-term monitoring has shown that Mono Lake is highly productive compared to other temperate salt lakes, that this productivity is nitrogen-limited, and that year-to-year variation in the plankton dynamics has largely been determined by the complex interplay between varying climate and hydrologic regimes and the resultant seasonal patterns of thermal and chemical stratification which modify internal recycling of nitrogen. The importance of internal nutrient cycling to productivity is highlighted in the years immediately following the onset of persistent chemical stratification (meromixis) when upward fluxes of ammonium are attenuated and during the breakdown of meromixis when ammonium supply is increased.

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

Laboratory, field, and analytical methods are described in Chapter 2 and the results of the 2009 limnological monitoring program including a number of integrative measures encompassing the long-term record (1982–2009) are presented in Chapter 3.

During 2009, hatching of over-wintering cysts was already well underway by the 21 February survey and increased significantly during March. The abundance of 1st generation adults (~72,000 m^{-2}) was the second highest on record (1981–2009). Low phytoplankton abundance accompanying abundant *Artemia* resulted in both below average summer ovoviviparous reproduction (58 %) and total annual cyst production (69 %). Low ovoviviparous production and subsequent recruitment into the late summer adult population led to an early decline, and *Artemia* were virtually absent by the mid-November survey. This pattern of a large first (early summer) generation followed by a rapid decline and autumn die-off is similar to recent years and constitutes a long-term trend of an overall shift of the temporal occurrence of *Artemia* to earlier in the year.

The estimated 2009 primary production was 1,411 g C m^{-2}, well above the long-term (1982–2009) mean of 686 g C m^{-2}. Annual average *Artemia* biomass in 2009, an index of secondary production, was 8.8 g m^{-2}, close to the long-term mean of 9.0 g m^{-2}. Total annual cyst production in 2009 (2.9 million m^{-2}) was 31 % below the long-term mean of 4.3 million m^{-2}.

Annually-filtered (365-day running mean) mixed-layer chlorophyll *a* concentration and adult *Artemia* abundance provide two measures of long-term ecological trends. They both highlight the role of year-to-year changes in the annual mixing regime (meromixis/monomixis). While there appears to be a long-term trend of increasing chlorophyll *a*, inter-year variation is large and a linear regression only explains 28% of the overall variation. The response of *Artemia* to variations in mixing is muted compared to chlorophyll and while there has been a shift to earlier in the year, there is no long term trend in annually-filtered adult *Artemia* abundance.

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LIMNOLOGICAL MONITORING COMPLIANCE

This report fulfills the Mono Lake limnological monitoring requirements set forth in compliance with State Water Resources Control Board Order Nos. 98-05 and 98-07. The limnological monitoring program consists of four components: meteorological, physical/chemical, phytoplankton, and brine shimp population data. Meteorological data are collected continuously at a station on Paoha Island, while the other three components are assessed on monthly surveys (except January). A summary of previous monitoring is included in Chapter 1, the methodology employed is detailed in Chapter 2, and results and discussion of the monitoring conducted during 2009 and long-term integrative measures presented in Chapter 3. The relevant pages of text, tables, and figures for the specific elements of each of the four required components are given below.

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CHAPTER 1
INTRODUCTION

Background

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

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

Long-term monitoring of the plankton and their physical, chemical, and biological environment is essential to understanding the effects of changing lake levels. Measurements of the vertical distribution of temperature, oxygen, conductivity, and nutrients are requisite for interpreting how variations in these variables affect the plankton populations. Consistent methodologies have been employed during the 30-yr period, 1979–2009, 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 x 10^6 m^{-2} compared to 4.03 x 10^6 m^{-2} in 2000. While this is 37% below the long-term mean of 4.77 x 10^6 m^{-2}, it is not expected to have a significant impact on 2002 abundance as food availability is a much stronger determinant of the spring generation of *Artemia*.

2002

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

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

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

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

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

2003

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

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

In 2003, the *Artemia* population was characterized by early development of a moderate 1st generation (18 June, 24,600 m^{-2}) followed by recruitment balancing mortality through the summer (13 August, 27,300 m^{-2}). Mean annual *Artemia* biomass increased 53% from 4.9 g m^{-2} in 2002 to 7.5 g m^{-2} in 2003, although it was still slightly below the long-term (1983-2003) average of 9.2 g m^{-2}. Recruitment of ovoviviparous (live-bearing) reproduction into the 2nd generation was low and accounts for below average mean annual biomass. Recent analysis of seasonal *Artemia* dynamics indicates small changes in algal biomass immediately following maturation of the 1st generation dramatically affects recruitment into the summer generation. A detailed cohort analysis of 2003 stage-specific *Artemia* data is being conducted. Total annual cyst production also increased over 2002 and was 4.2×10^6 m^{-2}, close to the long-term (1983-2003) mean of 4.5×10^6 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 (2005-2007)

2005

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

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

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

2006

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

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

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

2007

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

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

Recent monomictic period (2008-)

2008

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

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

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

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

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

Estimates of annual primary production integrate annual and seasonal changes in photosynthetic rates, algal biomass, temperature, and insolation. Although measurements of photosynthetic rates were discontinued after 1992 (restarted in 2002) most of the variation in photosynthetic rates can be explained by regressions on environmental covariates (i.e. temperature, nutrient, and light regimes) (Jellison and Melack 1993a, Jellison *et al.* 1994). Therefore, estimates of annual primary production using previously derived regressions and current measurements of algal biomass, temperature, and insolation were made during 1993-2001. These estimates of annual primary production indicate a period of declining productivity (1994–1997) associated with the onset of meromixis and increasing chemical stratification, followed by continually increasing estimates of annual primary production through the breakdown of meromixis in 2003 when the second highest estimated annual primary production occurred (1,645 g C m^{-2} y^{-1}). Estimated annual productivity declined somewhat in 2004–06 ranging from 864 to 1,111 g C m^{-2} y^{-1} and then increased to1,766 g C m^{-2} y^{-1} as the 2-yr episode of meromxis broke down. In 2009, estimated annual primary production was 1,411 g C m^{-2} y^{-1}.

The mean annual biomass of *Artemia* was estimated from instar-specific abundance and length-weight relationships for the period 1983–99 and by direct weighing from 2000 to the present. The mean annual biomass has varied from 5.3 to 17.6 g m^{-2} with a 23-yr (1983-2006) mean of 9.3 g m^{-2}. The highest estimated mean annual biomass (17.6 g m^{-2}) occurred in 1989 just after the breakdown of meromixis during a period of elevated phytoplankton nutrients (ammonium) and phytoplankton. The lowest annual estimate was in 1997 following two years of meromixis and increasing density stratification. Mean annual biomass was somewhat below the long-term mean during the first 3 years of the 1980s episode of meromixis and then above the mean the next 3 years as meromixis weakened and ended. The years with the lowest annual biomass of *Artemia* were 1997 (5.3 g m^{-2}) and 2002 (4.9 g m^{-2}), both during the extended period of meromixis, 1995–2003). However, mean annual *Artemia* biomass increased in 2003 as meromixis weakened to 7.5 g m^{-2}, and further to 11.0 g m^{-2} in 2004 following the breakdown of meromixis in late 2003. Mean annual *Artemia* biomass during 2005–09 varied from 5.8 to 8.8 g m^{-2}.

Peer-reviewed scientific publications

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

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CHAPTER 2

METHODS

Meteorology

Continuous meteorological data are collected at the Paoha station located on the southern tip of Paoha Island. The station is approximately 30 m from the shoreline of the lake with the base located at 1948 m asl, several meters above the current surface elevation of the lake. Sensor readings are made every second and stored as either ten minute or hourly values. A Campbell Scientific CR1000 datalogger records up to 6 months 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 (Campbell Scientific TE525MM-L tipping bucket), and ten minute averages of relative humidity (Vaisalia HMP35C) and air temperature (Vaisalia HMP35C and Campbell Scientific Temp 107) are also made and stored. The detection limit for the tipping bucket gage is 1 mm of water. As the tipping bucket is not heated, the instrument is less accurate during periods of freezing due to sublimation of ice and snow.

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. 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) with a high-precision conductivity-temperature-depth profiler (CTD)(Idronaut, Model 316Plus). The lowered at a rate of ~0.2 m s^{-1} and sampled at 200 ms intervals or approximately every 4 cm. Pressure readings were converted to depth using the density of Mono Lake water at the in situ temperature and salinity. Conductivity readings at in situ temperatures (C_t) were standardized to 25°C (C_{25}) using

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

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

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

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

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

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

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

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

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

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

Water samples

Chlorophyll and nutrient samples were collected from seven to eight 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 (Abbott Corporation, model SV1100D Spectrophotometer). 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 collected for brood size and length analysis were 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 (Idronaut, Model 316Plus) (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 twenty-four 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 2009. The episode of meromixis begun in 2005 ended in late 2007. The seasonal mixing patterns in both 2008 and 2009 exhibited a "typical" monomictic regime with an extended midwinter period of holomixis. However, the breakdown of even this short 2-year period of meromixis led to enhanced nutrient availability and more abundant phytoplankton biomass in early 2008. High spring phytoplankton abundance was also present in 2009 and the 1st generation of *Artemia* was among the three highest years observed in the 29-yr record beginning in 1981.

The inverse correlation between the sizes of the 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 and the autumn abundance is greatly reduced. This larval recruitment bottleneck, most apparent in recent years, is the key to understanding and interpreting much of the observed spatial and temporal variation in *Artemia* population dynamics.

Here, we describe the limnological conditions observed during 2009 and calculate several long-term integrative measures of ecosystem productivity.

Meteorological Data

The Mono Lake limnological monitoring program has included collection of a full suite of meteorological data at a station located on the southern tip of Paoha Island and radiation (shortwave, longwave, and photosynthetically available radiation) at Cain Ranch since 1990.

Wind Speed and Direction

Mean daily wind speed varied from 0.8 to 11.7 m s^{-1} over the year, with an overall annual mean of 3.4 m s^{-1} (Fig. 2). This annual mean is slightly higher than observed in 2008 (3.0 m s^{-1}); 2004 (3.1 m s^{-1}) and 2001–03 (3.2 m s^{-1}) but similar to 2005–06 (3.5 m s^{-1}) and 2007 (3.3 m s^{-1}). The daily maximum 10-min averaged wind speeds recorded on Paoha Island averaged 3.6 times mean daily wind speeds. The maximum recorded 10-min reading (30.3 m s^{-1}, 68 mph) occurred on the afternoon of December 6 (Fig. 2). The mean monthly wind speed varied from 2.2 to 4.0 m s^{-1} (coefficient of variation, 17 %). This was similar to 2007, and 2004 when the mean monthly wind speed varied only from 2.4 to 4.1 and 2.1 to 4.1 m s^{-1} respectively. As observed in the past, winds were predominately from the south (mean, 192 deg).

Air Temperature

Mean daily air temperatures ranged from a minimum of –8.5°C on 9 December to a maximum of 22.5°C on 25 July (Fig. 3). Air temperatures ranged from 3.7°C to 31.7°C during the summer (June through August) with a mean daily range of 8.3°C to 22.5°C and from –13.6°C to 15.6°C during the winter (December through February) with a mean daily range of -8.5°C to 3.2°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 2009, the annual mean was 39.0 Einsteins m^{-2} day^{-1}, with daily values ranging from 4.1 Einsteins m^{-2} day^{-1} on 28 November to 63.8 Einsteins m^{-2} day^{-1} on 21 June. The 2009 annual mean was within the range (35.0–39.9 Einsteins m^{-2} day^{-1}) observed during 2002–08.

Relative Humidity and Precipitation

Mean daily relative humidity values followed the general pattern of high values (mostly 60-80 %) in January, decreasing to lows (mostly 30-50 %) in April through September and then gradually to above 80 % through December (Fig. 5). The 2009 annual mean was 52.6%, slightly lower than means recorded during 2003–2007 (range 54.0-57.9%).

The 2009 annual precipitation measured at Paoha Island was 120.6 mm (4.7 inches). One large precipitation event occurred on 13 October delivering 36.8 mm (Fig. 6). Total precipitation was higher than in 2001, 2002, 2003, 2004 (87.9 mm, 69.1 mm, 101.1 mm, 102.7 mm, respectively) but lower than in 2005 and 2006 (230.9 mm and 242.5 mm). Annual precipitation data for 2007 and 2008 are not available from Paoha Island. Precipitation measured in Lee Vining (elevation 6800 ft, lat: 37º 57' 0" N, long: 119º07' 30" W) during 2007 and 2008 was 148.8 mm and 329 mm, respectively. However, average annual precipitation generally declines by half across the lake (LADWP unpub., Vorster 1985).

Surface Elevation

The surface elevation of Mono Lake was 6382.1 ft on 1 January 2009. Surface elevation rose to 6382.5 ft due to spring runoff and then in June began a gradual seasonal declinedto 6381.4 ft in December for a net annual decline of 0.7 ft (Fig. 7).

Temperature

The annual pattern of thermal stratification in Mono Lake results from seasonal variations in climatic factors (e.g. air temperature, solar radiation, wind speed, humidity) and their interaction with density stratification arising from the timing and magnitude of freshwater inputs. The annual pattern observed during 1990–94 is typical of large temperate lakes except that in hypersaline Mono Lake the absence of ice cover and temperature-density properties result in a single extended period of winter holomixis. 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. This pattern has been altered by three recent episodes of meromixis (1983–88, 1995–03, 2005–07) during which vertical salinity gradients accompanying increased freshwater inflows prevented winter holomixis (Fig. 7). During 2008 and 2009 winter holomixis and monomictic conditions returned.

January represents a period of low biological activity due to cold water temperatures, low light levels, and the absence of *Artemia*. January surveys are only conducted when unusual circumstances warrant it and weather permitting. Monthly surveys are initiated each year in February.

The 1st survey of the year was conducted on 19 February 2009 (Table 1, Fig. 8). A slight amount of warming was present in the upper 6 m with water temperatures ranging from 3.0 °C at 6 m depth to 3.5 °C at 1 m depth. Below 6 m the water column was well-mixed with temperature gradually decreasing from 2.8 °C at 7 m to 2.5 °C at 23 m depth and below.

During spring and early summer, multiple weak thermoclines and complex profiles were present due to the interactions among seasonal warming, freshwater inflows, and meteorological events. A strong persistent thermocline was not apparent until mid-June when a strong thermocline was present between 6 and 9 m depth. Epilimnetic water temperatures were 16.5–16.7 °C. Temperature declined almost linearly from 16.2 °C at 6 m depth to 6.9 °C at 15 m depth. Below this temperature declined more slowly in the hypolimnion to 4.4 °C at 38 m depth.

Annual maximum water temperatures were observed during July when temperatures in the well-defined epilimnion were 19.0–20.7 °C. July hypolimnetic water temperatures had only increased to 4.6–4.8 °C indicating little deep vertical mixing.

During late summer the epilimnion gradually cooled, the persistent thermocline deepened, and the hypolimnion warmed slowly. By 15 October 2009 the thermocline was at 17 m depth. The lake "turned over" prior to the mid-November survey and the water column was nearly isothermal with water temperatures only varying between 8.6 and 8.9°C in the upper 34 m of the water column with near bottom waters slightly cooler (8.4 °C).

Holomixis continued through December as indicated by a nearly isothermal water column (4.4–4.9 °C).

The seasonal pattern and magnitude of water temperatures observed during 2009 were typical of those observed in previous years during monomictic conditions in Mono Lake.

Conductivity and Salinity

The episode of meromixis initiated in 2005 ended in late 2007 and a monomictic regime of annual stratification was present during 2008 and 2009. During the March survey, conductivity was 81.8–81.9 mS cm^{-1} throughout the entire water column (Table 2, Fig. 9). Conductivity decreased to a minimum of 77.0–77.2 mS cm^{-1} in the upper 4 m of the water column in July due to snowmelt runoff and then increased through the rest of the year as the thermocline deepened and the surface elevation declined. During November and December following autumn "overturn" the conductivity ranged from 82.4–82.9 mS cm^{-1}.

Salinity, expressed as total dissolved solids, can be calculated from conductivity measurements corrected to a reference temperature (25 °C, see Methods). Because total dissolved solids are conservative at the current salinities in Mono Lake, salinity fluctuates with volume due to changes in the balance between freshwater inputs (streams and precipitation) and evaporative losses. The observed range of conductivities from an epilimnetic midsummer minimum of 77.0 mS cm^{-1} to the annual maximum of 82.9 mS cm^{-1} observed in December correspond to salinities of 72.1 and 79.5 g kg^{-1}, respectively. Given the density of Mono Lake water at 25°C this is equivalent to 76.5 and 84.8 g l^{-1}.

Density Stratification: Thermal and Chemical

The large seasonal variation in freshwater inflows associated with the eastern Sierra and year-to-year climatic variation have led to complex patterns of seasonal density stratification over the last 28 years. Much of the year-to-year variation in the plankton dynamics observed at Mono Lake can be attributed to marked differences in chemical stratification resulting from variation in freshwater inflows and its affect on nutrient cycling. Excess density varied from 61.7 to 72.4 kg m^{-3} over the course of the year (Table 3).

Seasonal density stratification reflected contribution from both thermal and salinity stratification (Table 4, Fig 10). In mid-June, the difference in salinity between 2 and 32 m contributed 5.53 kg m^{-3} to vertical density stratification, slightly more than the 4.00 kg m^{-3} due to temperature stratification.

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 2009, February–April lakewide transparencies during spring as measured by Secchi depth were among the lowest observed ranging from 0.74±0.01 in February to 0.67±0.01 m in mid March and April (Fig. 11, Table 5). As *Artemia* grazing reduced midsummer phytoplankton, mean lakewide transparency increased to 5.9±0.2 m, 6.6±0.3

and 5.5±0.2 m in June, July and August, respectively. These midsummer transparencies are among the lowest observed. The only other years in which midsummer transparencies were less than 7 m were 2003 and 2008. While both 2003 and 2008 followed periods of meromixis, low midsummer transparencies were not observed following the breakdown of meromixis in 1988. Secchi depths decreased to 0.8–0.9 m during October–December as *Artemia* abundance declined to near zero and a large autumn phytoplankton bloom occurred.

Secchi depth is an integrative measure of light attenuation within the water column. Because light absorption is exponential with depth, long-term variation in Secchi depth is most appropriately viewed on a logarithmic scale. While the annual pattern of Secchi depths during 2009 was similar to other years, the midsummer values were clearly among the lowest observed since 1979 (Fig. 12).

The attenuation of PAR within the water column varies seasonally, primarily as a function of changes in algal biomass. In 2009, the depth of the euphotic zone, operationally defined as the depth at which only 1 % of the surface insolation is present, increased from ~5 m during January and February to ~20 m during late summer, and then to 4–7 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 2009, dissolved oxygen concentrations in the upper mixed layer (< 10 m) ranged from 2.0 to 7.4 mg l^{-1} (Table 6, Fig. 14) with the highest concentrations occurring in the upper 5 m during March and April. The lowest epilimnetic values occurred during the October and November surveys when anoxic hypolimnetic waters were actively mixed into the surface. Although the hypolimnion was well oxygenated early in the year, it became suboxic in April and anoxic (<0.5 mg l^{-1}) shortly thereafter below the mid-depth thermocline through October. The high values throughout the water column in December indicate holomixis.

Nutrients (ammonia/ammonium)

Nitrogen is the primary limiting macronutrient in Mono Lake as phosphate is super-abundant (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 thermoand chemocline(s), release from sediments, ammonium volatilization, and small external inputs. Because a large portion of particulate nitrogen, in the form of algal debris and *Artemia* fecal pellets, sink to the bottom and are remineralized to ammonium in the hypolimnion (or monimolimnion during meromixis), vertical mixing controls much of the annual internal recycling of nitrogen.

Due to a winter period of holomixis, February ammonium concentrations were fairly uniform throughout the water column ranging from 0.7 to 2.0 µM (Table 7, Fig. 15). Lakewide epilimnetic ammonium concentrations remained low throughout the year peaking in June and July (lakewide mean, 5.9 and 8.3 µM, respectively) as the spring cohort of *Artemia* matured (Table 8, Fig. 16). Epilimnetic ammonium concentrations were higher at the western stations compared to the eastern ones during June through November . While this seasonal feature of higher concentrations accompanying the peak abundance of *Artemia* is observed during both meromictic and monomictic conditions, it is generally larger during monomictic periods. The causal connection to grazing is highlighted by the variation in the prominence of this feature across the lake which shows an inverse correlation with adult *Artemia* abundance.

Hypolimnetic ammonium concentrations increased through the stratified period. Beneath the chemocline, monimolimnetic ammonium concentrations in 2009 increased from ~7 µM in March to ~84 µM (35 m) in mid-September (Table 7). As stratification weakened in October, ammonium concentration at 35 m was reduced to 41.8 µM. Autumn “turnover” occurred prior to the mid-November survey when ammonium concentrations were >4.7 µM above 12 m and <1.2 µM below 20 m. By mid December the lake was completely mixed with concentration ranging from 1.0 to 2.0 µM between 2 and 35 m.

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 2009, chlorophyll concentrations at Station 6 were high throughout the water column ranging from 80 to 94 µg chl l^{-1} (Table 9, Fig. 17). Chlorophyll *a* in the upper 9-m integrated samples at 7 lakewide stations ranged from 84 to 91 µg chl l^{-1} with a mean of 86.3 ± 1.1 µg chl l^{-1} (Table 10, Fig. 18). Concentrations at Station 6 remained high during March and April ranging from 82 to 94 and 74 to 88 µg chl l^{-1}, respectively. By May algal biomass in the upper 9 m, as measured by chlorophyll *a* concentration, was reduced to 20.4–54.0 µg chl l^{-1}, slightly higher than values in 2008 (14.5–26.5 µg chl l^{-1}) but much higher than in 2007 (1.2–2.5 µg chl l^{-1}). Lower algal biomass observed in 2007 is due to reduced vertical mixing and internal recycling of nutrients accompanying meromixis.

Epilimnetic chlorophyll concentrations remained low (≤4.7 µg chl l^{-1}) during June through August and only started to increase in September as the mixed-layer deepened and the *Artemia* population declined. By October, epilimnetic chlorophyll had increased to 48–60 µg liter^{-1} with a lakewide mean of 54.0 µg liter^{-1}. High algal biomass was present during both the November and December surveys as ammonium availability increased during holomixis and *Artemia* were absent. A peak chlorophyll concentration of 97 µg chl l^{-1} was observed at 2 m depth on 17 December 2009.

As observed in all years, chlorophyll *a* concentration in deep samples (24 and 28 m depth) were high throughout the year ranging from 74 to 99 µg chl l^{-1} during February through August, decreasing slightly to 64–68 µg chl l^{-1} in September and October before increasing in November and December to 79–80 µg chl l^{-1}.

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

***Artemia* Population Dynamics**

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

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

Hatching of over-wintering cysts is initiated by warming water temperatures and oxic conditions. The peak of hatching usually occurs during March but significant hatching may also occur during February. A small amount of hatching may even occur during January in shallow nearshore regions during periods of above normal air temperatures. The 19 February survey indicated the spring hatch of over-wintering cysts was well underway. Mean abundance of 1st instars was 15,806±5,922 m^{-2} (Table 12). This is much higher than the 21-year mean of 8,249 m^{-2}. In addition, small numbers of instars 2 through 6, juveniles, and adults were present.

Artemia lakewide abundance reached 43,335±15,160 m^{-2} by the mid-March survey as the spring hatch continued (Table 11a, b). The March population was dominated by 1st instars (90.9 %) (Table 12). Naupliar abundance continued to increase with 13 April 2009 abundance ranging from 7,324 to 132,636 m^{-2} across the 12 stations with an overall lakewide mean of 54,145 ±11,444 m^{-2} (Table 11a,b). The population consisted almost entirely of naupliar instars with instars 1-4 constituting 99.6 % of the total population. One juvenile and no adults were present. Naupliar abundance dropped significantly in May to 27,311±4,051 m^{-2}. Lakewide mean naupliar abundance declined further to 11,107±1,067 m^{-2} on 15 June and continued a steady decline through the end of the year reaching 483 m^{-2} measured at station 6 on 17 December (Fig 19).

While a few adult *Artemia* were present in Feb and March, they did not appear in significant numbers until May when abundance reached 43,099±6,204 and constituted 55.9% of the population. Fecund females did not appear until June. Adult abundance peaked in June at 72,086±5,626 m^{-2}, declining to 45,231±4,093 m^{-2} by 15 July. Adult abundance continued to decline through 13 August (18,645±2,412 m^{-2}), 15 September (9,058±1,144 m^{-2}), 15 October (2,981±475 m^{-2}), 17 November (235±44 m^{-2}) and 17 December (20 m^{-2}; only station 6 sampled) (Table 12, Fig. 19).

Typically, hatching of over-wintering cysts is greater in the eastern sectors of the lake. February nauplii abundance at the eastern station (Stations 7-12) was roughly 5.5 times higher than that observed at the western stations (Stations 1-6). Naupliar abundance remained higher at the eastern stations through May. This changed by June when naupliar abundance in the western sector was more than double that observed in the east. On 15 July naupliar abundance was once again slightly more abundant in the east followed by western sector dominance in August and September. Eastern stations were higher in October and November (Table 11a).

The lakewide mean abundance of adults peaked in June and declined steadily through the remainder of the year (18 May, 43,099±6,204 m^{-2}; 15 June, 72,086±4,934 m^{-2}; 15 July, 45,231±4,093 m^{-2}; 13 August 18,645±2,412 m^{-2}). The 2009 abundance of 1st generation adults (15 June) was 2nd highest in the 29-yr record (1981-2009) (Fig. 20). However, recruitment of ovoviviparously-produced nauplii into the summer adult population was very low and late summer and early autumn adult abundance (August through October) was among the lowest on record (Fig. 20).

Ovoviviparous reproduction and the second generation

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

On 18 May 23,528±3,411 adult females comprised 30.5% of the total population, although none were ovigerous (Table 11a, b, c, 13a, b, c, Fig. 21). Ovigery increased to 31.3 % of 34,554±2,693 individuals on 15 June with 6.3% reproducing ovoviviparously (naupliar eggs as opposed to encapsulated cysts) and the remaining 93.7% producing cysts. Ovigery increased to 40.0% of 20,268±1,748 females on 15 July; 85.9% of 8,283±1,350 on 13 August, peaked on 15 September with 97.2% of 2,832±571 and decreased in October and November (90.0% of 1,269±199 and 42.9% of 94±25 respectively). Cyst production ranged between 90.0% and 97.4% from mid June through mid November when females stopped reproducing (Table 13a, b, c). As no ovigerous females were counted in May, it is possible that the original wave of ovoviviparous reproduction was missed due to the timing of sampling as indicated by the small peak in the June abundance of 1st instar nauplii. The low numbers of later naupliar instars during August–September (Table 12) and the absence of a second peak in adult abundance indicate that relatively few of these individuals survived to adult. As total abundance declines from the peak in June, recruitment is not keeping pace with adult mortality.

Fecundity (eggs per brood) is a function of food availability and adult female size. Lakewide mean fecundity ranged from 20 to 33 eggs brood^{-1} during June to August, (Table 14). Lakewide mean individual fecundity increased in September and October (83 and 99 eggs brood^{-1}, respectively) as food became abundant but total reproduction was virtually absent by mid-November as the population declined.

The mean length of adult females varied from 9.6 to 12.6 mm (Table 14) during the course of the year. These sizes are similar to previous years.

Due to threatening winter conditions and the virtual absence of *Artemia*, only the centrally-located deep Station 6 was sampled in December. On 17 December 2009 only a single adult male and 24 naupliar instars were retrieved in a single vertical net tow yielding an areal abundance of 503 m^{-2} (Table 11a).

Artemia Population Statistics, 1979–2009

Year to year variation in climate, hydrological conditions, vertical stratification, food availability, and salinity have led to large inter-year differences in *Artemia* dynamics. During years when the first generation was small due to reduced hatching, high mortality, or delayed development, (1981, 1982, and 1989) the second generation peak of adults was 2–3 times the long term average (Table 15, Fig. 22). Seasonal peak abundances were also significantly higher (1.5–2 times the mean) in 1987 and 1988 as the 1980s episode of meromixis weakened and nutrients that had accumulated beneath the chemocline were transported upward, during 2004 following breakdown of the 1990s episode of meromixis, and during 2009. 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}) occurred during 2005–07. The seasonal (1 May to November 30) mean of adult abundance varied less within a range of 11,000–37,000 m^{-2}. The overall mean seasonal abundance of adult *Artemia* from 1979 to 2008 was 19,790 m^{-2}. During this 30-yr record, mean seasonal abundance was lowest in 2000 (~10,500 m^{-2}) and 2002 (~11,600 m^{-2}) and highest in 1982 (~36,600 m^{-2}), 1989 (~36,400 m^{-2}), and 2004 (~32,000 m^{-2}). During the previous three years (2005, 17,888 m^{-2}; 2006, 21,518 m^{-2}; 2007, 18,269 m^{-2}) seasonal abundance has been close to the long-term mean of 19,584 m^{-2}. In 2008, mean seasonal abundance is 11,823 m^{-2} making it the 3rd lowest in the 30-year history. This year, mean seasonal abundance was 25,970 m^{-2}, well above the long-term mean.

During most years, the seasonal distribution of adult abundance is roughly normal or lognormal. However, in several years the seasonal abundance was not described well by either of these distributions. Therefore, the abundance-weighted centroid of temporal occurrence was calculated to compare overall seasonal shifts in the timing of adult abundance. The center of the temporal distribution of adults varied from day 180 (28

June) to 252 (9 September) in the 30-yr record from 1979 to 2008 (Table 15, Fig. 23). During five years when there was a small spring hatch (1980–83, and 1989) the overall temporal distribution of adults was much later (24 August – 9 September) and during 2004 the exceptionally large and early 1st generation shifted the seasonal temporal distribution much earlier to 28 June. In 2009, the center of the temporal distribution was day 181, close to the earliest (day 180) of record.

Over the long-term record there has been a general shift in seasonal adult abundance to earlier in the year. Although there has been significant year-to-year variation among years due to the onset, persistence, and breakdown of three episodes of meromixis during the period 1979 to 2008, a linear regression explains 54 % of the variation in the temporal abundance of adults. The centroid of adult abundance has shifted an average of 1.6 d yr^{-1} over the 30-yr period of variable but generally decreasing salinity. The larger size of the 1st generation and subsequent earlier autumn decline is advantageous to breeding gulls (Wrege et al. 2006) and disadvantageous to migrating grebes (Jellison & Jehl unpublished).

Long term integrative measures of productivity

Planktonic primary production

Photosynthetic rates were determined by laboratory radiocarbon uptake measurements from 1982-1992 (Jellison and Melack 1988, 1993b) and combined with an interpolative model of chlorophyll, temperature, and in situ photosynthetically-available light (PAR) to estimate annual productivity. While radiocarbon uptake measurements were not conducted from 1993-2001, a significant fraction of the chlorophyll-specific variance in maximum (P_m^B) and light-limited uptake rates (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:

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

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

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

In 2001, new “photosynthetrons” (see Methods, Chapter 2) were constructed and direct measurements of carbon uptake were resumed to determine photosynthetic parameters. The new “photosynthetrons” provide more light levels and better control and measurement of the incubator’s light and temperature. Thus, more accurate measurements of P_m^B and 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 2009, eleven carbon uptake experiments were conducted with natural phytoplankton assemblages from the upper mixed-layer (2 m depth) (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 (Fig 24). Chlorophyll-specific maximum carbon uptakes (P_m^B) rates for samples collected at 2 m depth ranged from 0.2 g C g Chl a^{-1} h^{-1} early and late in the year to 4.5 g C g Chl a^{-1} h^{-1} on 15 July (Table 16, Fig. 24), while light-limited rates (α^B) for these samples ranged from 1.0 to 13.3 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 1,411 g C m^{-2} during 2009 (Table 17, Figs. 24-26). The estimated daily production values vary throughout the year in a complex fashion. Compared to the previous 7 years, the most notable difference is the prominent peak observed in July. Prominent peaks were observed in May during 2003 and 2007 (Fig. 27).

Estimated annual primary production in 2009 was about twice the long-term mean (1982–2009) of 686 g C m^{-2} (Table 17, Fig. 28). Estimates from previous years ranged from 149 g C m^{-2} in 1997 to 1645 g C m^{-2} in 2003. In 1988, a 5-yr episode of meromixis was breaking down and nutrients which had accumulated beneath the thermocline were mixed into the euphotic zone leading to higher algal biomass and estimated annual production of 1,064 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 2009, *Artemia* biomass was 0.06 g dry weight m^{-2} on 19 February and increased to the yearly peak of 37.2 g dry weight m^{-2} on 15 June. The 2009 value is among the highest peak biomasses of record. Other recent years, have also displayed high peak biomasses; 2005 (30.5 g dry weight m^{-2}), 2006 (30.7 g dry weight m^{-2}), and 2007 (26.5 g dry weight m^{-2}). The 2009 mean annual *Artemia* biomass was 8.8 g m^{-2}, just slightly below the long-term (1983–2009) mean of 9.0 g m^{-2} (Table 17, Fig. 29)

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

In Mono Lake, oviparous (cyst) reproduction is always much higher than ovoviviparous (live-bearing) reproduction (Fig. 30, Table 17). In 2009, total annual naupliar production (0.15 x 10^6 m^{-2}) was only half that observed from 2005 to 2008 (0.29–0.34 x 10^6 m^{-2}) and well below the long-term mean of 0.25 x 10^6 m^{-2}. Low ovoviviparous reproduction resulted from low food conditions associated with the almost record number of summer adults. Total annual cyst production in 2009 was 2.9 x 10^6 m^{-2}, slightly lower than the previous four years (3.1–4.8 m^{-2} x 10^6 m^{-2}) and 32 % below the long-term mean of 4.3 x 10^6 m^{-2}.

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

The long-term record of plankton dynamics in Mono Lake show marked seasonal and inter-year variation (Figs. 31-32). Multi-year episodes of meromixis have markedly increased the inter-year variation compared to periods of monomixis in which an annual winter period of holomixis occurs. The large variations caused by changes in mixing regime preclude the possibility of determining the effects of variation in salinity from any small subset of years. Here, we examine the long-term trends in algal biomass in the upper water column (< 10 m) and adult *Artemia* biomass from 1982 through 2009.

The seasonal trend can be removed by calculating a yearly moving average. Because the intervals between sampling dates varied among years, daily values were derived by linearly interpolating between sample dates prior to calculating a 365-day moving average. Thus, each point represents a moving average of 365 days centered about a given day. The seasonally-filtered chlorophyll *a* concentrations (Fig. 31, heavy line) show the marked impact of the three episodes of meromixis, 1983–88, 1995–03, 2005–07). The seasonally-filtered mean chlorophyll ranged from a minimum of 2.8 µg liter^{-1} following the onset of meromixis in 1984 to 50.3 µg liter^{-1} in late 2003 and 60.2 µg liter^{-1} in 2008 as the second and third episodes of meromixis ended. This represents an 18-fold difference. While there appears to be a trend of increasing chlorophyll over the long-term record, the variation due to three episodes of meromixis is large and only 28% of the observed variation is explained by a long-term temporal trend.

The seasonally-filtered adult *Artemia* abundance shows much less inter-year variation (Fig. 32) with mean abundance ranging from 6,200 m^{-2} in 2000 to 24,000 m^{-2} in 1982 or about a 4-fold difference. There is no significant long-term trend in this seasonally-filtered measure of *Artemia* abundance. However, a significant shift in *Artemia* abundance to earlier in the year has occurred over the last couple decades.

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Table 1. Temperature (ºC) at Station 6, February – December, 2009.

Depth (m)	2/19*	3/18	4/13	5/18	6/15*	7/15	8/13	9/15	10/15	11/17	12/17
1	3.5	6.0	7.1	18.3	16.6	20.6	19.9	18.6	-	8.7	4.4
2	3.2	5.0	7.1	19.0	16.5	20.7	19.7	18.6	12.1	8.7	4.5
3	3.2	4.8	7.2	16.7	16.5	20.6	19.7	18.6	12.1	8.6	4.5
4	3.1	4.8	6.8	14.5	16.7	20.6	20.0	18.6	12.4	8.6	4.6
5	3.1	4.7	6.4	13.5	16.5	20.0	20.3	18.6	12.5	8.6	4.6
6	3.0	4.3	6.1	13.1	16.2	19.9	20.1	18.7	12.5	8.6	4.6
7	2.8	4.1	6.0	12.1	15.6	19.9	19.8	18.6	12.3	8.6	4.7
8	2.8	4.0	6.0	10.6	15.0	19.9	19.4	18.6	12.1	8.7	4.7
9	2.8	4.0	5.9	9.9	13.5	19.6	18.7	18.7	12.1	8.7	4.7
10	2.8	3.9	5.8	9.3	12.6	19.0	18.3	18.7	12.1	8.8	4.7
11	2.7	3.4	5.8	8.5	9.4	13.6	17.3	18.6	12.0	8.8	4.8
12	2.7	3.2	5.6	7.8	9.3	11.3	14.9	17.4	12.0	8.8	4.9
13	2.7	3.1	5.4	7.1	8.5	9.6	11.0	16.7	12.1	8.8	4.9
14	2.7	3.1	5.1	6.6	7.7	8.5	8.5	11.9	12.2	8.8	4.9
15	2.7	3.1	4.7	6.3	6.9	7.2	7.4	9.4	12.2	8.8	4.9
16	2.7	3.0	4.6	5.7	6.7	6.7	6.7	7.8	12.1	8.8	4.8
17	2.7	3.0	4.3	5.6	6.4	6.4	6.2	7.0	11.6	8.8	4.9
18	2.6	3.0	4.1	5.4	6.1	6.0	6.1	6.6	10.9	8.7	4.9
19	2.6	3.0	4.0	5.2	6.0	5.8	6.0	6.5	10.1	8.7	4.9
20	2.6	3.0	3.8	4.9	5.9	5.7	5.9	6.4	9.7	8.7	4.9
21	2.6	3.0	3.7	4.7	5.6	5.6	5.8	6.2	9.8	8.7	4.9
22	2.6	3.0	3.5	4.5	5.5	5.5	5.7	6.1	9.1	8.7	4.9
23	2.5	3.0	3.5	4.5	5.3	5.3	5.6	6.0	8.7	8.7	4.9
24	2.5	2.9	3.4	4.4	5.1	5.3	5.5	6.0	8.2	8.7	4.9
25	2.5	2.9	3.4	4.3	5.0	5.2	5.4	5.8	8.0	8.7	4.9
26	2.5	2.9	3.3	4.2	4.9	5.2	5.3	5.7	8.0	8.6	4.9
27	2.5	2.9	3.3	4.1	4.8	5.1	5.3	5.7	7.8	8.6	4.9
28	2.5	2.9	3.2	4.1	4.7	5.1	5.2	5.6	7.2	8.7	4.9
29	2.5	2.9	3.2	4.0	4.7	5.1	5.1	5.5	7.2	8.7	4.9
30	2.5	2.9	3.2	4.0	4.6	5.0	5.1	5.4	7.2	8.7	4.9
31	2.5	2.9	3.2	3.9	4.6	4.9	5.0	5.4	7.2	8.7	4.9
32	2.5	2.9	3.2	3.9	4.6	4.8	5.0	5.3	7.2	8.6	4.9
33	2.5	2.9	3.2	3.9	4.5	4.8	5.0	5.2	7.3	8.6	4.9
34	2.5	2.9	3.2	3.9	4.5	4.7	4.9	5.2	7.2	8.6	4.9
35	2.5	2.9	3.1	3.8	4.5	4.6	4.9	5.2	7.2	8.5	4.9
36	2.5	2.9	3.1	3.8	4.4	4.6	4.8	5.1	7.1	8.5	4.9
37	2.5	2.9	3.1	3.8	4.4	4.6	4.8	5.1	7.1	8.4	4.8
38	2.5	2.9	-	3.8	4.4	4.6	4.8	5.0	6.9	8.4	4.8

*Temperature taken with YSI 58 on these dates due to failure of the CTD probe

Table 2. Conductivity (mS cm^{-1} at 25ºC) at Station 6, February – December, 2009.

Depth (m)	2/19*	3/18	4/13	5/18	6/15*	7/15	8/13	9/15	10/15	11/17	12/17
1	-	81.8	81.5	80.6	-	77.1	78.4	80.8	-	82.4	82.4
2	-	81.9	81.6	80.0	-	77.0	78.7	80.8	82.3	82.5	82.5
3	-	81.9	81.7	81.8	-	77.2	78.8	80.7	82.5	82.5	82.6
4	-	81.9	81.7	81.8	-	77.2	78.3	80.8	82.7	82.5	82.6
5	-	81.9	81.5	82.1	-	78.3	77.7	80.8	82.7	82.5	82.6
6	-	81.8	81.7	82.0	-	78.4	78.1	80.6	82.7	82.6	82.6
7	-	81.8	81.7	82.0	-	78.5	78.6	80.7	82.6	82.6	82.6
8	-	81.8	81.7	81.7	-	78.5	79.2	80.7	82.5	82.6	82.6
9	-	81.9	81.7	81.6	-	79.0	80.6	80.6	82.8	82.7	82.7
10	-	81.8	81.6	81.9	-	80.0	81.4	80.7	82.6	82.6	82.7
11	-	81.7	81.7	81.7	-	81.2	81.5	80.8	82.7	82.6	82.7
12	-	81.8	81.7	81.8	-	80.6	81.9	82.1	82.7	82.6	82.7
13	-	81.9	81.7	81.7	-	82.0	82.0	82.5	82.8	82.7	82.7
14	-	81.9	81.7	81.9	-	81.3	82.5	81.3	82.8	82.7	82.7
15	-	81.8	81.8	81.8	-	81.7	81.6	81.2	82.8	82.7	82.7
16	-	81.9	81.8	81.8	-	81.9	81.7	81.9	82.6	82.7	82.7
17	-	81.9	81.8	81.9	-	81.8	82.0	82.5	82.4	82.6	82.8
18	-	81.9	81.8	81.8	-	81.8	81.9	81.8	82.6	82.7	82.8
19	-	81.9	81.7	81.7	-	81.8	82.0	81.9	82.2	82.6	82.8
20	-	81.9	81.8	81.8	-	81.9	81.9	81.8	82.6	82.7	82.8
21	-	81.8	81.8	82.0	-	82.0	82.0	81.8	82.5	82.7	82.8
22	-	81.9	81.8	81.9	-	81.9	81.9	81.9	82.4	82.7	82.8
23	-	81.9	81.8	81.9	-	81.8	81.8	82.0	82.3	82.7	82.8
24	-	81.9	81.9	81.9	-	81.9	81.9	81.8	82.0	82.7	82.8
25	-	81.9	81.8	81.9	-	81.9	81.8	81.8	82.4	82.7	82.8
26	-	81.9	81.9	81.9	-	81.8	81.9	81.8	82.2	82.7	82.8
27	-	81.9	81.9	81.9	-	81.9	81.9	81.8	82.1	82.7	82.8
28	-	81.9	81.8	81.9	-	81.9	81.8	81.8	82.2	82.7	82.8
29	-	81.9	81.9	81.9	-	81.8	81.8	81.7	82.2	82.7	82.8
30	-	81.9	81.9	81.9	-	81.8	81.9	81.8	82.2	82.7	82.8
31	-	81.9	81.9	81.9	-	81.8	81.9	81.7	82.2	82.7	82.8
32	-	81.9	81.9	81.9	-	81.9	81.9	81.7	82.1	82.8	82.8
33	-	81.9	81.9	81.9	-	81.8	81.8	81.8	82.2	82.8	82.8
34	-	81.9	81.9	81.8	-	81.8	81.9	81.8	82.2	82.8	82.8
35	-	81.9	81.9	81.9	-	81.8	81.9	81.8	82.3	82.8	82.8
36	-	81.9	81.9	81.9	-	81.8	81.9	81.8	82.3	82.8	82.9
37	-	81.9	81.9	81.9	-	81.8	81.9	81.7	82.3	82.8	82.8
38	-	81.9	-	81.9	-	81.8	81.9	81.8	82.3	82.8	82.8

*Conductivity not available on these two dates due to failure of the CTD probe

Table 3. Excess density (kg m^{-3}) at Station 6, February – December, 2009.

Depth (m)	2/19*	3/18	4/13	5/18	6/15*	7/15	8/13	9/15	10/15	11/17	12/17
1	-	71.0	70.5	66.5	-	61.8	63.5	66.7		71.1	71.9
2	-	71.2	70.6	65.6	-	61.7	63.9	66.6	70.3	71.3	72.0
3	-	71.3	70.6	68.4	-	61.9	64.0	66.6	70.4	71.3	72.1
4	-	71.2	70.7	69.0	-	61.9	63.3	66.6	70.7	71.3	72.1
5	-	71.3	70.6	69.7	-	63.3	62.6	66.6	70.6	71.3	72.1
6	-	71.2	70.8	69.6	-	63.5	63.1	66.5	70.6	71.3	72.1
7	-	71.3	70.8	69.9	-	63.6	63.8	66.5	70.6	71.4	72.2
8	-	71.3	70.9	69.9	-	63.6	64.6	66.5	70.5	71.4	72.1
9	-	71.4	70.9	70.0	-	64.3	66.3	66.5	70.9	71.5	72.2
10	-	71.3	70.8	70.5	-	65.6	67.5	66.5	70.7	71.4	72.2
11	-	71.3	70.9	70.3	-	68.5	67.9	66.6	70.7	71.4	72.3
12	-	71.4	70.9	70.6	-	68.5	69.1	68.5	70.8	71.4	72.2
13	-	71.5	70.9	70.6	-	70.5	70.2	69.2	70.8	71.4	72.2
14	-	71.5	70.9	70.9	-	69.9	71.3	69.1	70.8	71.4	72.2
15	-	71.4	71.1	71.0	-	70.6	70.4	69.6	70.8	71.4	72.2
16	-	71.5	71.1	71.0	-	71.0	70.7	70.7	70.6	71.4	72.2
17	-	71.5	71.2	71.1	-	70.8	71.2	71.6	70.6	71.4	72.3
18	-	71.5	71.3	71.1	-	71.0	71.1	70.8	70.9	71.5	72.3
19	-	71.5	71.1	70.9	-	71.0	71.2	71.0	70.6	71.4	72.3
20	-	71.5	71.3	71.2	-	71.1	71.1	70.9	71.2	71.5	72.3
21	-	71.5	71.3	71.5	-	71.2	71.2	70.9	71.1	71.5	72.3
22	-	71.5	71.4	71.3	-	71.2	71.1	71.1	71.1	71.5	72.3
23	-	71.5	71.4	71.3	-	71.1	71.1	71.2	71.1	71.5	72.3
24	-	71.5	71.4	71.3	-	71.2	71.1	71.0	70.8	71.5	72.3
25	-	71.5	71.4	71.3	-	71.2	71.1	71.0	71.2	71.5	72.3
26	-	71.5	71.5	71.4	-	71.1	71.2	71.1	71.1	71.5	72.3
27	-	71.5	71.5	71.3	-	71.2	71.2	71.0	71.0	71.5	72.3
28	-	71.5	71.4	71.3	-	71.2	71.1	71.0	71.3	71.5	72.3
29	-	71.5	71.5	71.4	-	71.2	71.1	71.0	71.2	71.6	72.3
30	-	71.5	71.5	71.4	-	71.1	71.2	71.1	71.2	71.6	72.4
31	-	71.5	71.5	71.4	-	71.2	71.2	71.0	71.2	71.5	72.4
32	-	71.5	71.5	71.4	-	71.2	71.2	71.0	71.1	71.6	72.4
33	-	71.5	71.5	71.4	-	71.2	71.2	71.1	71.2	71.6	72.4
34	-	71.5	71.5	71.4	-	71.2	71.2	71.1	71.3	71.6	72.4
35	-	71.5	71.5	71.4	-	71.2	71.2	71.1	71.3	71.6	72.4
36	-	71.5	71.5	71.4	-	71.2	71.2	71.1	71.3	71.6	72.4
37	-	71.5	71.5	71.4	-	71.2	71.2	71.0	71.3	71.6	72.4
38	-	71.5		71.4	-	71.2	71.2	71.1	71.3	71.6	72.4

*Excess density not available on these two dates due to failure of the CTD probe

Table 4. Temperature, conductivity, and density stratification (kg m^{-3}) at Station 6, February – December, 2009.

Date	Temperature		Conductivity		Density Difference due to		
	2 m	32 m	2 m	32 m	Temperature	Conductivity	Both
3/18	5.0	2.9	81.9	81.9	0.31	-0.02	0.29
4/13	7.1	3.2	81.6	81.9	0.63	0.31	0.94
5/18	19.0	3.9	80.0	81.9	3.59	2.11	5.71
7/15	20.7	4.8	77.0	81.9	4.00	5.53	9.53
8/13	19.7	5.0	78.7	81.9	3.66	3.64	7.30
9/15	18.6	5.3	80.8	81.7	3.26	1.09	4.34
10/15	12.1	7.2	82.3	82.1	1.08	-0.21	0.87
11/17	8.7	8.6	82.5	82.8	0.01	0.32	0.33
12/17	4.5	4.9	82.5	82.8	-0.07	0.44	0.37

Table 5. Secchi Depths (m), February – December 2009.

	Dates										
Station	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17	12/17*
Western Sector											
1	0.8	0.7	0.7	0.7	7.0	8.4	6.0	5.5	0.9	0.80	-
2	0.8	0.65	0.7	0.9	6.1	7.6	5.8	4.2	0.9	0.80	-
3	0.75	0.65	0.7	1.6	6.5	6.0	4.1	0.9	0.8	-	-
4	0.75	0.7	0.7	1.6	5.8	7.3	5.9	4.0	0.9	0.75	-
5	0.7	0.65	0.7	2.0	6.8	6.3	5.2	3.1	1.0	0.80	-
6	0.7	0.6	0.7	1.8	6.7	6.2	6.4	3.8	0.95	0.80	0.9
Avg.	0.75	0.66	0.70	1.43	6.48	6.97	5.57	3.58	0.91	0.79	-
S.E.	0.02	0.02	0.00	0.21	0.19	0.39	0.33	0.62	0.03	0.01	-
n	6	6	6	6	6	6	6	6	6	5	1
Eastern Sector											
7	0.7	0.65	0.7	1.8	6	6.5	6.2	3.2	0.9	0.80	
8	0.7	0.65	0.7	1.8	4.8	6.1	5.2	2.2	0.85	0.70	
9	0.7	0.75	0.6	1.5	5.2	5.7	5.5	2.8	0.85	0.90	
10	0.8	0.65	0.6	2.1	5	5.2	4	2.2	0.9	0.80	
11	0.7	0.7	0.6	1.5	5.8	4.9	6	2.2	0.95	0.80	
12	0.8	0.65	0.6	1.6	5	8.3	5.6	3	0.85	0.80	
Avg.	0.73	0.67	0.63	1.72	5.30	6.12	5.42	2.60	0.88	0.80	
S.E.	0.02	0.02	0.02	0.09	0.20	0.50	0.32	0.19	0.02	0.03	
n	6	6	6	6	6	6	6	6	6	6	
Total Lakewide											
Avg.	0.74	0.67	0.67	1.57	5.89	6.54	5.49	3.09	0.90	0.80	0.9
S.E.	0.01	0.01	0.01	0.12	0.22	0.33	0.22	0.34	0.02	0.01	
n	12	12	12	12	12	12	12	12	12	11	1

*Only the central, deep Station 6 sampled due to poor and threatening weather.

Table 6: Dissolved Oxygen (mg l^{-1}) at Station 6, February – December, 2009.

Depth (m)	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17	12/17
1	5.27	6.97	7.11	3.87	2.99	3.00	4.29	3.92	3.56	2.95	5.80
2	5.38	7.38	7.08	3.27	2.99	3.08	4.35	3.98	3.59	2.62	5.59
3	5.15	6.91	7.03	5.09	2.96	3.13	4.37	3.97	3.27	2.33	5.26
4	5.00	6.76	6.82	6.81	2.86	3.24	4.31	3.99	3.15	2.20	4.99
5	4.90	6.57	6.61	6.53	2.83	3.35	4.44	4.01	3.14	2.07	4.98
6	4.87	6.23	5.89	6.01	2.86	3.40	4.54	4.03	3.05	2.03	5.00
7	4.91	6.19	5.73	5.14	3.03	3.42	4.99	4.06	2.48	2.01	4.95
8	4.91	6.16	5.48	4.89	3.06	3.40	4.74	4.09	2.33	2.05	5.32
9	4.86	6.13	5.39	4.06	3.15	3.33	4.44	4.10	2.60	2.35	5.12
10	4.88	5.91	5.25	3.09	3.55	3.25	4.27	4.07	2.84	2.29	5.15
11	4.93	5.17	4.97	2.72	1.87	3.68	3.71	3.80	2.88	2.71	4.95
12	4.93	4.63	4.63	2.57	2.31	3.88	3.01	2.97	2.74	2.84	4.91
13	4.86	4.60	4.49	2.39	1.34	2.03	2.33	2.87	2.65	2.88	4.92
14	4.85	4.69	4.46	2.26	0.90	1.61	0.85	0.28	2.82	2.91	4.93
15	4.84	4.62	3.82	2.09	0.33	0.39	0.22	0.24	2.82	2.93	4.95
16	4.83	4.62	3.67	1.84	0.27	0.28	0.22	0.24	2.34	3.01	4.99
17	4.82	4.63	3.57	1.65	-	0.26	-	-	1.16	3.23	4.99
18	5.00	4.64	3.23	1.59	-	-	-	-	0.39	3.27	5.00
19	5.11	4.65	3.03	1.58	-	-	-	-	0.17	3.28	5.00
20	5.16	4.65	3.01	1.12	-	-	-	-	0.15	3.30	4.92
21	5.19	4.65	2.91	1.04	-	-	-	-	-	3.29	4.91
22	5.22	4.65	2.68	0.73	-	-	-	-	-	3.29	4.69
23	5.32	4.61	2.57	0.97	-	-	-	-	-	3.32	4.77
24	5.46	4.60	2.47	0.39	-	-	-	-	-	3.34	4.78
25	5.48	4.51	2.40	0.78	-	-	-	-	-	3.36	4.80
26	5.40	4.51	2.40	0.82	-	-	-	-	-	3.37	4.80
27	5.38	4.51	2.46	0.80	-	-	-	-	-	3.37	4.80
28	5.36	4.53	2.42	0.62	-	-	-	-	-	3.48	4.80
29	5.35	4.52	2.37	0.31	-	-	-	-	-	3.47	4.79
30	5.35	4.51	2.38	0.27	-	-	-	-	-	3.46	4.81
31	5.35	4.46	2.31	-	-	-	-	-	-	3.47	4.82
32	5.33	4.42	2.24	-	-	-	-	-	-	3.49	4.50
33	5.33	-	2.19	-	-	-	-	-	-	3.54	-
34	5.33	-	2.15	-	-	-	-	-	-	3.56	-
35	5.33	-	2.13	-	-	-	-	-	-	3.59	-
36	5.33	-	-	-	-	-	-	-	-	3.59	-
37	5.33	-	-	-	-	-	-	-	-	3.60	-

Table 7. Ammonium (µM) at Station 6, February – December, 2009.

Depth (m)	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17	12/17
1	-	-	-	-	-	-	-	-	-	-	-
2	0.92	4.70	0.29	1.68	8.45	7.94	2.18	0.69	0.28	5.02	0.95
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	0.97	2.20	0.01	1.91	2.60	6.03	1.59	0.60	4.82	5.43	1.93
9	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	1.98	0.88	0.23	0.88	0.01	1.09	4.53	0.74	2.55	4.71	2.04
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-
16	1.52	0.88	0.68	0.99	3.04	6.39	19.28	26.18	1.95	2.25	1.31
17	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	1.02	1.81	0.74	4.19	21.87	28.09	48.73	43.73	25.06	0.31	1.78
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	0.66	1.67	2.66	8.93	10.51	29.64	47.74	57.44	26.45	1.18	1.88
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	1.07	1.86	3.79	8.42	16.46	14.69	44.25	60.28	32.94	0.87	1.93
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-
35	0.97	1.71	7.06	16.30	31.07	30.67	59.70	83.92	41.76	0.56	2.45
36	-	-	-	-	-	-	-	-	-	-	-
37	-	-	-	-	-	-	-	-	-	-	-

Table 8. Ammonium (µM) at 7 stations in upper 9 m of water column, February – December, 2009.

Station	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17
1	0.51	1.37	0.57	0.31	8.45	11.39	2.43	2.35	3.02	1.38
2	0.66	2.11	0.40	0.94	6.66	9.95	2.33	1.31	1.72	4.76
5	0.66	1.91	0.17	0.31	7.53	9.23	0.89	0.55	4.27	5.73
6	0.71	1.47	0.51	0.88	5.85	6.96	1.69	0.64	1.58	6.30
7	1.57	0.83	0.17	0.88	5.42	7.37	1.89	0.64	0.79	0.97
8	1.78	1.23	0.51	1.28	3.69	10.41	0.94	0.64	1.21	3.68
11	1.17	2.40	0.85	1.39	4.01	6.50	1.59	0.69	0.37	0.87
Mean	1.01	1.62	0.45	0.86	5.94	8.83	1.68	0.97	1.85	3.38
SE	0.19	0.21	0.09	0.16	0.66	0.72	0.23	0.25	0.51	0.87

Table 9. Chlorophyll *a* (µg l^{-1}) at Station 6, February – December, 2009.

Depth (m)	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17	12/17
1	-	-	-	-	-	-	-	-	-	-	-
2	82.7	81.5	74.3	17.9	1.3	1.3	2.7	9.5	51.5	80.0	96.8
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	94.0	88.9	77.8	68.7	4.8	2.9	7.2	12.7	51.7	78.2	80.2
9	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	84.8	93.2	84.4	86.9	35.5	7.9	9.9	15.7	46.5	81.1	85.5
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-
16	85.1	93.6	82.8	78.5	64.9	81.0	69.4	67.3	51.2	80.6	85.2
17	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	82.2	90.7	88.0	73.6	86.2	84.7	73.0	65.9	60.6	72.4	83.4
21	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	80.0	94.4	80.6	73.5	98.9	87.0	73.7	68.4	64.0	78.9	79.7
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	93.2	85.3	79.6	76.9	91.3	92.3	84.6	65.9	67.1	78.8	79.3

Table 10. Chlorophyll *a* (µg l^{-1}) at 7 stations in upper 9 m of water column, February – December 2009.

Station	2/19	3/18	4/13	5/18	6/15	7/15	8/13	9/15	10/15	11/17
1	85.5	84.7	65.4	40.1	1.6	1.0	5.8	6.2	56.6	85.7
2	91.4	89.4	73.2	54.1	2.6	1.7	3.9	7.4	59.6	75.0
5	85.4	79.5	73.9	30.1	2.0	2.1	5.1	11.4	57.4	75.8
6	89.2	85.7	70.8	28.7	2.8	2.5	4.1	8.7	54.2	77.6
7	84.4	83.5	72.0	48.8	3.9	2.4	4.6	12.3	50.9	78.1
8	85.0	93.2	67.9	20.4	4.0	1.2	5.6	11.1	48.1	75.5
11	83.6	72.9	65.6	24.4	3.7	2.6	3.6	10.6	51.5	83.3
Mean	86.3	84.1	69.8	35.2	2.9	1.9	4.7	9.7	54.0	78.7
SE	1.1	2.5	1.3	4.8	0.4	0.2	0.3	0.9	1.5	1.6

Table 11a. *Artemia* lake and sector means, 2009.

	Instars 1-7	8-11	adult male	adult fem ?	adult fem e	adult fem c	adult fem n	adult fem tot	adult total	total
Lakewide Mean:										
2/19	19,308	20	18	0	17	0	0	17	35	19,363
3/18	43,317	2	5	0	12	0	0	12	17	43,335
4/13	54,145	27	0	0	0	0	0	0	0	54,172
5/18	27,311	6,667	19,571	0	23,528	0	0	23,528	43,099	77,076
6/15	11,107	1,583	37,532	2,173	23,742	8,102	537	34,554	72,086	84,775
7/15	6,948	309	24,963	1,757	12,153	6,197	161	20,268	45,231	52,488
8/13	2,354	0	10,362	651	1,167	6,056	409	8,283	18,645	20,999
9/15	2,592	39	6,226	69	79	2,591	94	2,832	9,058	11,688
10/15	1,522	40	1,712	37	127	1,068	37	1,269	2,981	4,544
11/17	599	29	141	7	54	30	3	94	235	862
12/17	483	0	20	0	0	0	0	0	20	503
Western Sector Mean:										
2/19	5,993	7	0	0	0	0	0	0	0	5,999
3/18	35,553	0	3	0	10	0	0	10	13	35,567
4/13	32,046	0	0	0	0	0	0	0	0	32,046
5/18	16,419	3,353	11,670	0	14,111	0	0	14,111	25,781	45,553
6/15	15,345	1,073	40,134	2,146	25,325	9,765	537	37,773	77,907	94,326
7/15	6,600	322	27,525	1,878	13,521	6,117	54	21,569	49,095	56,016
8/13	3,018	0	12,059	778	1,194	5,969	295	8,236	20,295	23,313
9/15	3,367	40	7,847	80	121	3,997	134	4,333	12,180	15,587
10/15	1,097	23	1,231	37	87	882	30	1,036	2,267	3,387
11/17	91	13	107	0	7	10	7	23	131	235
12/17	483	0	20	0	0	0	0	0	20	503
Eastern Sector Mean:										
2/19	32,622	34	37	0	34	0	0	34	70	32,726
3/18	51,080	3	7	0	13	0	0	13	20	51,103
4/13	76,244	54	0	0	0	0	0	0	0	76,298
5/18	38,203	9,980	27,471	0	32,944	0	0	32,944	60,416	108,598
6/15	6,868	2,093	34,930	2,200	22,160	6,439	537	31,335	66,264	75,225
7/15	7,297	295	22,401	1,636	10,785	6,278	268	18,967	41,368	48,960
8/13	1,690	0	8,665	523	1,140	6,144	523	8,330	16,995	18,685
9/15	1,818	37	4,604	57	37	1,184	54	1,331	5,936	7,790
10/15	1,948	57	2,193	37	168	1,254	44	1,502	3,696	5,701
11/17	1,107	44	174	13	101	50	0	164	339	1,489
12/17										

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

Table 11b. Standard errors of *Artemia* sector means (Table 11a), 2009.

	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:										
2/19	4,761	13	13	0	14	0	0	14	26	4,768
3/18	15,152	2	4	0	4	0	0	4	7	15,160
4/13	11,444	27	0	0	0	0	0	0	0	11,448
5/18	4,051	1,273	2,958	0	3,411	0	0	3,411	6,204	11,084
6/15	1,986	335	2,479	315	1,847	953	107	2,693	4,934	5,626
7/15	1,067	80	2,584	242	1,377	634	63	1,748	4,093	4,514
8/13	572	0	1,569	157	222	1,041	76	1,350	2,412	2,574
9/15	633	15	807	18	27	554	26	571	1,144	1,459
10/15	270	15	305	13	50	161	9	199	475	723
11/17	184	7	25	4	20	9	2	25	44	222
12/17										
SE of Western Sector Mean:										
2/19	1,482	7	0	0	0	0	0	0	0	1,479
3/18	9,827	0	3	0	4	0	0	4	7	9,832
4/13	6,872	0	0	0	0	0	0	0	0	6,872
5/18	2,214	588	2,047	0	2,790	0	0	2,790	4,809	7,016
6/15	3,067	489	1,893	429	2,954	1,345	198	4,214	5,929	5,654
7/15	1,509	118	3,707	435	1,478	532	54	1,542	5,015	6,053
8/13	1,025	0	2,746	221	304	1,489	99	1,760	3,485	3,704
9/15	1,104	27	832	29	45	712	45	691	1,006	1,455
10/15	167	8	166	6	22	175	7	172	279	382
11/17	33	8	31	0	4	7	4	12	36	56
12/17										
SE of Eastern Sector Mean:										
2/19	5,161	26	26	0	26	0	0	26	51	5,139
3/18	29,824	3	7	0	7	0	0	7	13	29,839
4/13	18,267	54	0	0	0	0	0	0	0	18,263
5/18	4,457	1,548	3,055	0	2,818	0	0	2,818	5,128	9,690
6/15	874	388	4,554	502	2,298	1,042	107	3,163	7,641	8,414
7/15	1,637	121	3,607	251	2,326	1,218	99	3,224	6,526	6,932
8/13	459	0	1,464	231	351	1,595	101	2,218	3,517	3,645
9/15	550	15	1,058	23	23	225	17	239	920	1,083
10/15	470	28	537	26	99	264	18	351	844	1,272
11/17	212	8	38	7	28	13	0	25	55	238
12/17										

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

Table 11c. Percentage in different classes for *Artemia* sector means (Table 11a), 2009.

	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 (%):										
2/19	99.7	0.1	0.1	0.0	100.0	0.0	0.0	0.1	0.2	100
3/18	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100
4/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/18	35.4	8.6	25.4	0.0	100.0	0.0	0.0	30.5	55.9	100
6/15	13.1	1.9	44.3	20.1	68.7	74.9	5.0	40.8	85.0	100
7/15	13.2	0.6	47.6	21.7	60.0	76.4	2.0	38.6	86.2	100
8/13	11.2	0.0	49.3	9.1	14.1	85.1	5.7	39.4	88.8	100
9/15	22.2	0.3	53.3	2.5	2.8	94.1	3.4	24.2	77.5	100
10/15	33.5	0.9	37.7	3.2	10.0	93.5	3.2	27.9	65.6	100
11/17	69.5	3.3	16.3	16.7	57.1	75.0	8.3	10.9	27.2	100
12/17	96.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	4.0	100
Western Sector (%):										
2/19	99.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
3/18	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
4/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/18	36.0	7.4	25.6	0.0	100.0	0.0	0.0	31.0	56.6	100
6/15	16.3	1.1	42.5	17.2	67.0	78.4	4.3	40.0	82.6	100
7/15	11.8	0.6	49.1	23.3	62.7	76.0	0.7	38.5	87.6	100
8/13	12.9	0.0	51.7	11.0	14.5	84.8	4.2	35.3	87.1	100
9/15	21.6	0.3	50.3	1.9	2.8	94.9	3.2	27.8	78.1	100
10/15	32.4	0.7	36.3	3.9	8.4	92.9	3.2	30.6	66.9	100
11/17	38.6	5.7	45.7	0.0	28.6	60.0	40.0	10.0	55.7	100
12/17	96.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	4.0	100
Eastern Sector (%):										
2/19	99.7	0.1	0.1	0.0	100.0	0.0	0.0	0.1	0.2	100
3/18	100.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0	100
4/13	99.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100
5/18	35.2	9.2	25.3	0.0	100.0	0.0	0.0	30.3	55.6	100
6/15	9.1	2.8	46.4	24.0	70.7	70.2	5.8	41.7	88.1	100
7/15	14.9	0.6	45.8	20.0	56.9	76.7	3.3	38.7	84.5	100
8/13	9.0	0.0	46.4	7.3	13.7	85.4	7.3	44.6	91.0	100
9/15	23.3	0.5	59.1	4.4	2.8	91.5	4.1	17.1	76.2	100
10/15	34.2	1.0	38.5	2.8	11.2	94.0	3.3	26.4	64.8	100
11/17	74.3	2.9	11.7	21.1	61.2	78.9	0.0	11.0	22.7	100
12/17										

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

Table 12. Lakewide *Artemia* instar analysis, 2009.

	Instars									
	1	2	3	4	5	6	7	8-11	adults	total
Mean:										
2/19	15,806	69	23	23	23	46	0	0	9	15,999
3/18	37,666	3,570	46	92	0	23	0	0	17	41,414
4/13	10,940	21,012	16,079	3,484	144	0	0	46	0	51,705
5/18	1,817	2,254	2,070	3,472	5,312	4,829	3,058	6,278	38,103	67,192
6/15	8,370	2,437	276	138	322	230	184	1,518	64,340	77,815
7/15	3,840	1,587	0	0	0	0	46	437	48,980	54,889
8/13	816	1,184	126	0	0	23	0	0	21,374	23,524
9/15	187	454	296	308	170	167	40	26	9,623	11,270
10/15	331	454	316	287	175	69	29	37	2,762	4,461
11/17	152	103	115	129	72	14	11	20	193	811
12/17	322	101	20	40	0	0	0	0	20	503
Standard error of the mean:										
2/19	5,922	48	23	23	23	30	0	0	6	6,033
3/18	9,317	1,215	46	92	0	23	0	0	5	10,492
4/13	3,619	7,710	5,005	1,080	95	0	0	46	0	14,934
5/18	515	508	613	982	1,249	1,469	1,361	2,045	7,599	13,335
6/15	2,541	843	191	96	122	116	184	490	6,735	8,079
7/15	888	389	0	0	0	0	46	104	6,187	7,222
8/13	247	561	74	0	0	23	0	0	3,715	3,899
9/15	41	96	90	95	38	66	23	14	1,617	1,641
10/15	172	132	38	62	54	16	12	15	558	936
11/17	62	49	52	68	46	8	6	8	54	328
12/17	322	101	20	40	0	0	0	0	20	503
Percentage in different age classes:										
2/19	98.8	0.4	0.1	0.1	0.1	0.3	0.0	0.0	0.1	100
3/18	90.9	8.6	0.1	0.2	0.0	0.1	0.0	0.0	0.0	100
4/13	21.2	40.6	31.1	6.7	0.3	0.0	0.0	0.1	0.0	100
5/18	2.7	3.4	3.1	5.2	7.9	7.2	4.6	9.3	56.7	100
6/15	10.8	3.1	0.4	0.2	0.4	0.3	0.2	2.0	82.7	100
7/15	7.0	2.9	0.0	0.0	0.0	0.0	0.1	0.8	89.2	100
8/13	3.5	5.0	0.5	0.0	0.0	0.1	0.0	0.0	90.9	100
9/15	1.7	4.0	2.6	2.7	1.5	1.5	0.4	0.2	85.4	100
10/15	7.4	10.2	7.1	6.4	3.9	1.5	0.6	0.8	61.9	100
11/17	18.8	12.8	14.2	16.0	8.9	1.8	1.4	2.5	23.8	100
12/17	66.7	20.8	4.2	8.3	0.0	0.0	0.0	0.0	4.0	100

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

Table 13a. *Artemia* reproductive summary, lake and sector means, 2009.

		Adult Females				
	Total	Ovigery	e	?	c	n
Lakewide Mean:						
2/19	17	0	17	0	0	0
3/18	12	0	12	0	0	0
4/13	0	0	0	0	0	0
5/18	23,528	0	23,528	0	0	0
6/15	34,554	10,812	23,742	2,173	8,102	537
7/15	20,268	8,115	12,153	1,757	6,197	161
8/13	8,283	7,116	1,167	651	6,056	409
9/15	2,832	2,754	79	69	2,591	94
10/15	1,269	1,142	127	37	1,068	37
11/17	94	40	54	7	30	3
12/17	0	0	0	0	0	0
Western Sector Mean:						
2/19	0	0	0	0	0	0
3/18	10	0	10	0	0	0
4/13	0	0	0	0	0	0
5/18	14,111	0	14,111	0	0	0
6/15	37,773	1,2448	25,325	2,146	9,765	537
7/15	21,569	8,049	13,521	1,878	6,117	54
8/13	8,236	7,042	1,194	778	5,969	295
9/15	4,333	4,211	121	80	3,997	134
10/15	1,036	949	87	37	882	30
11/17	23	17	7	0	10	7
12/17	0	0	0	0	0	0
Eastern Sector Mean:						
2/19	34	0	34	0	0	0
3/18	13	0	13	0	0	0
4/13	0	0	0	0	0	0
5/18	32,944	0	32,944	0	0	0
6/15	31,335	9,176	22,160	2,200	6,439	537
7/15	18,967	8,182	10,785	1,636	6,278	268
8/13	8,330	7,190	1,140	523	6,144	523
9/15	1,331	1,295	37	57	1,184	54
10/15	1,502	1,335	168	37	1,254	44
11/17	164	63	101	13	50	0
12/17	34	0	34	0	0	0

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

Table 13b. Standard errors of *Artemia* reproductive summary (Table 13a), 2009.

	Adult Females					
	Total	Ovigery	e	?	c	n
Standard Error of Lakewide Mean:						
2/19	14	0	14	0	0	0
3/18	4	0	4	0	0	0
4/13	0	0	0	0	0	0
5/18	3,411	0	3,411	0	0	0
6/15	2,693	1,119	1,847	315	953	107
7/15	1,748	766	1,377	242	634	63
8/13	1,350	1,194	222	157	1,041	76
9/15	571	565	27	18	554	26
10/15	199	163	50	13	161	9
11/17	25	11	20	4	9	2
12/17	14	0	14	0	0	0
Standard Error of Western Sector Mean:						
2/19	0	0	0	0	0	0
3/18	4	0	4	0	0	0
4/13	0	0	0	0	0	0
5/18	2,790	0	2,790	0	0	0
6/15	4,214	1,811	2,954	429	1,345	198
7/15	1,542	831	1,478	435	532	54
8/13	1,760	1,638	304	221	1,489	99
9/15	691	703	45	29	712	45
10/15	172	168	22	6	175	7
11/17	12	11	4	0	7	4
12/17	0	0	0	0	0	0
Standard Error of Eastern Sector Mean:						
2/19	26	0	26	0	0	0
3/18	7	0	7	0	0	0
4/13	0	0	0	0	0	0
5/18	2,818	0	2,818	0	0	0
6/15	3,163	1,077	2,298	502	1,042	107
7/15	3,224	1,375	2,326	251	1,218	99
8/13	2,218	1,893	351	231	1,595	101
9/15	239	242	23	23	225	17
10/15	351	271	99	26	264	18
11/17	25	14	28	7	13	0
12/17	26	0	26	0	0	0

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

Table 13c. *Artemia* percentages in different reproductive categories (Table 13a), 2009.

		Adult Females				
	Total	Ovigery	e	?	c	n
Lakewide Mean (%):						
2/19	100	0.0	100.0	0.0	0.0	0.0
3/18	100	0.0	100.0	0.0	0.0	0.0
4/13	0	0.0	0.0	0.0	0.0	0.0
5/18	100	0.0	100.0	0.0	0.0	0.0
6/15	100	31.3	68.7	20.1	93.7	6.3
7/15	100	40.0	60.0	21.7	97.4	2.6
8/13	100	85.9	14.1	9.1	93.7	6.3
9/15	100	97.2	2.8	2.5	96.5	3.5
10/15	100	90.0	10.0	3.2	96.7	3.3
11/17	100	42.9	57.1	16.7	90.0	10.0
12/17	0	0.0	0.0	0.0	0.0	0.0
Western Sector Mean (%):						
2/19	0	0.0	0.0	0.0	0.0	0.0
3/18	0	0.0	0.0	0.0	0.0	0.0
4/13	0	0.0	0.0	0.0	0.0	0.0
5/18	100	0.0	100.0	0.0	0.0	0.0
6/15	100	33.0	67.0	17.2	94.8	5.2
7/15	100	37.3	62.7	23.3	99.1	0.9
8/13	100	85.5	14.5	11.0	95.3	4.7
9/15	100	97.2	2.8	1.9	96.7	3.3
10/15	100	91.6	8.4	3.9	96.7	3.3
11/17	100	71.4	28.6	0.0	60.0	40.0
12/17	0	0.0	0.0	0.0	0.0	0.0
Eastern Sector Mean (%):						
2/19	100	0.0	100.0	0.0	0.0	0.0
3/18	100	0.0	100.0	0.0	0.0	0.0
4/13	0	0.0	0.0	0.0	0.0	0.0
5/18	100	0.0	100.0	0.0	0.0	0.0
6/15	100	29.3	70.7	24.0	92.4	7.6
7/15	100	43.1	56.9	20.0	95.9	4.1
8/13	100	86.3	13.7	7.3	92.1	7.9
9/15	100	97.2	2.8	4.4	95.7	4.3
10/15	100	88.8	11.2	2.8	96.6	3.4
11/17	100	38.8	61.2	21.1	100.0	0.0
12/17	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, 2009.

	#eggs/brood mean	#eggs/brood SE	%cyst	%intended	female length mean	female length SE	n
Lakewide Mean:							
6/15	29.2	1.2	0.9	0.6	10.0	0.1	7
7/15	20.3	0.7	1.0	0.5	9.6	0.1	7
8/13	33.3	0.8	1.0	0.4	10.1	0.1	7
9/15	82.9	4.9	0.9	0.5	11.8	0.1	7
10/15	99.4	4.0	1.0	0.5	12.6	0.1	7
Western Sector Mean:							
6/15	28.0	1.5	0.9	0.6	10.0	0.2	4
7/15	19.9	1.2	1.0	0.5	9.6	0.0	4
8/13	32.9	0.9	1.0	0.4	10.1	0.1	4
9/15	73.9	4.5	1.0	0.4	11.6	0.1	4
10/15	98.3	4.6	1.0	0.6	12.7	0.1	4
Eastern Sector Mean:							
6/15	30.8	1.8	1.0	0.6	10.0	0.1	3
7/15	20.9	0.7	1.0	0.6	9.2	0.2	3
8/13	33.9	1.7	1.0	0.3	9.9	0.3	3
9/15	94.9	1.4	0.8	0.6	12.0	0.1	3
10/15	100.9	8.4	0.9	0.5	12.5	0.2	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, 1979–2009.

Year	Mean	Median	Peak	Centroid*
1979	14,118	12,286	31,700	216
1980	14,643	10,202	40,420	236
1981	32,010	21,103	101,670	238
1982	36,643	31,457	105,245	252
1983	17,812	16,314	39,917	247
1984	17,001	19,261	40,204	212
1985	18,514	20,231	33,089	218
1986	14,667	17,305	32,977	190
1987	23,952	22,621	54,278	226
1988	27,639	25,505	71,630	207
1989	36,359	28,962	92,491	249
1990	20,005	16,775	34,930	230
1991	18,129	19,319	34,565	226
1992	19,019	19,595	34,648	215
1993	15,025	16,684	26,906	217
1994	16,602	18,816	29,408	212
1995	15,584	17,215	24,402	210
1996	17,734	17,842	34,616	216
1997	14,389	16,372	27,312	204
1998	19,429	21,235	33,968	226
1999	20,221	21,547	38,439	225
2000	10,550	9,080	22,384	210
2001	20,031	20,037	38,035	209
2002	11,569	9,955	25,533	200
2003	13,778	12,313	29,142	203
2004	32,044	36,909	75,466	180
2005	17,888	15,824	45,419	192
2006	21,518	20,316	55,748	186
2007	18,826	17,652	41,751	186
2008	11,823	12,524	27,606	189
2009	25,970	17,919	72,086	181
Mean	**19,790**	**18,812**	**45,032**	**213**
Min	10,550	9,080	22,384	180
Max	36,643	36,909	105,245	252

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

Table 16. Photosynthetic parameters during 2009.

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)
2/19	2	3.0	1.1	0.2
3/18	2	5.3	5.0	1.1
4/13	2	7.3	5.9	1.4
5/18	2	18.6	1.0	0.4
6/15	2	16.3	4.1	1.1
7/15	2	20.7	13.3	4.5
8/13	2	19.7	5.0	2.1
9/15	2	18.3	1.4	0.6
10/15	2	12.5	1.8	0.3
11/17	2	8.5	4.2	0.2
12/17	2	4.3	3.0	0.2

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), 1982-2009.

Year	**Planktonic Primary Production** (g C m^{-2} y^{-1})	***Artemia***		
		Biomass (g dry weight m^{-2})	**Naupliar Production** (10^6 m^{-2})	**Cyst Production** (10^6 m^{-2})
1982	1,107	-	-	-
1983	523	9.3	0.15	4.8
1984	269	7.8	0.08	3.7
1985	399	7.8	0.22	4.6
1986	462	7.7	0.44	3.0
1987	371	12.5	0.23	6.4
1988	1,064	15.2	0.21	4.7
1989	499	17.6	0.11	6.7
1990	641	11.0	1.02	6.1
1991	418	9.7	0.69	5.5
1992	435	10.2	0.26	5.8
1993	602	8.9	0.35	6.3
1994	446	8.7	0.16	5.6
1995	227	8.4	0.40	4.9
1996	221	8.2	0.05	3.6
1997	149	5.3	0.01	2.5
1998	228	8.0	0.01	2.8
1999	297	8.9	0.03	4.2
2000	484	8.2	0.08	4.0
2001	532	8.8	0.10	3.0
2002	763	4.9	0.10	2.5
2003	1,645	7.5	0.60	4.2
2004	864	11.0	0.04	2.6
2005	1,111	8.8	0.31	3.8
2006	1,075	6.8	0.32	4.8
2007	1,766	7.0	0.29	3.4
2008	1,189	5.7	0.34	3.1
2009	1,411	8.8	0.15	2.9
Mean	**686**	**9.0**	**0.25**	**4.3**

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

FIGURE CAPTIONS

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

Fig. 2. Wind speed; daily mean and 10-min. maximum, 2009.

Fig. 3. Daily air temperature; mean, maximum, and minimum, 2009.

Fig. 4. Daily photosynthetically available radiation, 2009.

Fig. 5. Mean daily relative humidity, 2009.

Fig. 6. Daily precipitation, 2009.

Fig. 7. Mono Lake surface elevation (ft asl), 1979–09, USGS datum.

Fig. 8. Temperature (°C) at station 6, 2009.

Fig. 9. Conductivity (mS cm^{-1} corrected to 25°C) at station 6, 2009.

Fig. 10. Density difference (kg m^{-3}) between 2 and 32 m at station 6 due to temperature and chemical stratification from 1991–2009.

Fig. 11. Transparency as measured by mean lakewide Secchi depth (m), 1994–09. Error bars show standard errors of the lakewide estimate based on 12-20 stations.

Fig. 12. Mean lakewide Secchi depth ($\log_{10}$ m) 1979–09.

Fig. 13. Light attenuation (% of surface) at station 6, 2009.

Fig. 14. Dissolved oxygen (mg O_2 l^{-1}) at station 6, 2009. Dots denote the dates and depths of samples.

Fig. 15. Ammonium (µM) at station 6, 2009. Dots denote the dates and depths of samples.

Fig. 16. Ammonium (µM) in upper 9 m of the water column at 7 stations, 2009.

Fig. 17. Chlorophyll *a* (µg chl *a* l^{-1}) at station 6, 2009. 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, 2009.

Fig. 19. Lakewide *Artemia* abundance during 2009: nauplii (instars 1-7), juveniles (instars 8-11), and adults (instars 12+).

Fig. 20. Lakewide estimates of adult *Artemia* based on 3-20 stations, 1982–09 (see Methods). The mean relative error of the lakewide estimates is 20-25%.

Fig. 21. Reproductive characteristics of *Artemia* during 2009: lakewide mean abundance of total females and ovigerous females (top), percent of females ovoviviparous and ovigerous (middle), and brood size (bottom). Vertical lines are the standard error of the estimate.

Fig. 22. Summary statistics of the seasonal (1 May through 30 November) lakewide abundance of adult *Artemia*, 1979–09. Values are based on interpolated daily abundances.

Fig. 23. Temporal center of abundance-weighted centroid of the seasonal (1 May through 30 November) distribution of adult *Artemia*, 1979–09. Centroid is based on interpolated daily abundances of adult *Artemia*.

Fig. 24. Chlorophyll-specific uptake rates during March, August, and December 2009 for samples collected from the surface mixed layer and the deep chlorophyll maximum.

Fig. 25. Chlorophyll-specific light saturated carbon uptake rate (g C g Chl^{-1} h^{1}), algal biomass (mg m^{-3}), and daily primary production (g C m^{-2}), 2009.

Fig. 26. Comparison of 2002–09 photosynthetic rates and algal biomass. A) Chlorophyll-specific specific light saturated carbon uptake rate (g C g Chl^{-1} h^{1}) B) Mixed-layer (2 m depth) chlorophyll *a* concentrations µg Chl l^{-1}.

Fig. 27. Comparison of 2002–09 daily primary production (g C m^{-2} y^{-1}) calculated with a numerical interpolative model of chlorophyll, temperature, insolation, attenuation, and photosynthetic parameters.

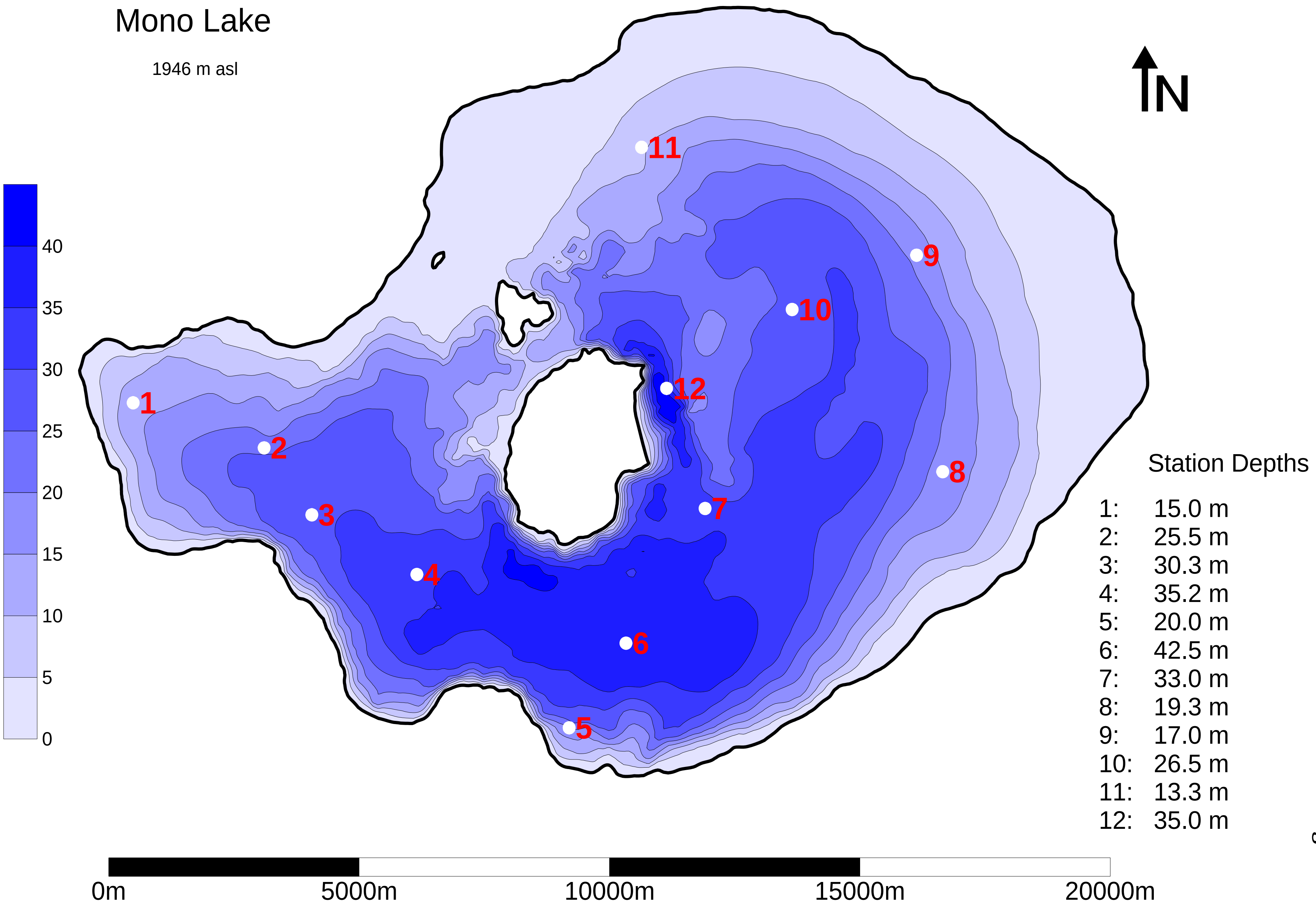
Fig. 28. Annual phytoplankton production estimates (g C m^{-2}), 1982–09.

Fig. 29. Mean annual *Artemia* biomass, 1983–09. Data for the period 1982–99 estimated from instar-specific population data and previously derived weight-length relationships. In 2000–09, *Artemia* biomass was measured directly by determining dry weights of plankton tows.

Fig. 30. Annual *Artemia* reproduction, ovoviviparous (live-bearing) and oviparous (cyst-bearing), 1983–09.

Fig. 31. Lakewide mean of mixolimnetic (<10 m) chlorophyll *a*, 1982–09. Heavy line shows seasonally filtered data formed by linearly interpolating between sampling dates to daily values and then calculating a 365-day running mean.

Fig. 32. Lakewide mean of adult *Artemia* abundance, 1982–09. 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

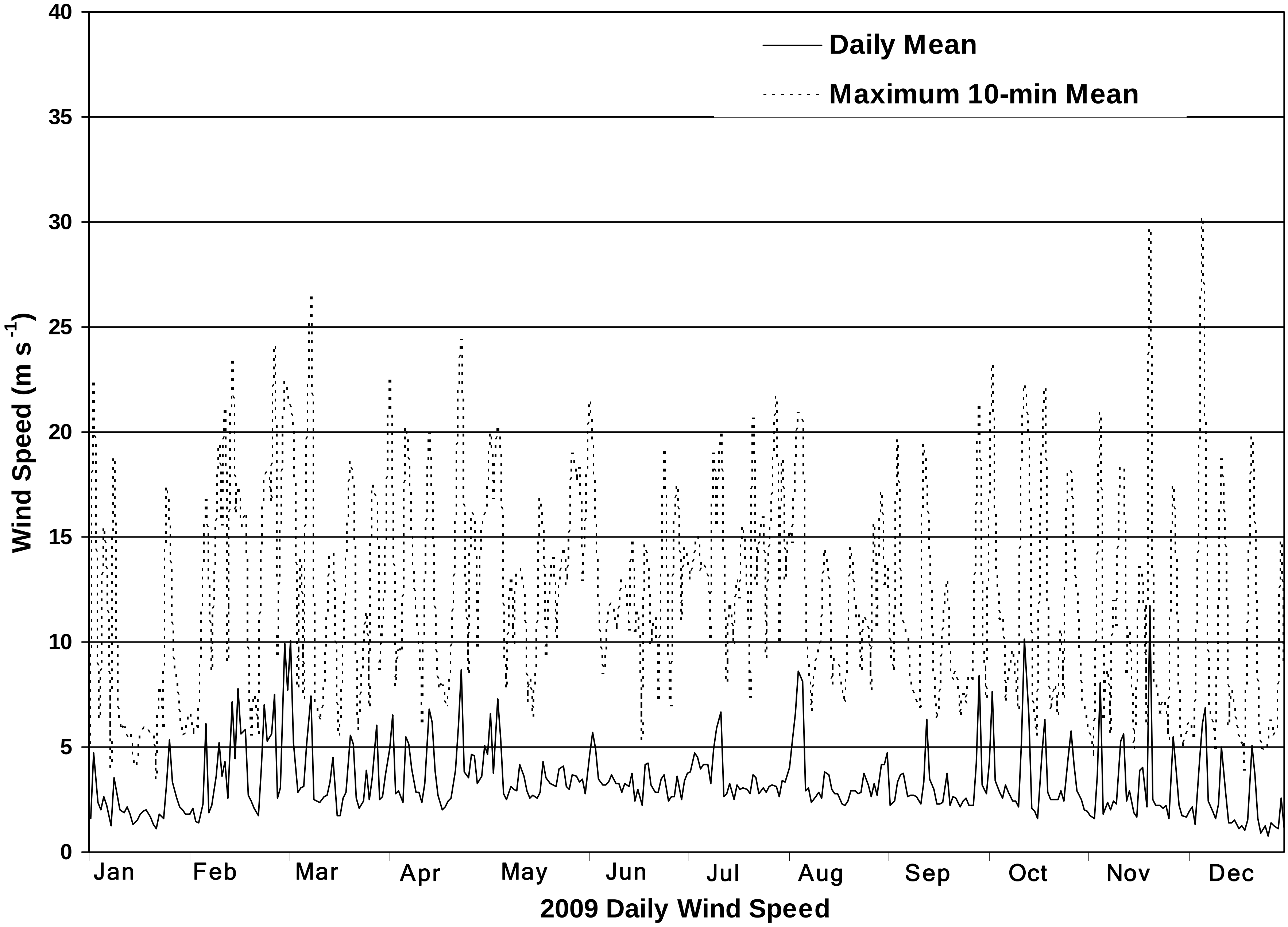

Daily Mean
Maximum 10-min Mean
Wind Speed (m s^{-1})
40
35
30
25
20
15
10
5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009 Daily Wind Speed

Figure 2

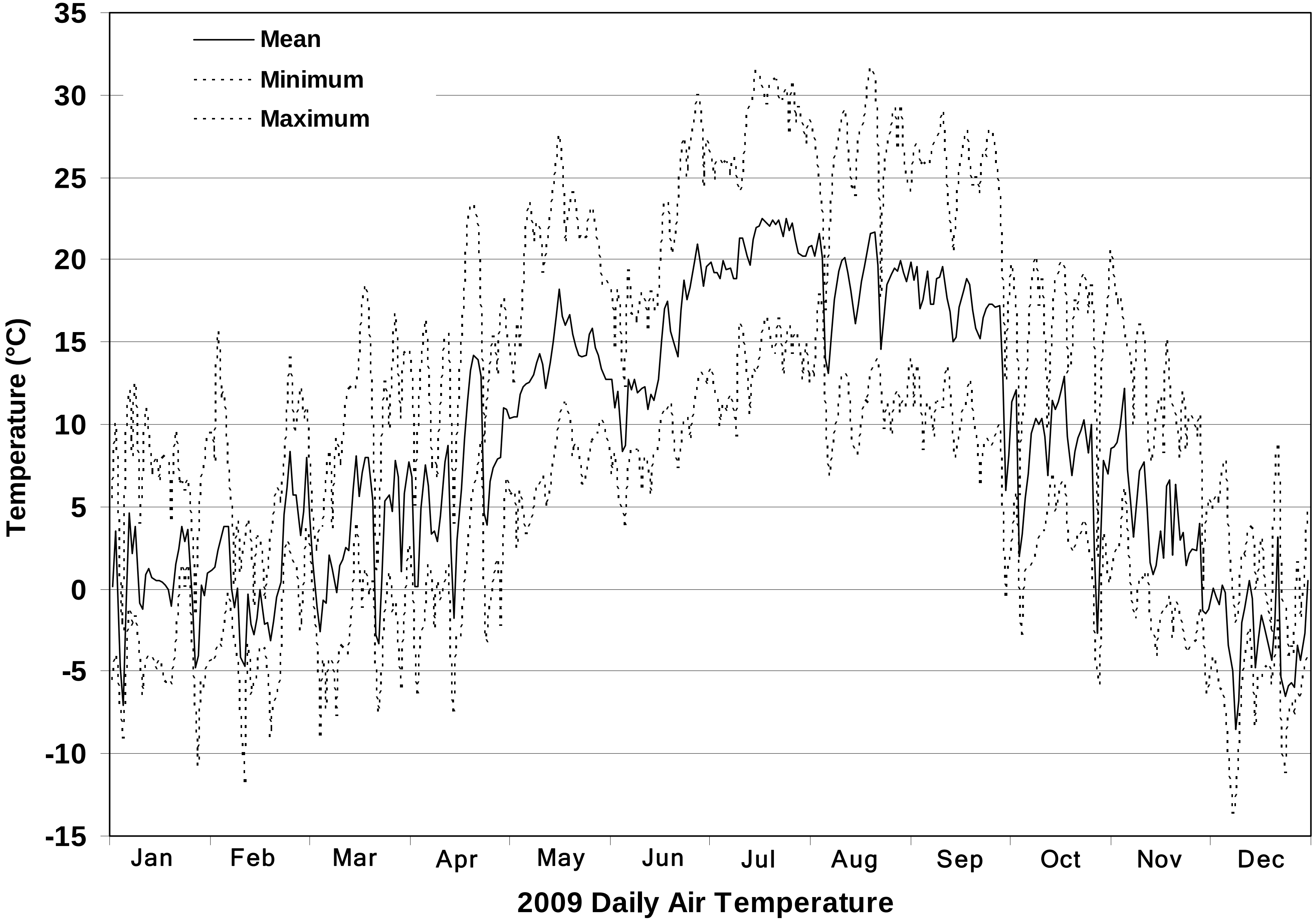

Mean
Minimum
Maximum
Temperature (°C)
35
30
25
20
15
10
5
0
-5
-10
-15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009 Daily Air Temperature

Figure 3

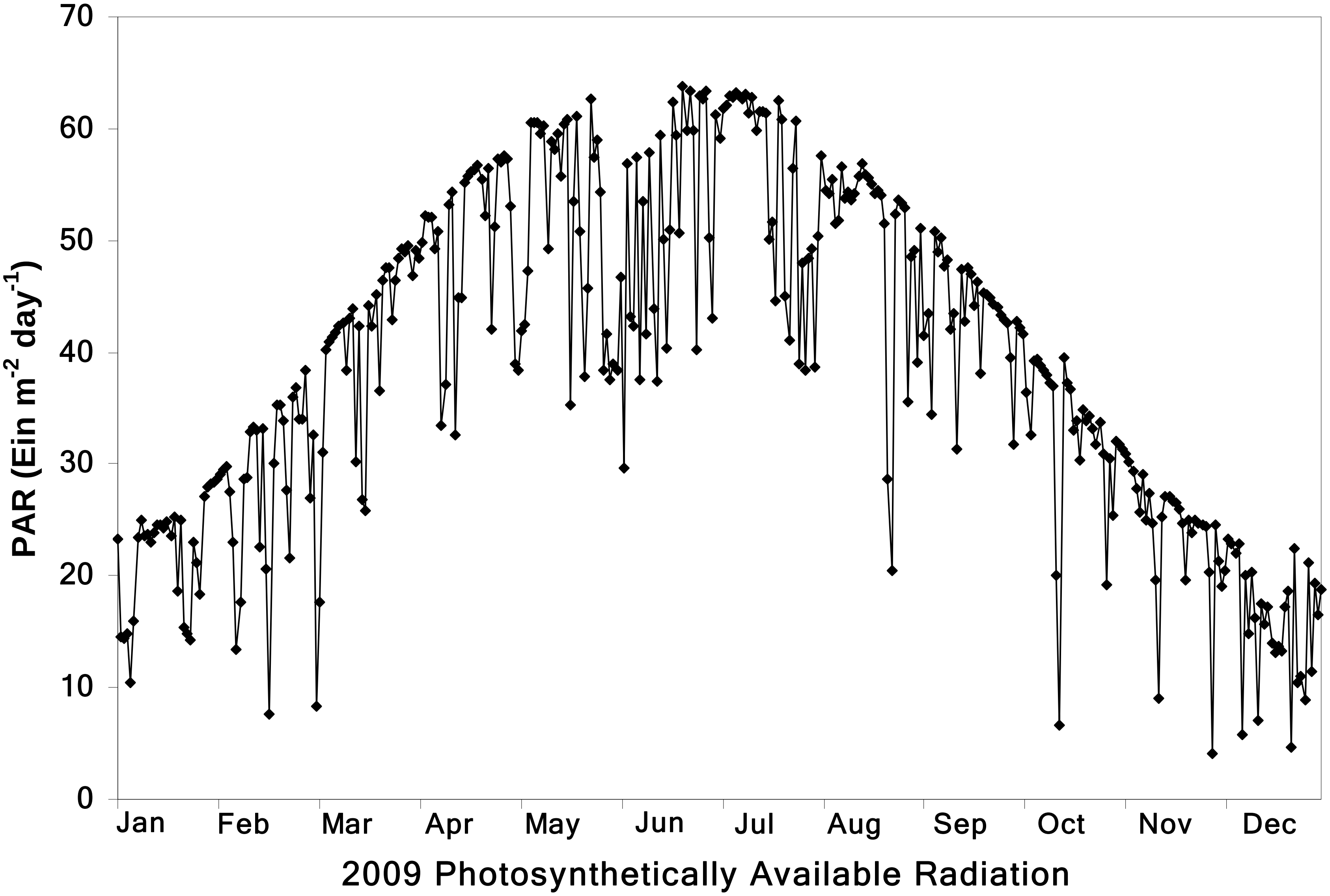
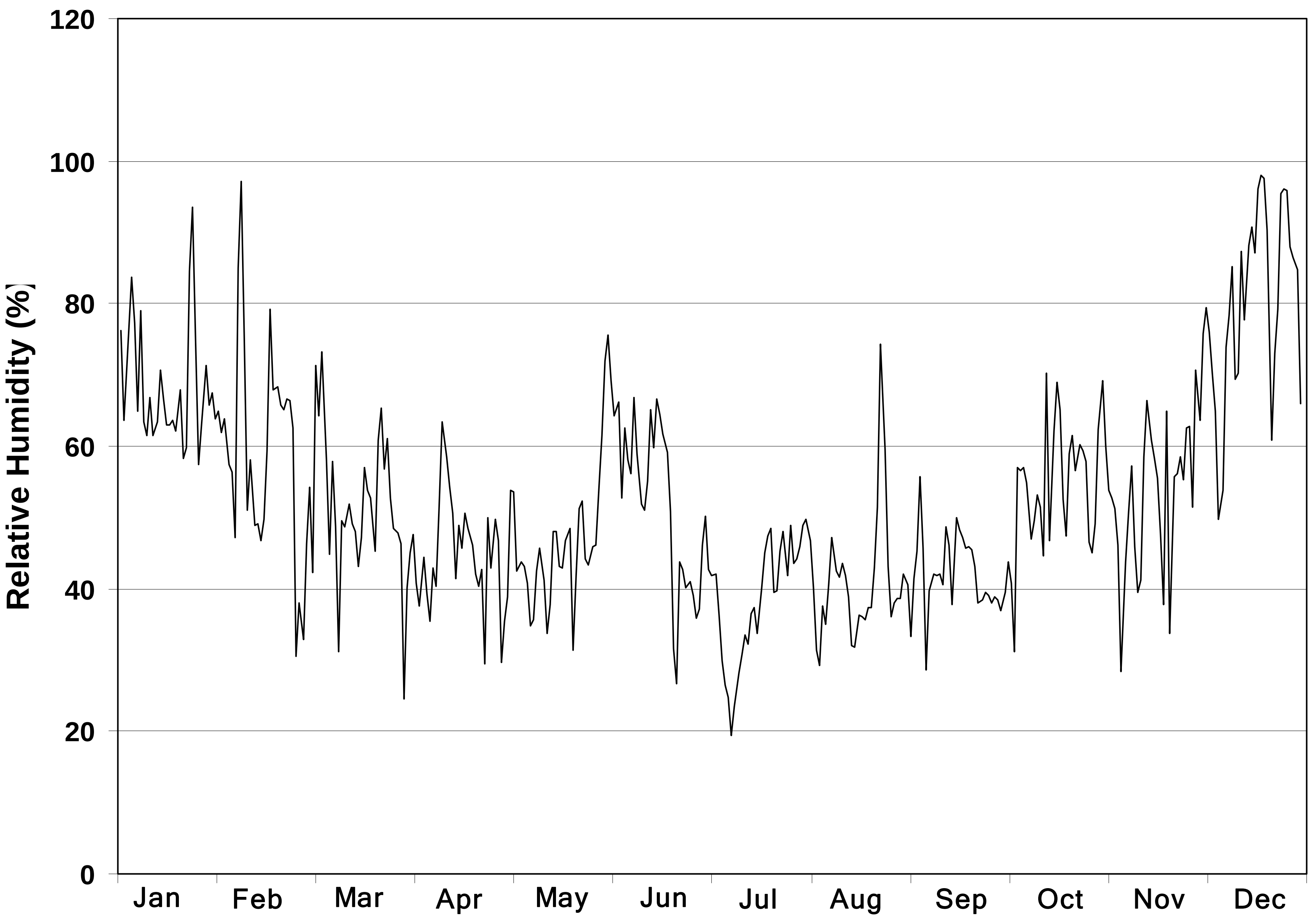

PAR (Ein m^{-2} day^{-1})
70
60
50
40
30
20
10
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009 Photosynthetically Available Radiation

Figure 4



2009 Mean Daily Relative Humidity

Figure 5

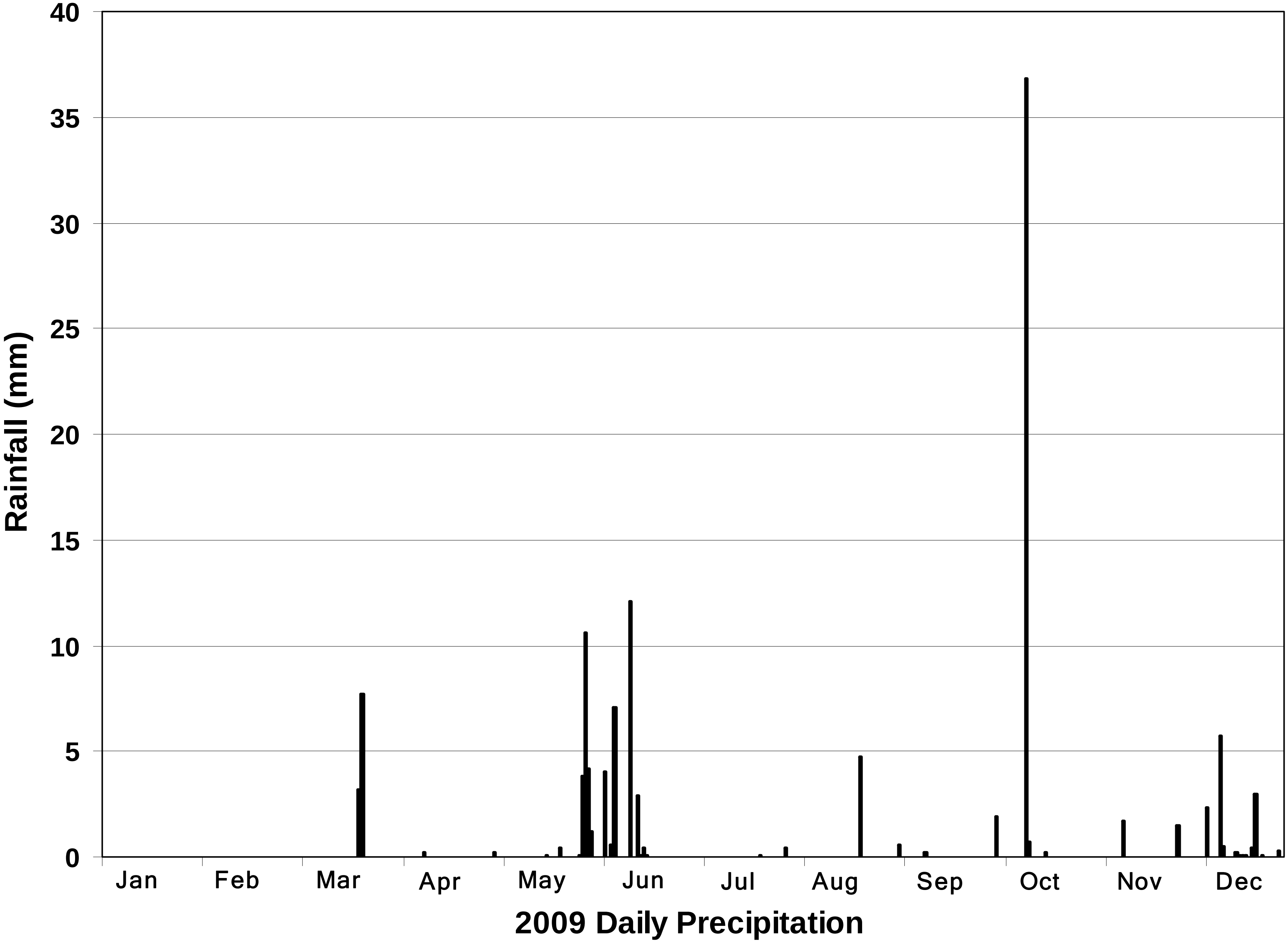
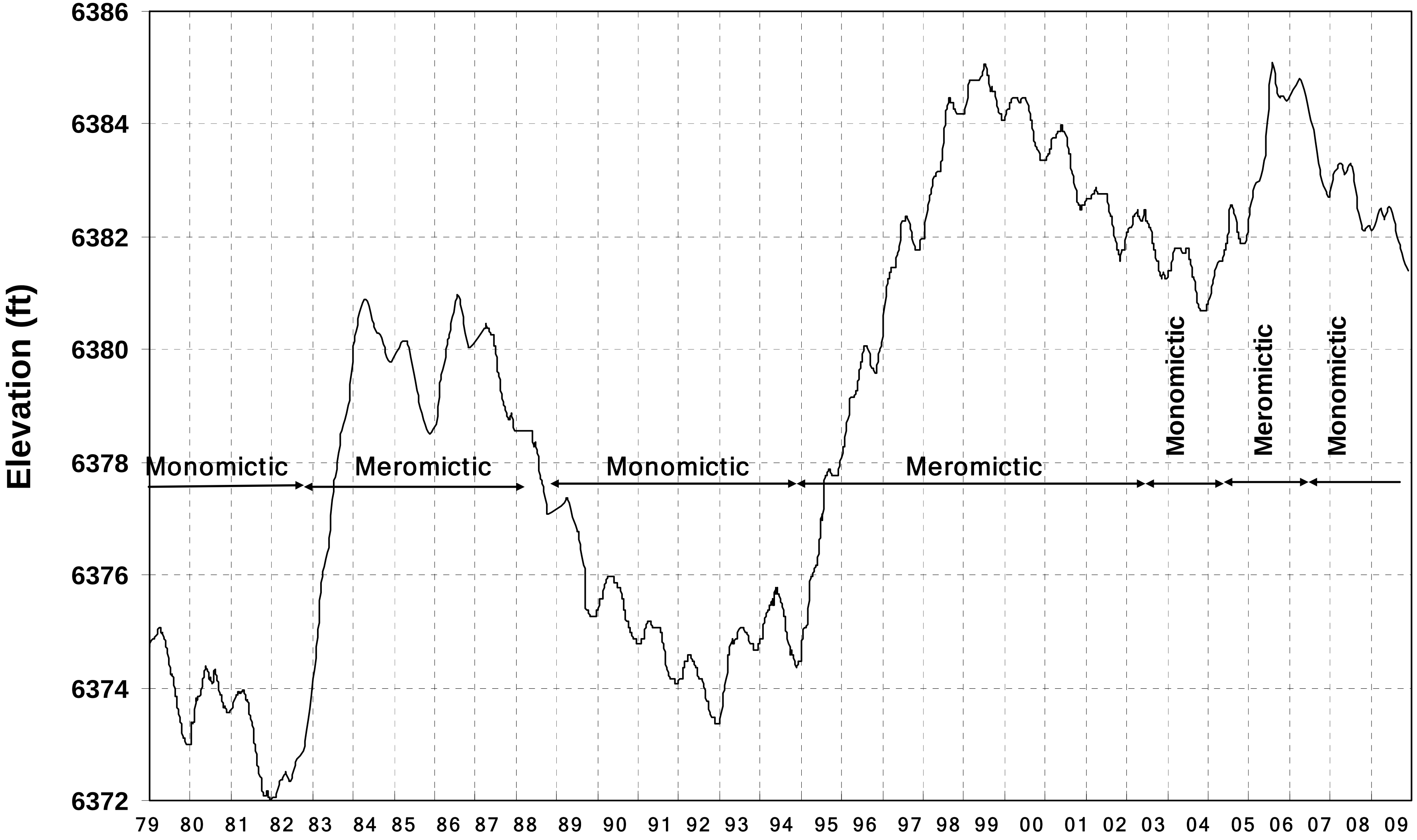
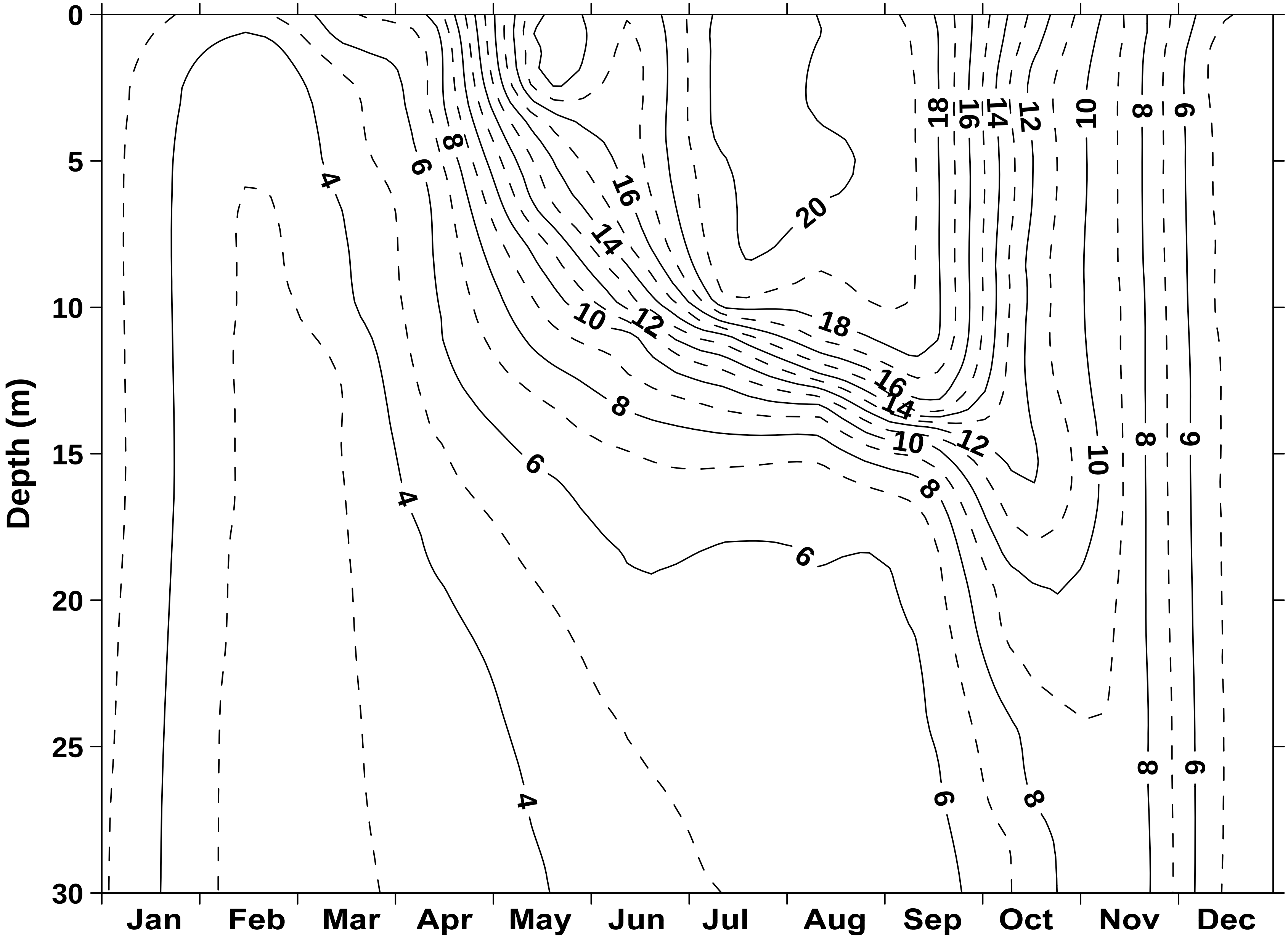

40
35
30
25
20
15
10
5
0
Rainfall (mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2009 Daily Precipitation

Figure 6



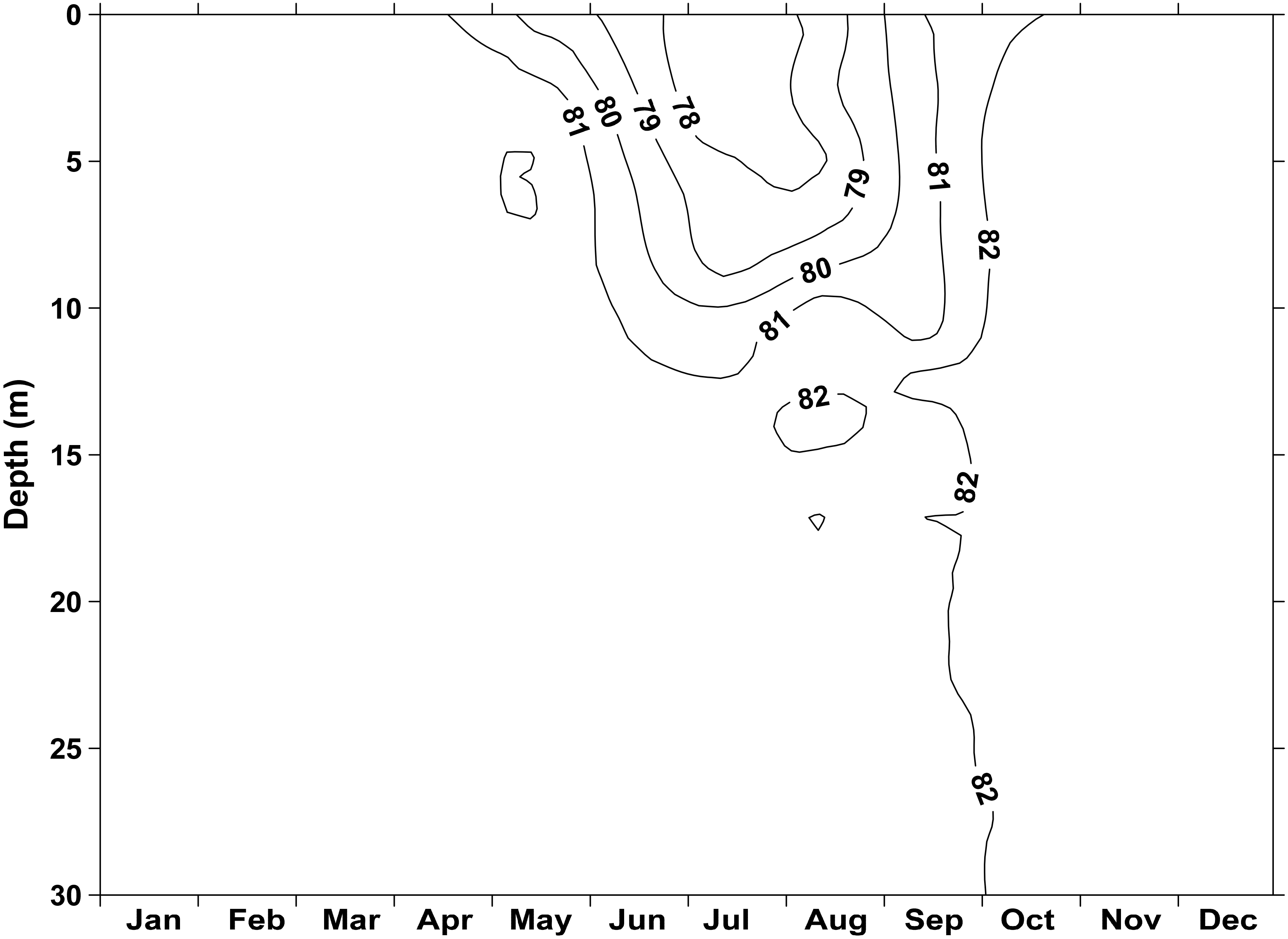
Mono Lake Surface Elevation

Figure 7



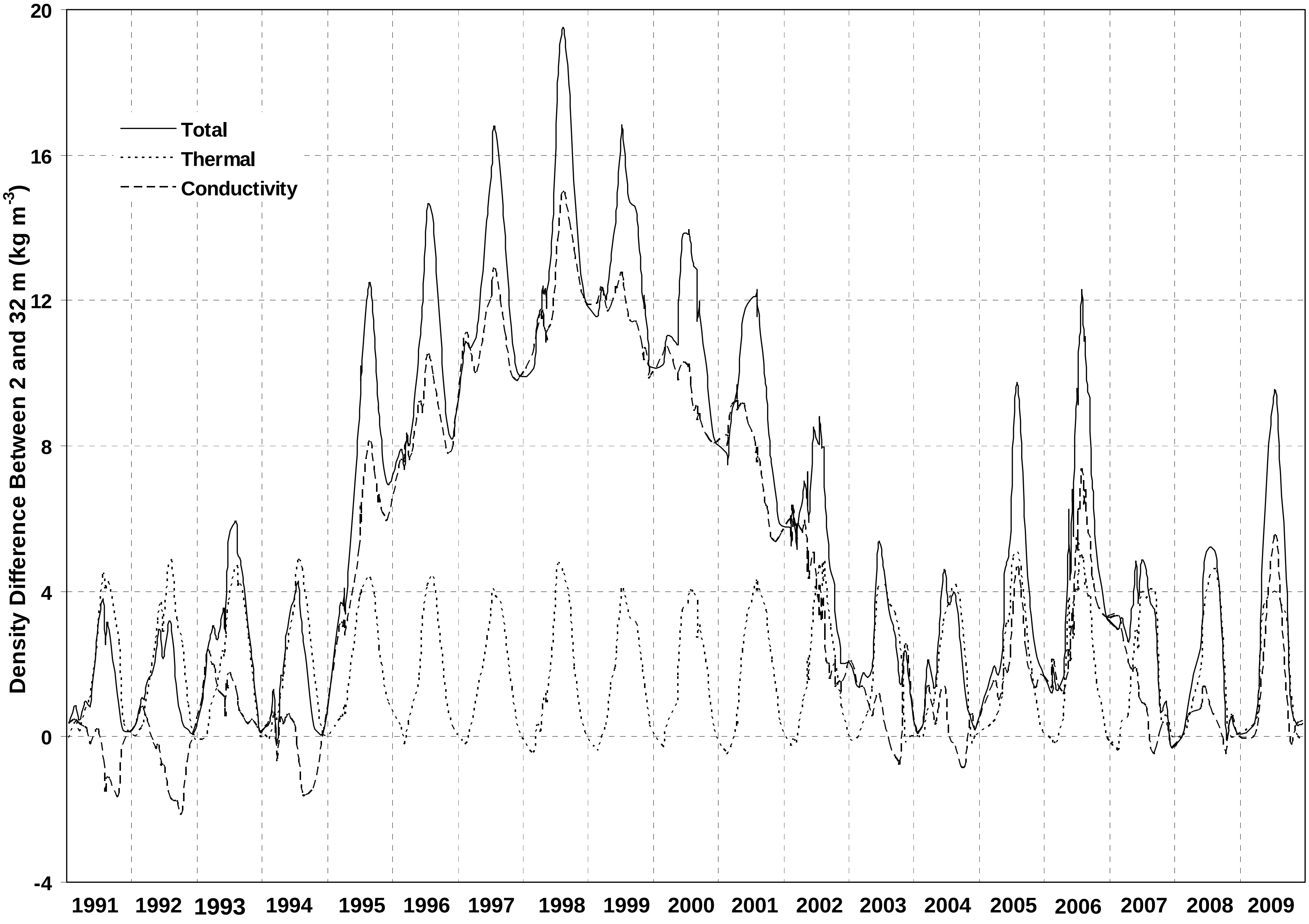
Temperature (°C) at Station 6, 2009

Figure 8



Conductivity (mS/cm) at Stations 6, 2009

Figure 9



Density Stratification (2-32 m)

Figure 10

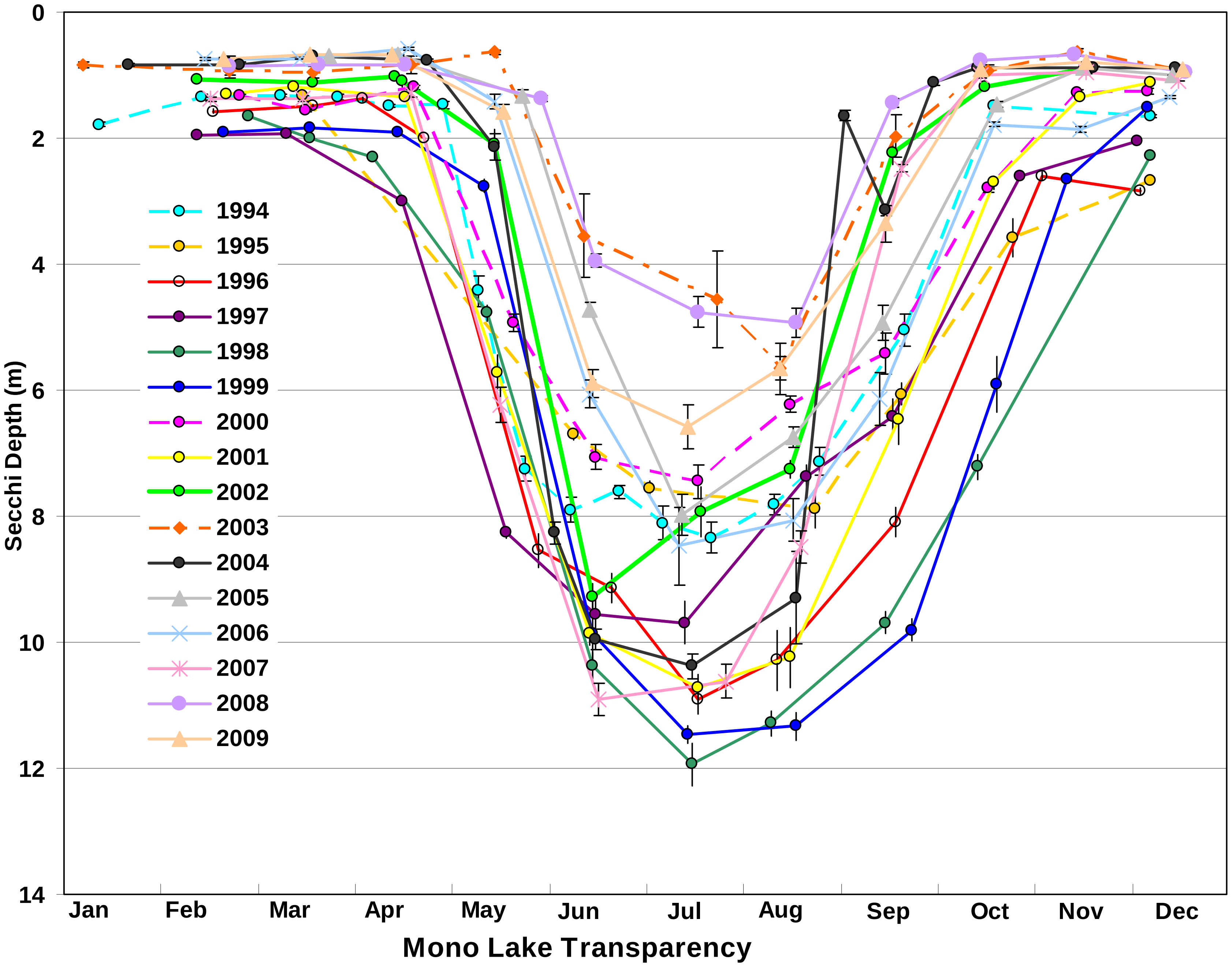
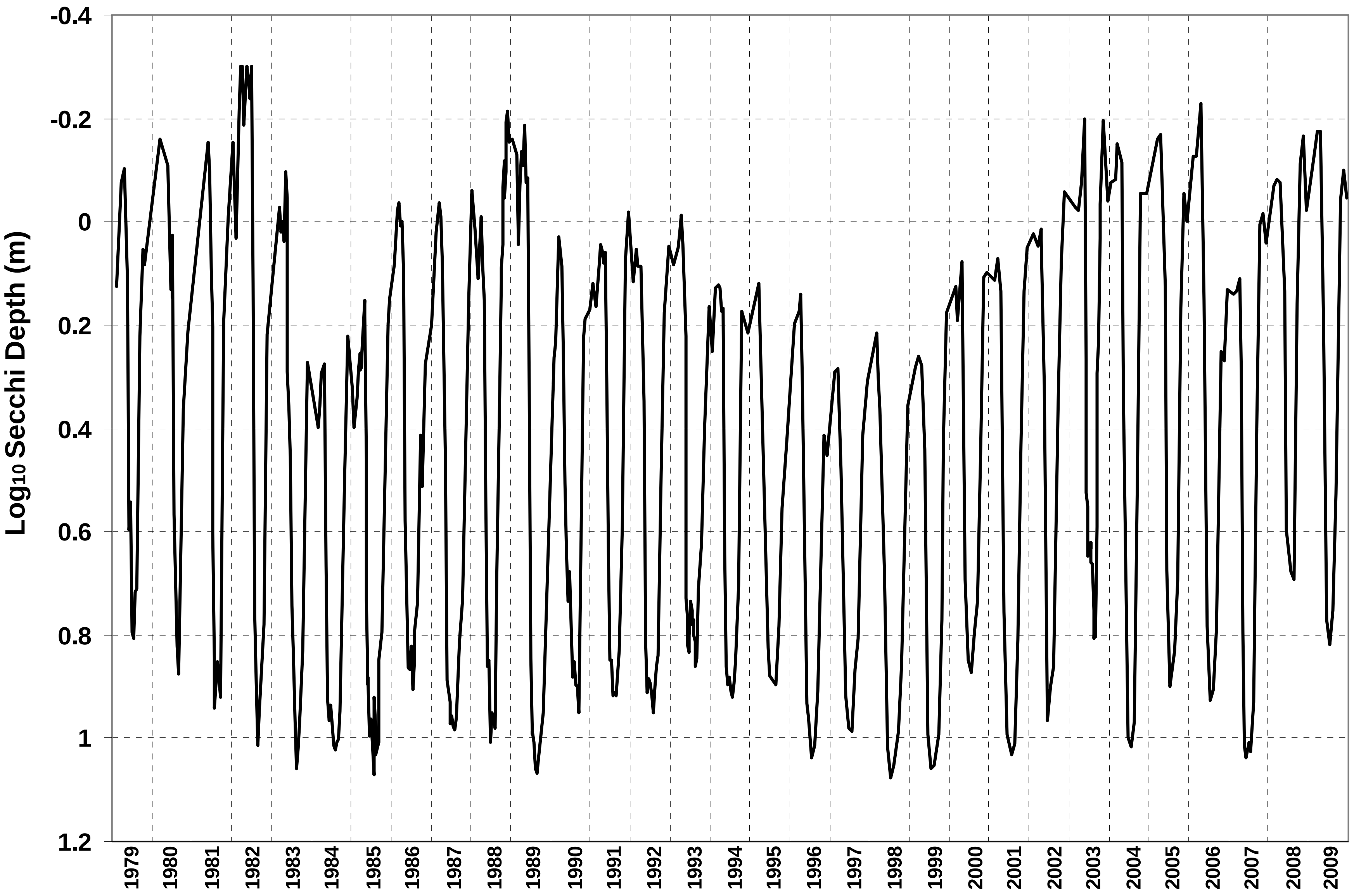
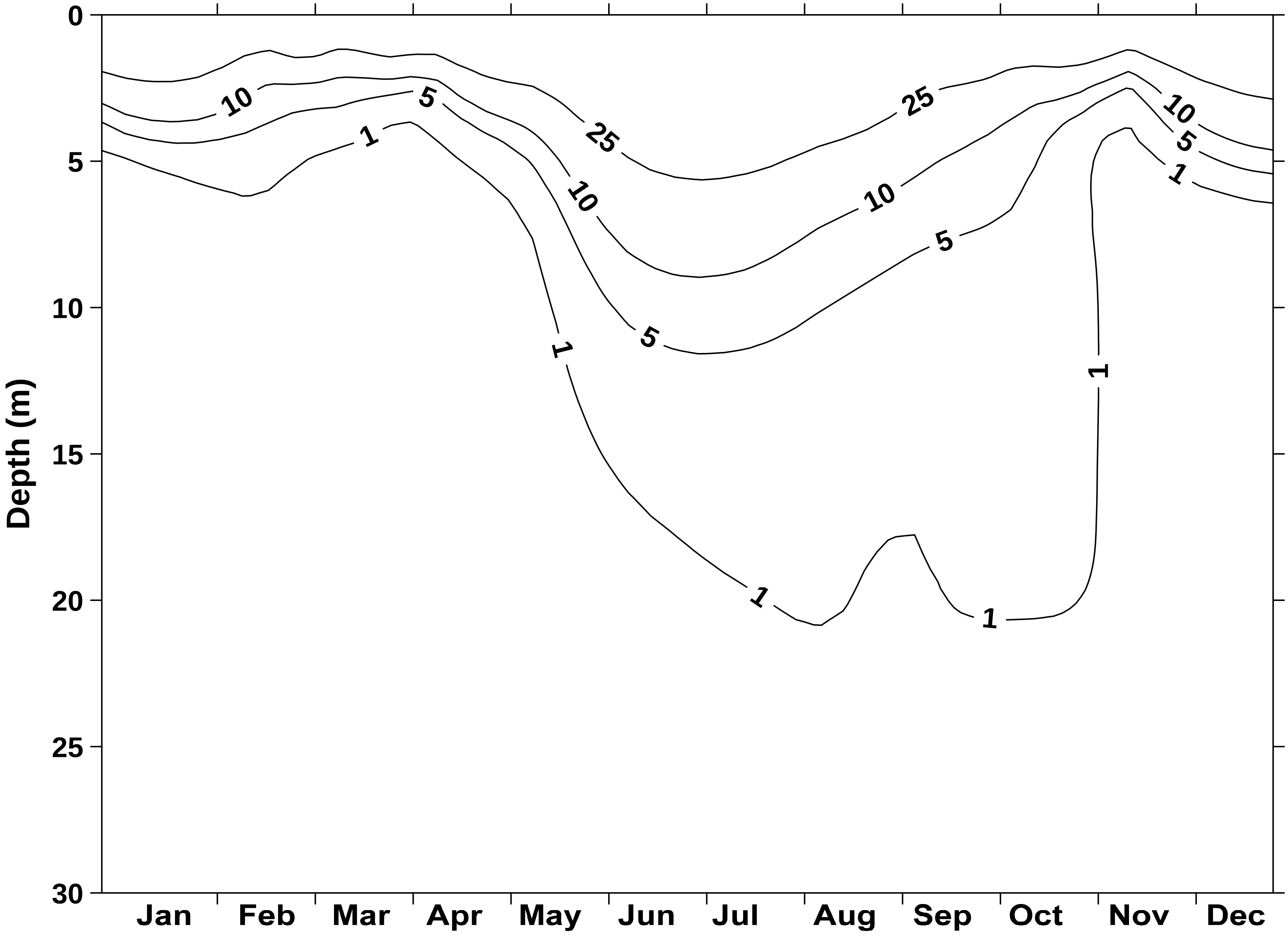

Secchi Depth (m)
0
2
4
6
8
10
12
14
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Mono Lake Transparency
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009

Figure 11



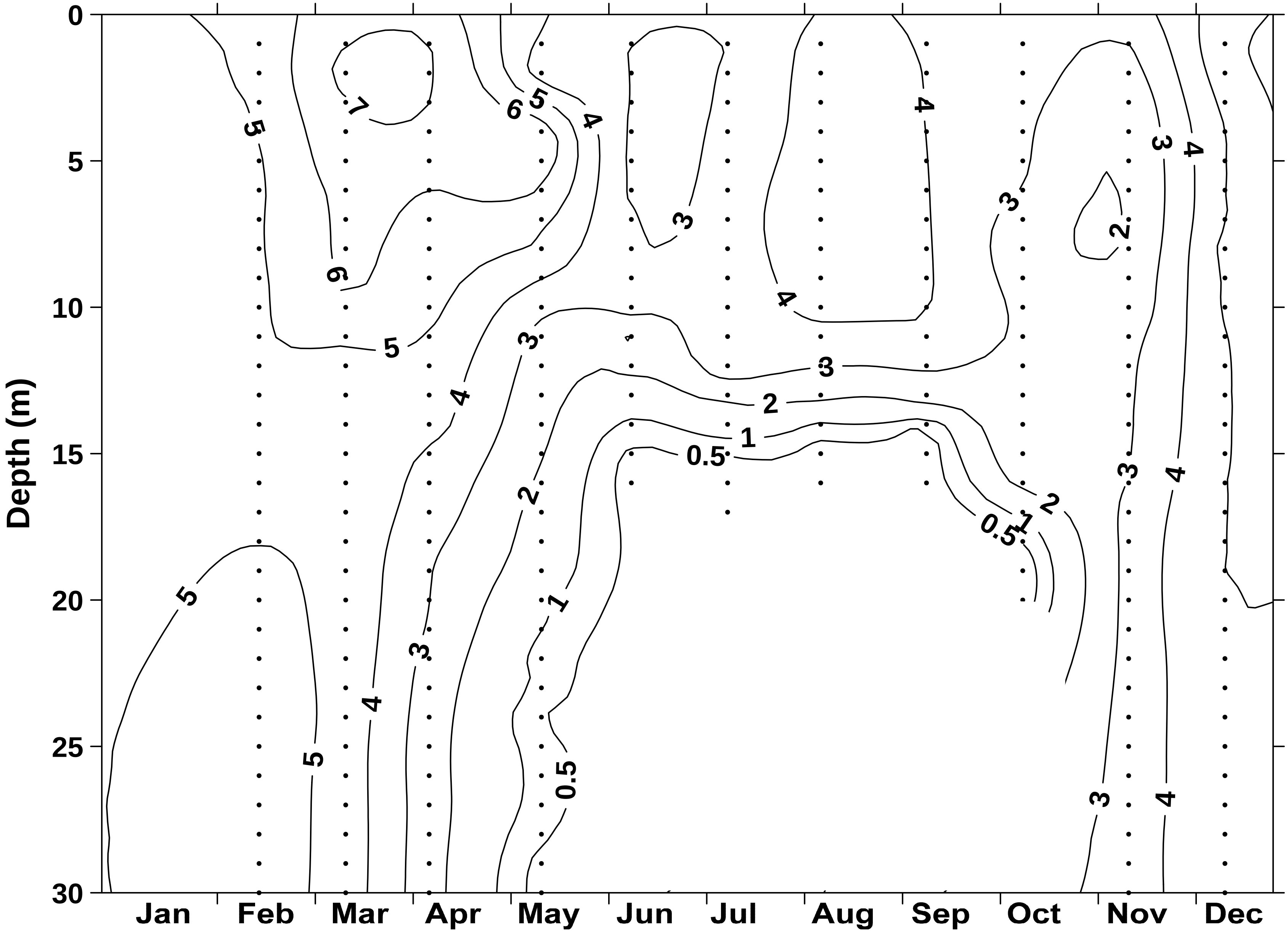
Water Transparency in Mono Lake

Figure 12



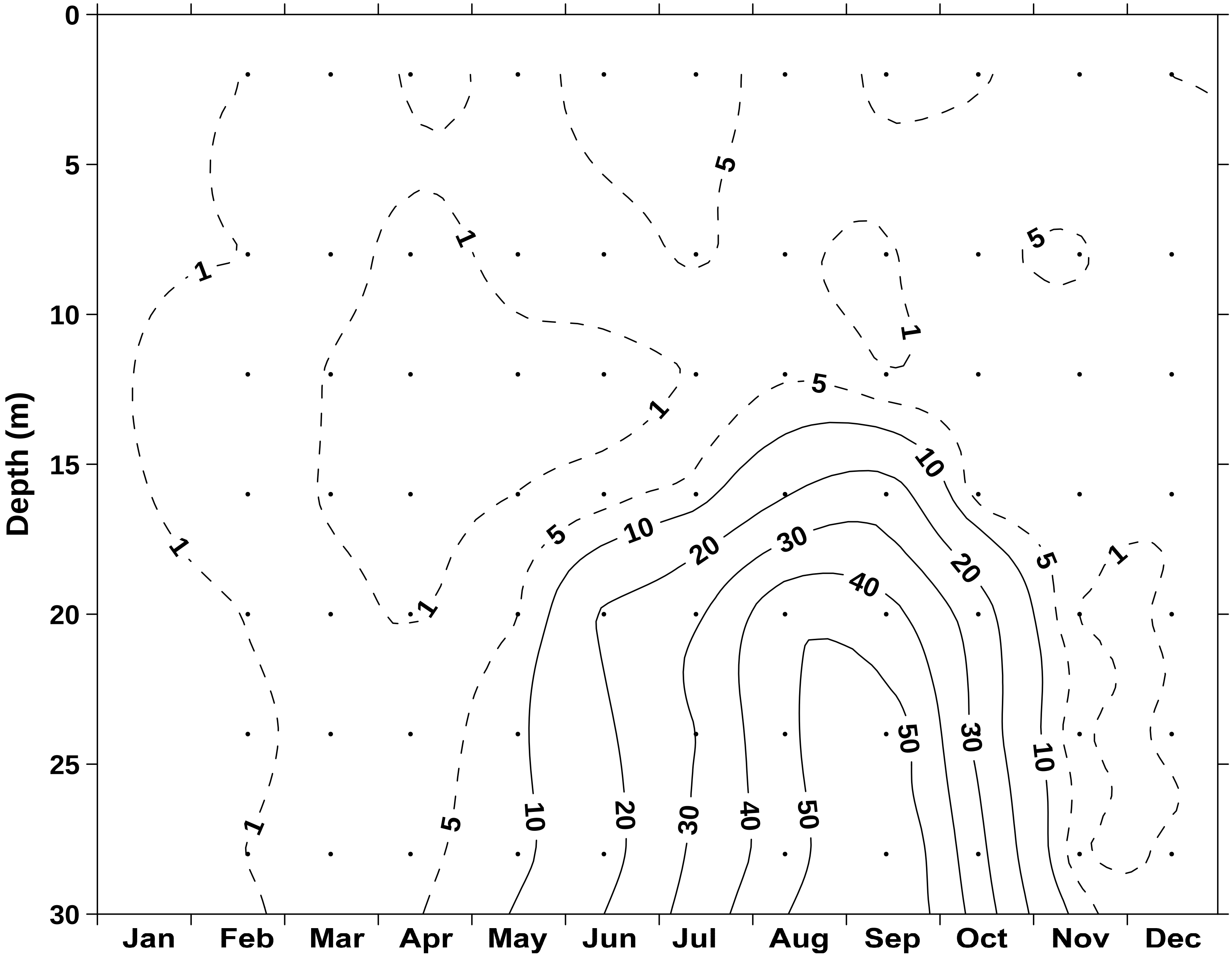
Light attenuation (% of surface) at Station 6, 2009

Figure 13



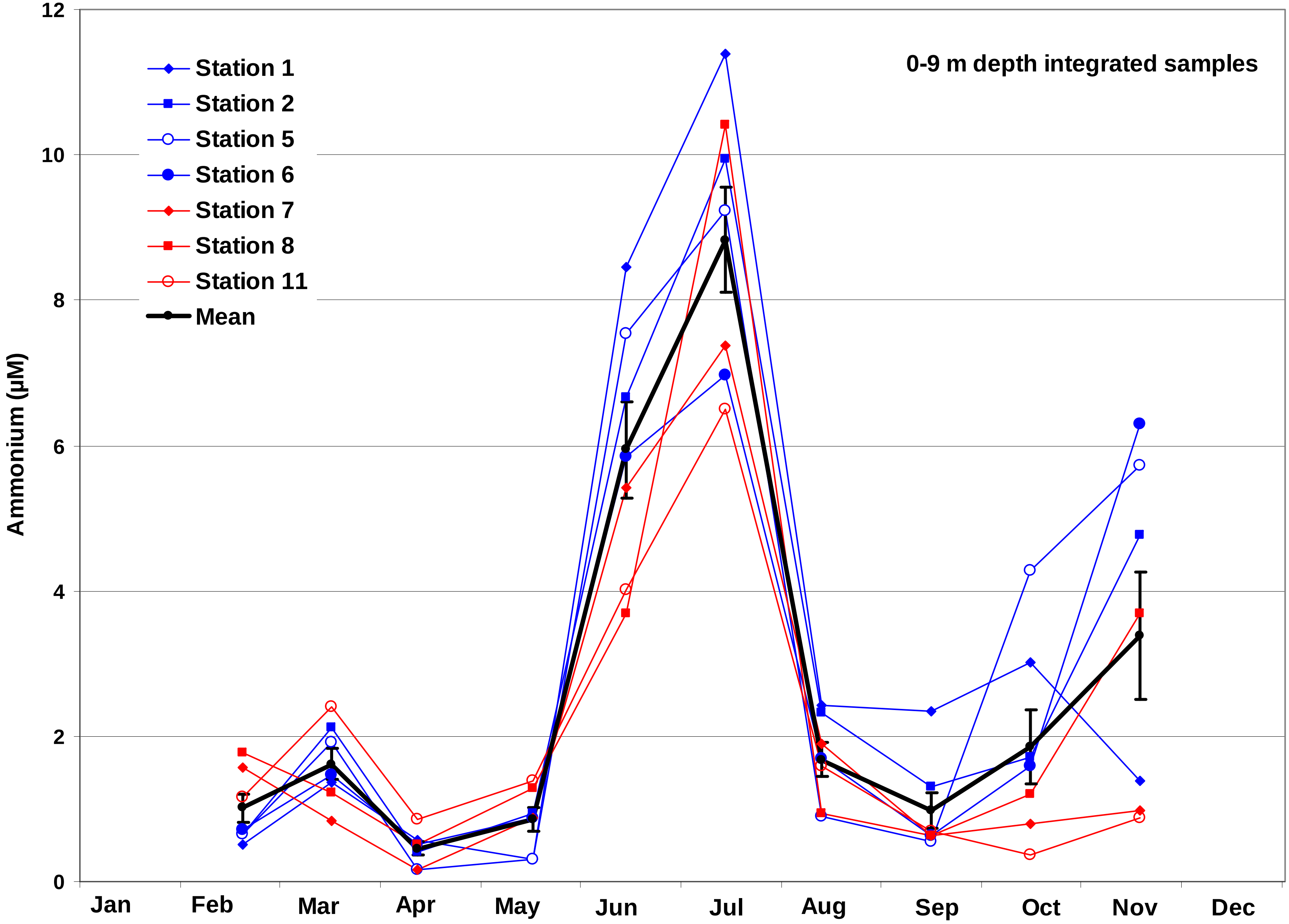
Dissolved oxygen (mg/l) at Station 6, 2009

Figure 14



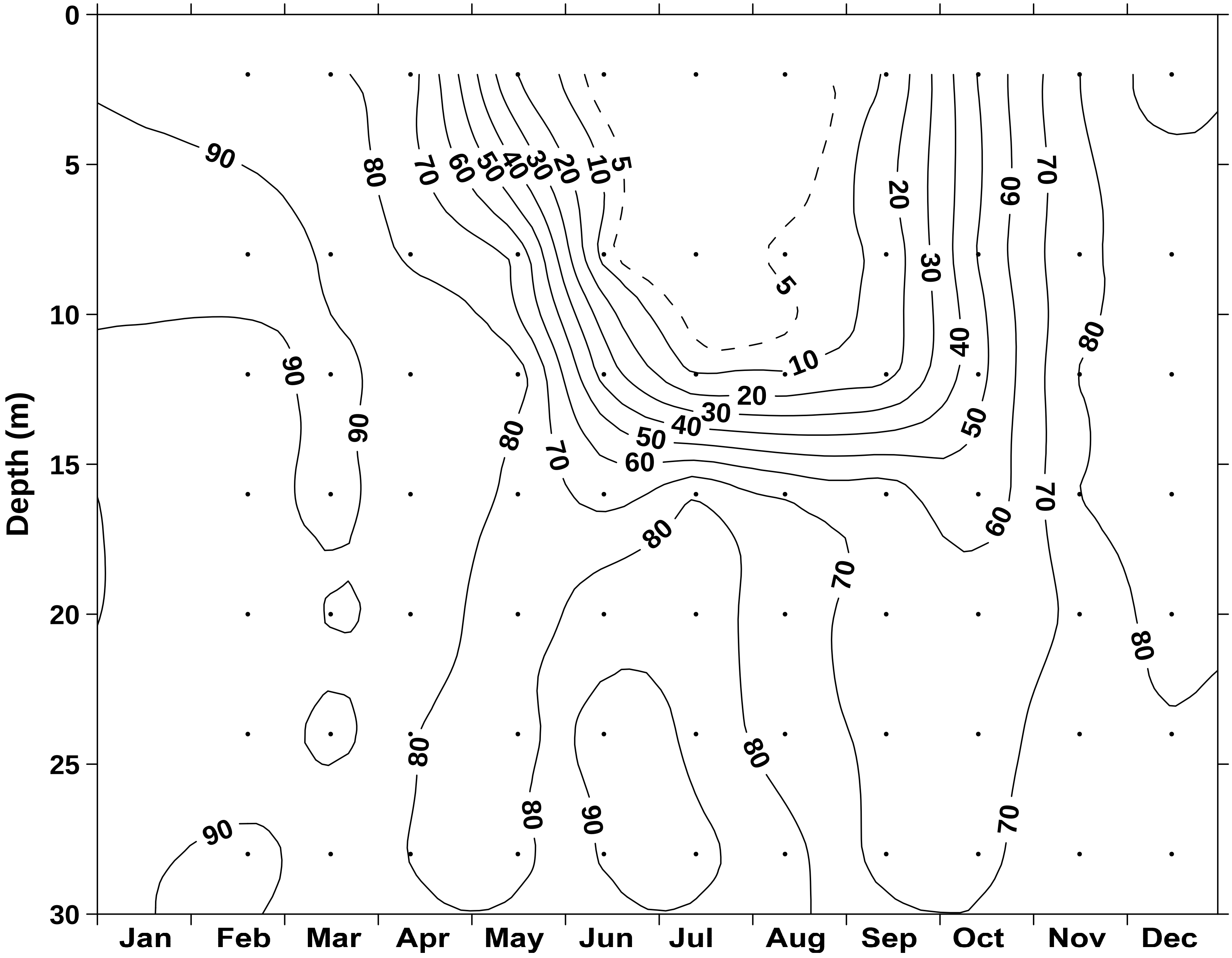
Ammonia (µM) at Station 6, 2009

Figure 15



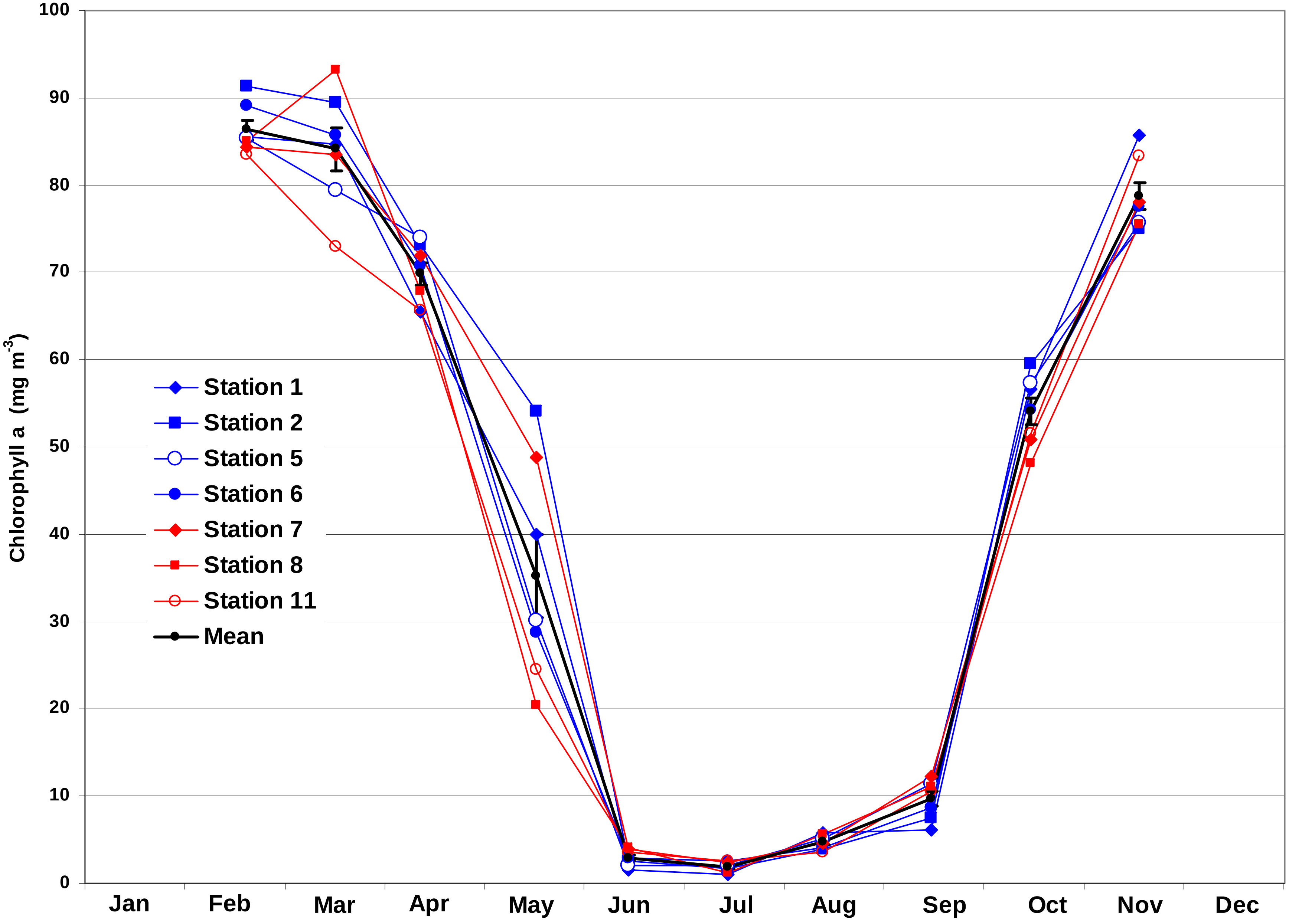
Ammonium Spatial Variability, 2009

Figure 16



Chlorophyll a (µg/l) at Station 6, 2009

Figure 17



Chlorophyll Spatial Variability, 2009

Figure 18

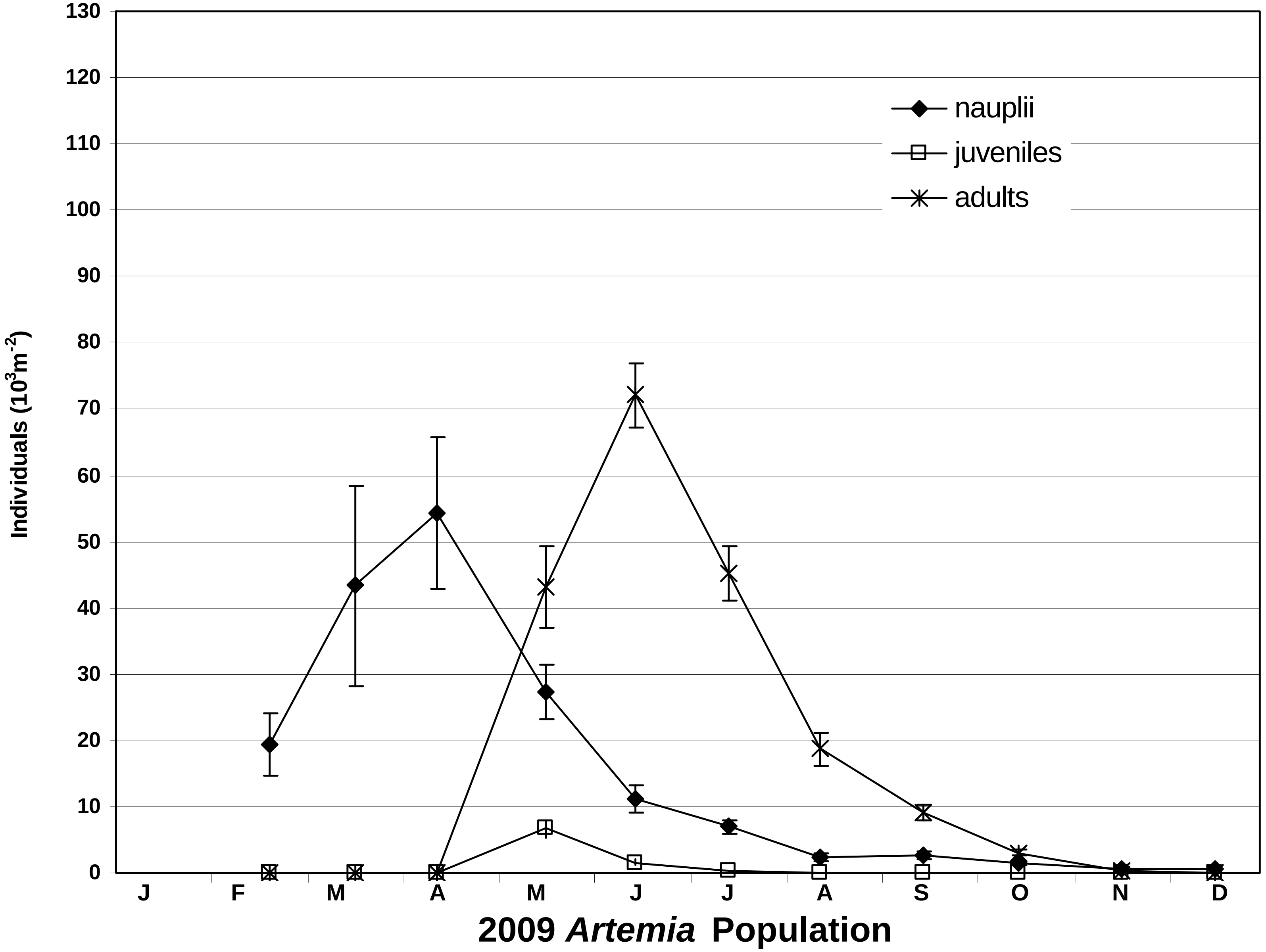
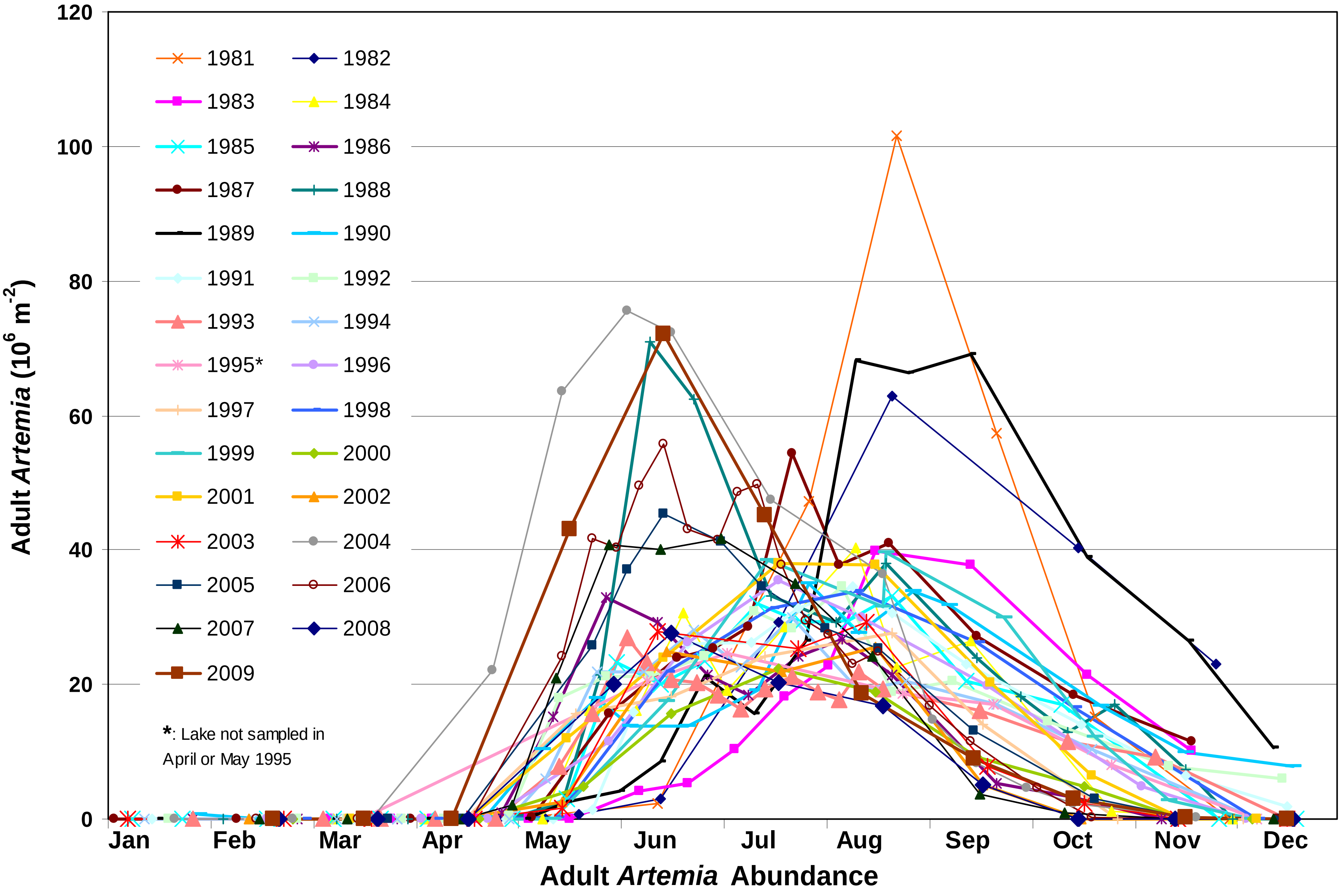

130
120
110
100
90
80
70
60
50
40
30
20
10
0
Individuals ($10^3 m^{-2}$)
nauplii
juveniles
adults
J
F
M
A
M
J
J
A
S
O
N
D
2009 *Artemia* Population

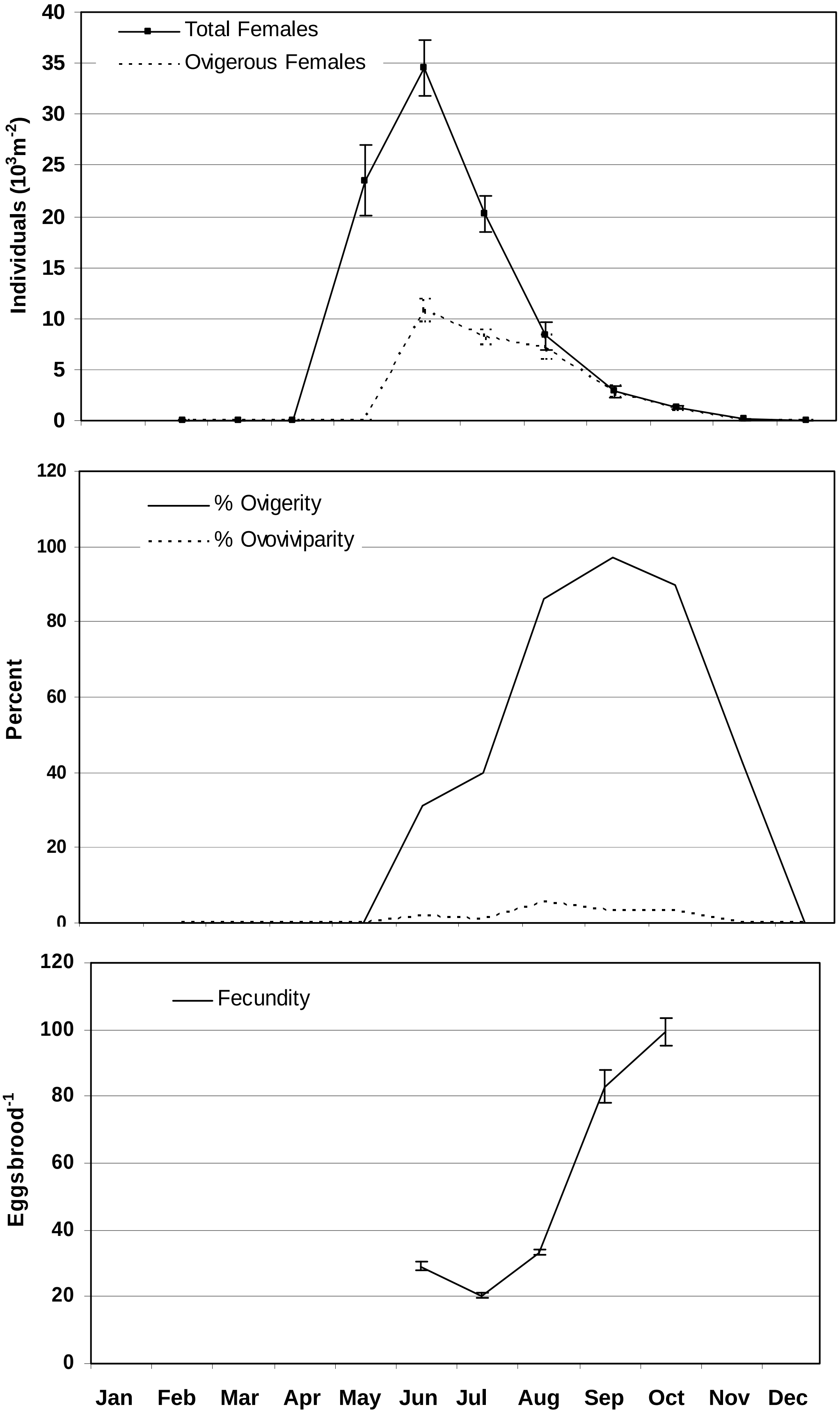
Figure 19



120
100
80
60
40
20
0
Adult Artemia (10^6 m^-2)
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995*
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
*: Lake not sampled in April or May 1995
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Adult Artemia Abundance

Figure 20

Figure 21



***Artemia* Reproductive Parameters**

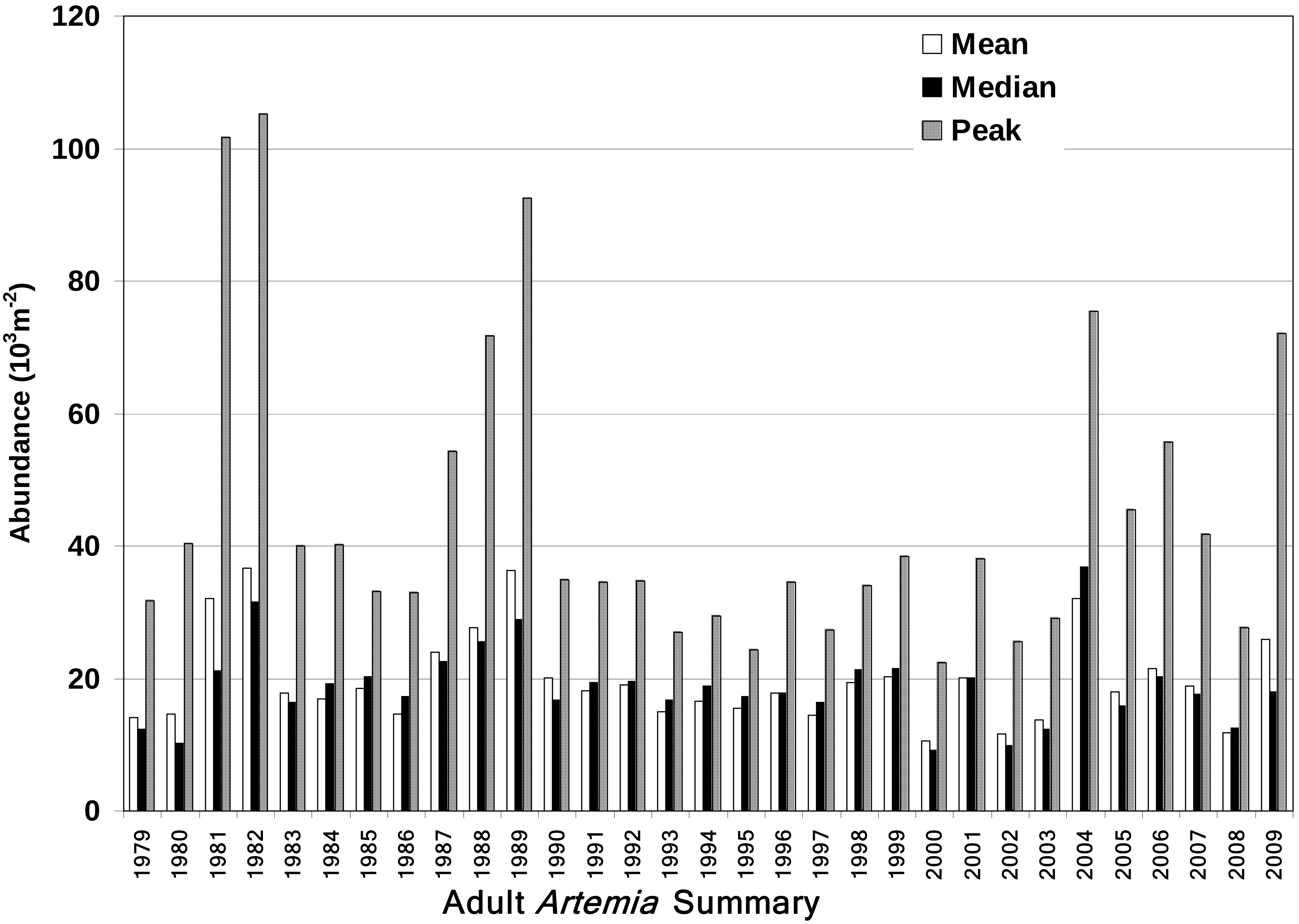
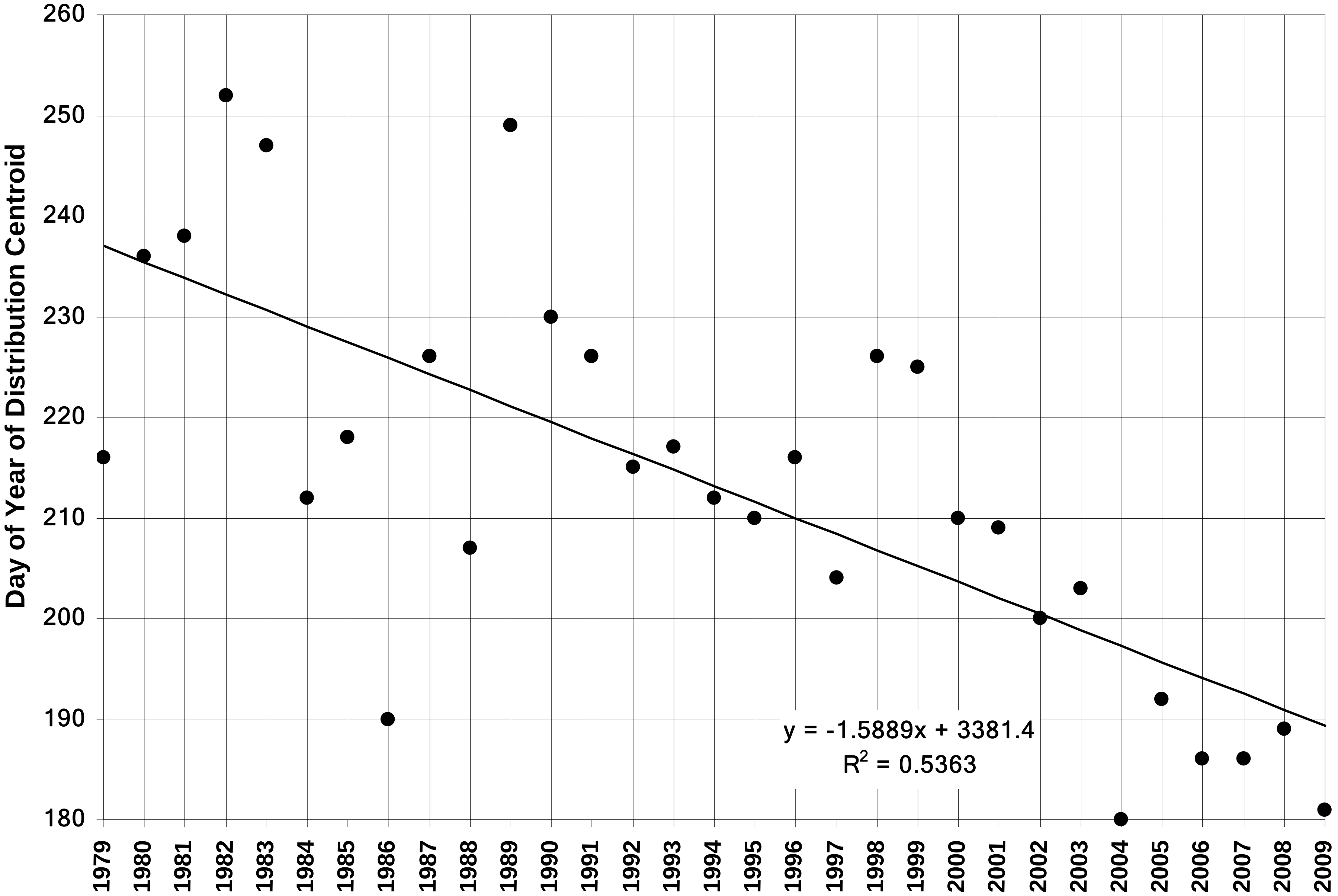

Mean
Median
Peak
Abundance ($10^3 m^{-2}$)
0
20
40
60
80
100
120
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Adult *Artemia* Summary

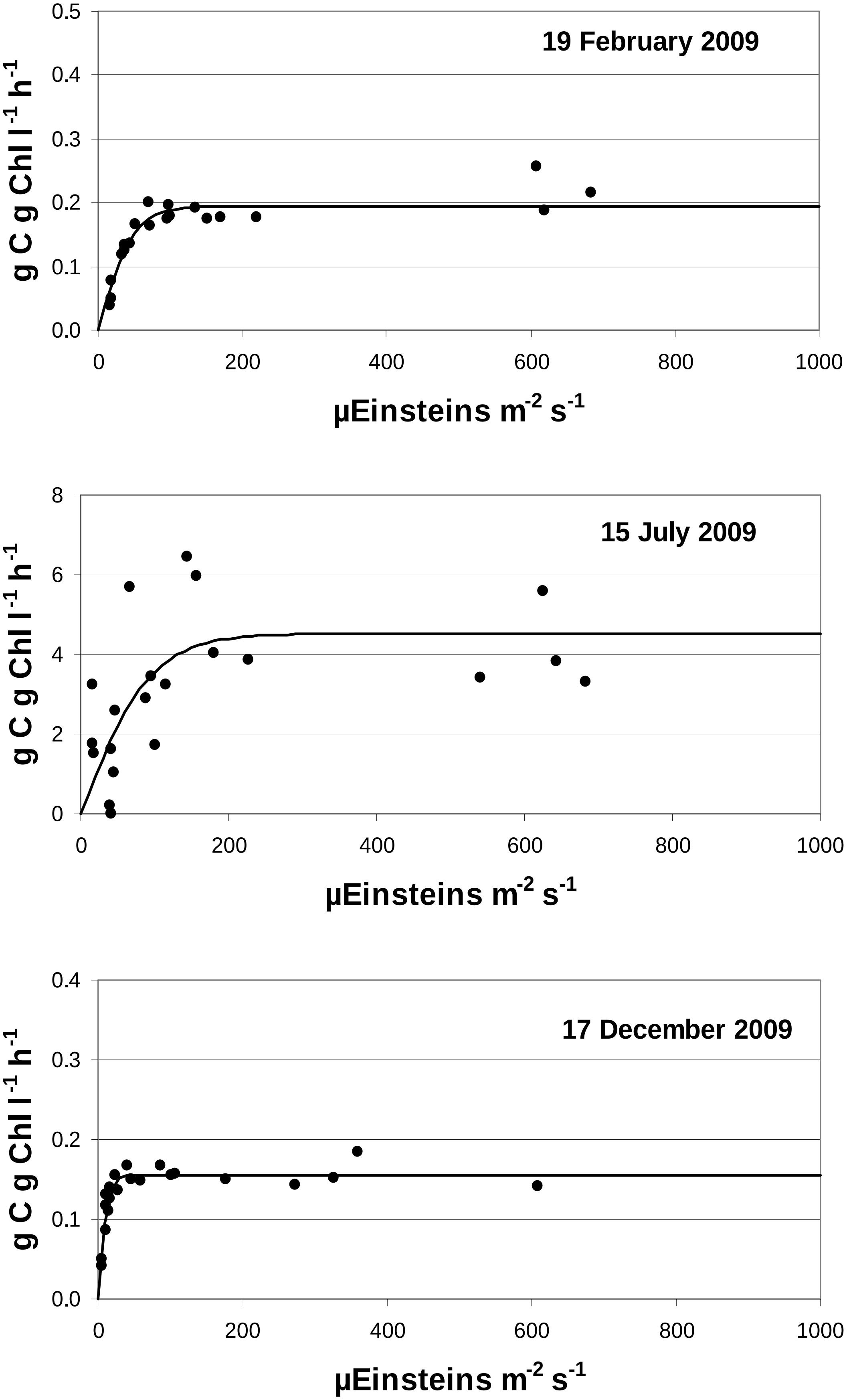
Figure 22



Adult *Artemia* Temporal Distribution

Figure 23

Figure 24



Photosynthetic Rates

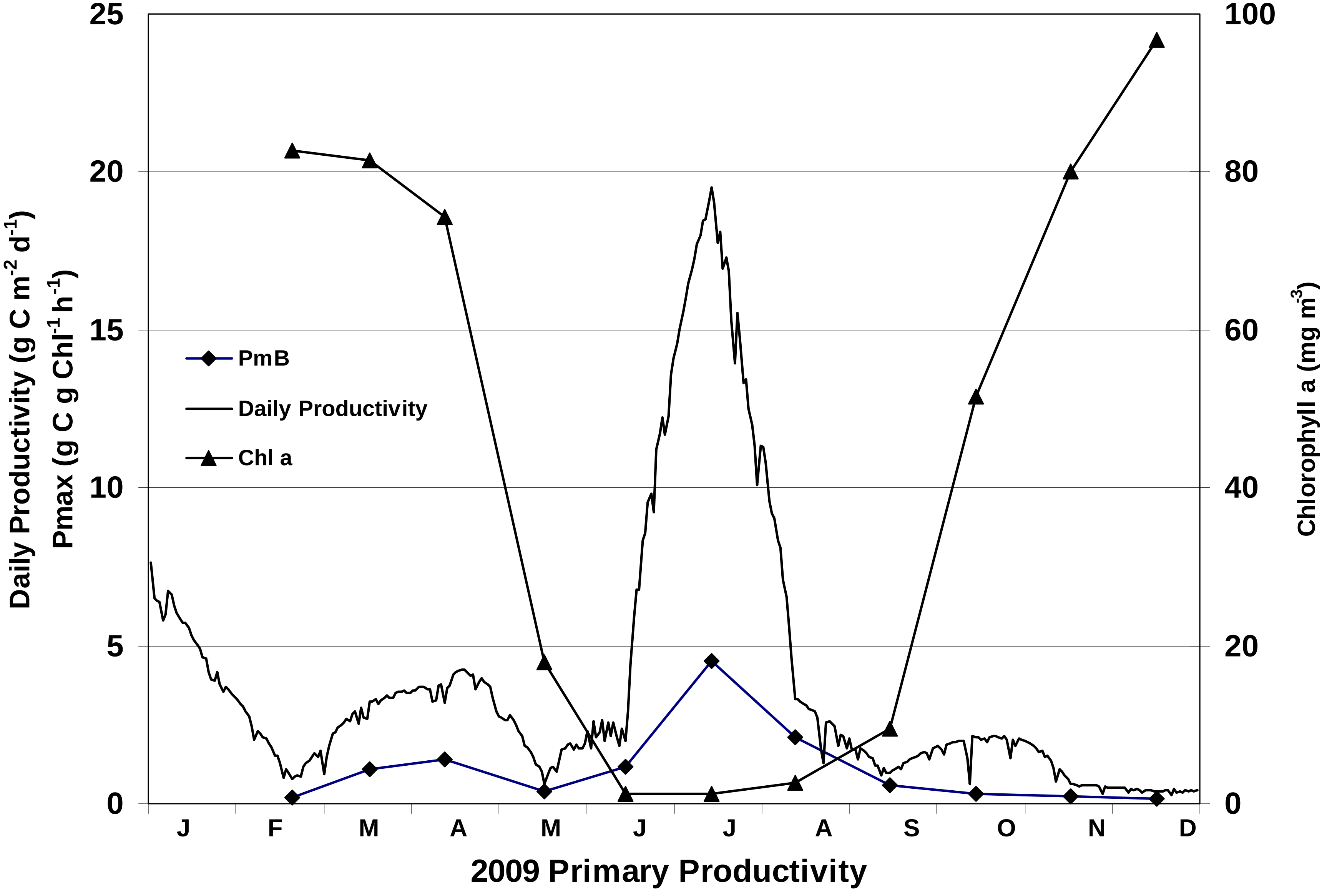
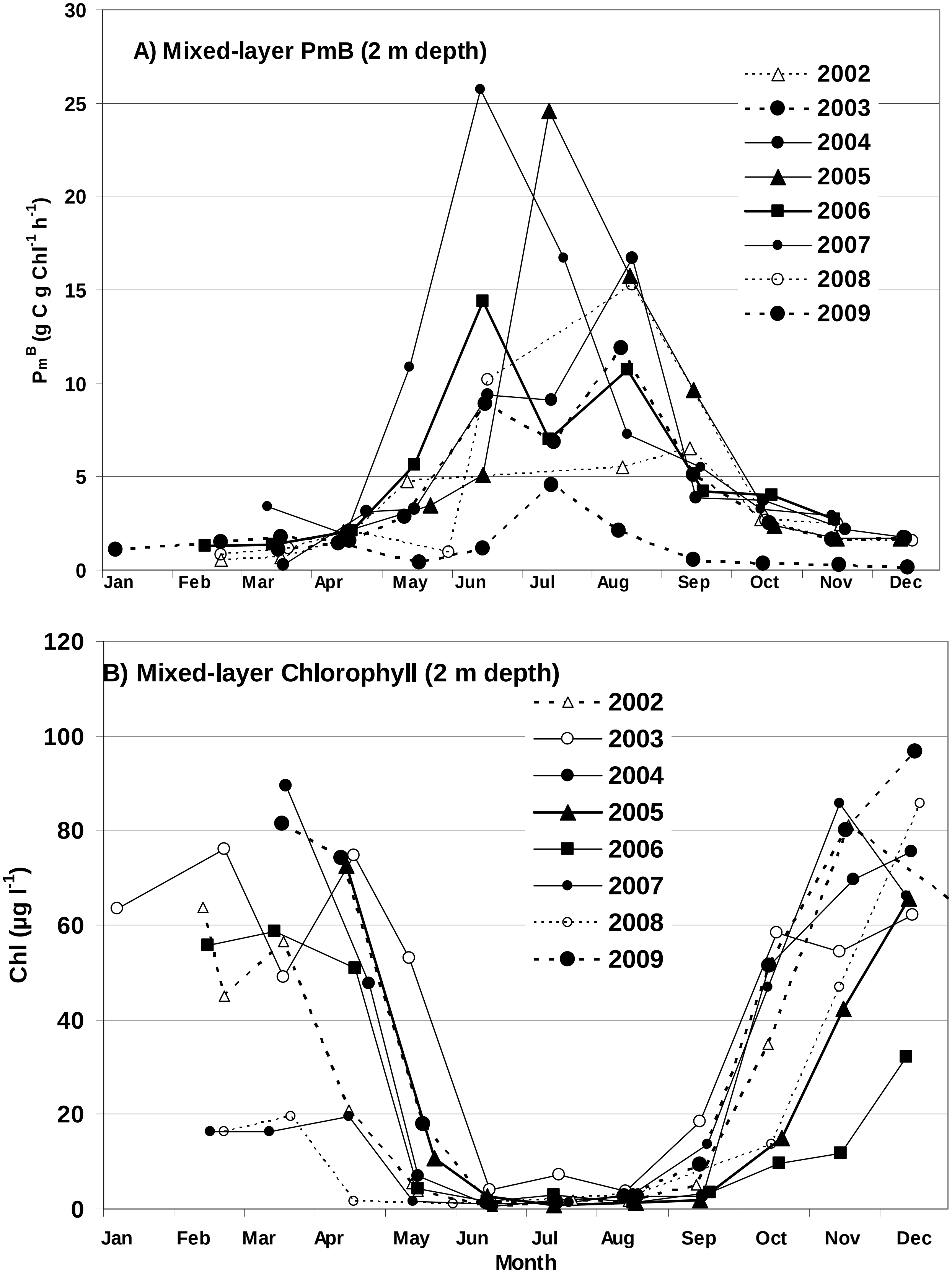

25
20
15
10
5
0
Daily Productivity (g C m^{-2} d^{-1})
Pmax (g C g Chl^{-1} h^{-1})
100
80
60
40
20
0
Chlorophyll a (mg m^{-3})
PmB
Daily Productivity
Chl a
J
F
M
A
M
J
J
A
S
O
N
D
2009 Primary Productivity

Figure 25

Figure 26


A) Mixed-layer PmB (2 m depth)
P_m^B (g C g Chl^{-1} h^{-1})
0
5
10
15
20
25
30
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2002
2003
2004
2005
2006
2007
2008
2009
B) Mixed-layer Chlorophyll (2 m depth)
Chl (µg l^{-1})
0
20
40
60
80
100
120
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2002
2003
2004
2005
2006
2007
2008
2009

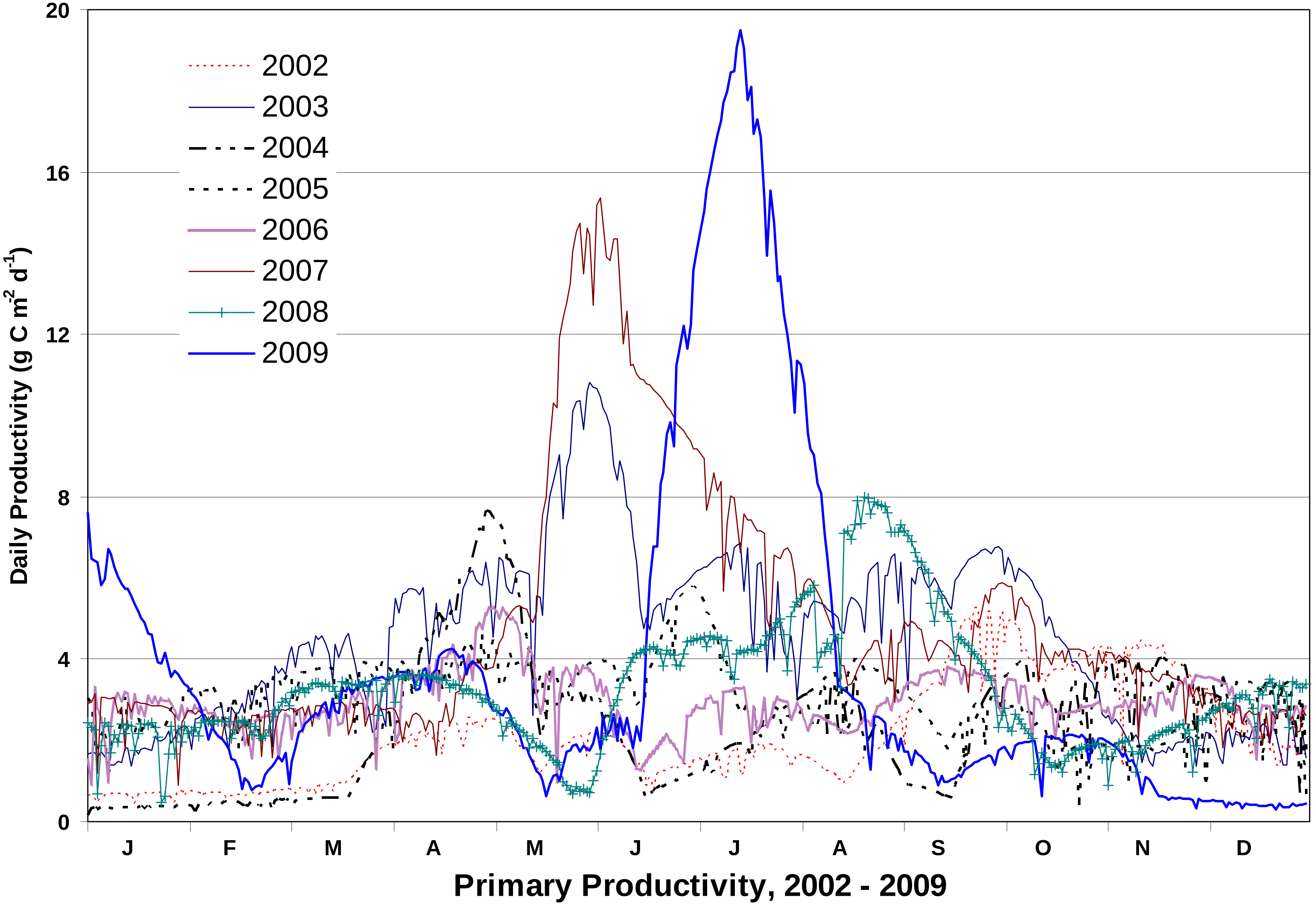

2002
2003
2004
2005
2006
2007
2008
2009
Daily Productivity (g C m^{-2} d^{-1})
20
16
12
8
4
0
J
F
M
A
M
J
J
A
S
O
N
D
Primary Productivity, 2002 - 2009

Figure 27

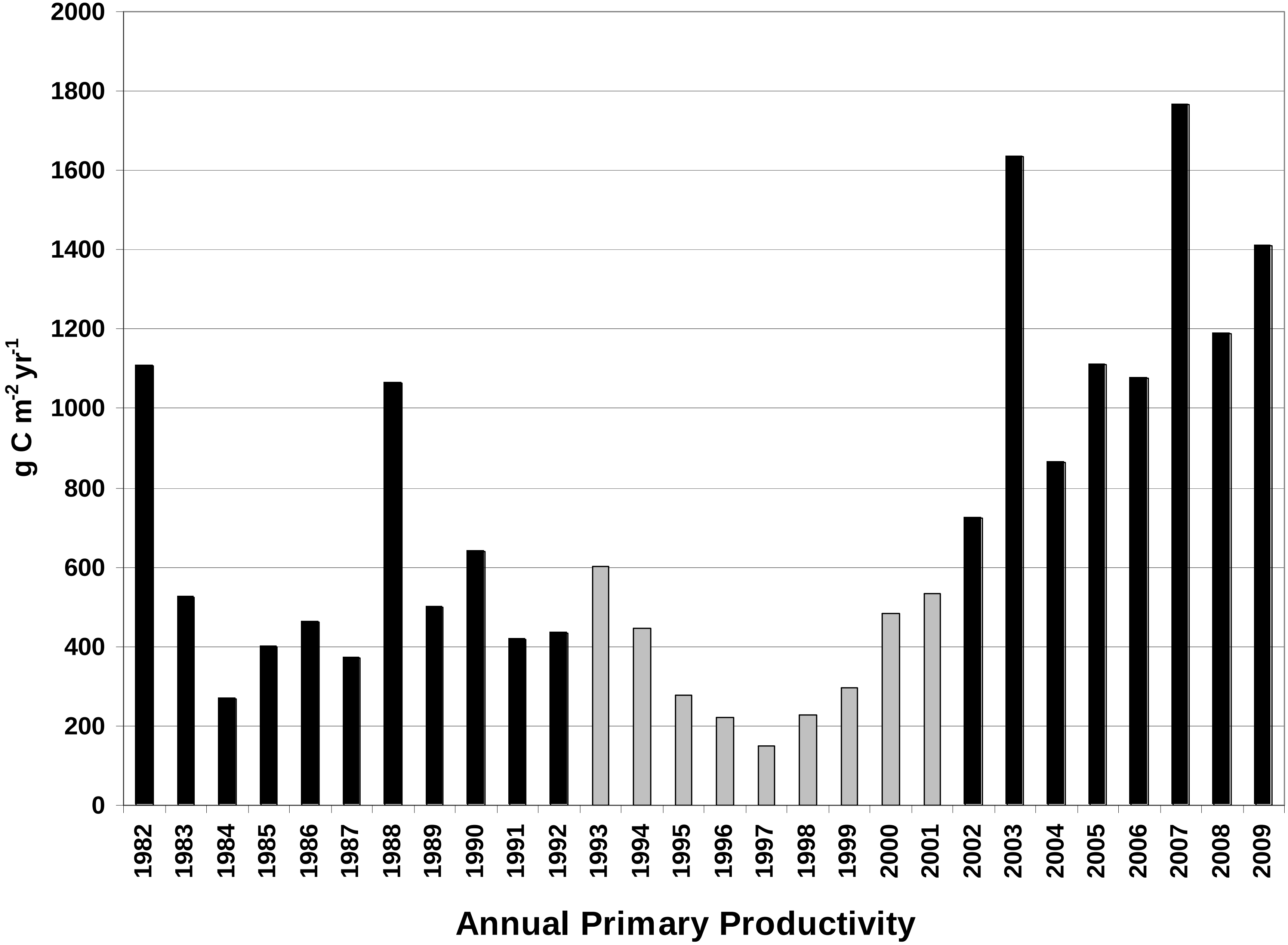
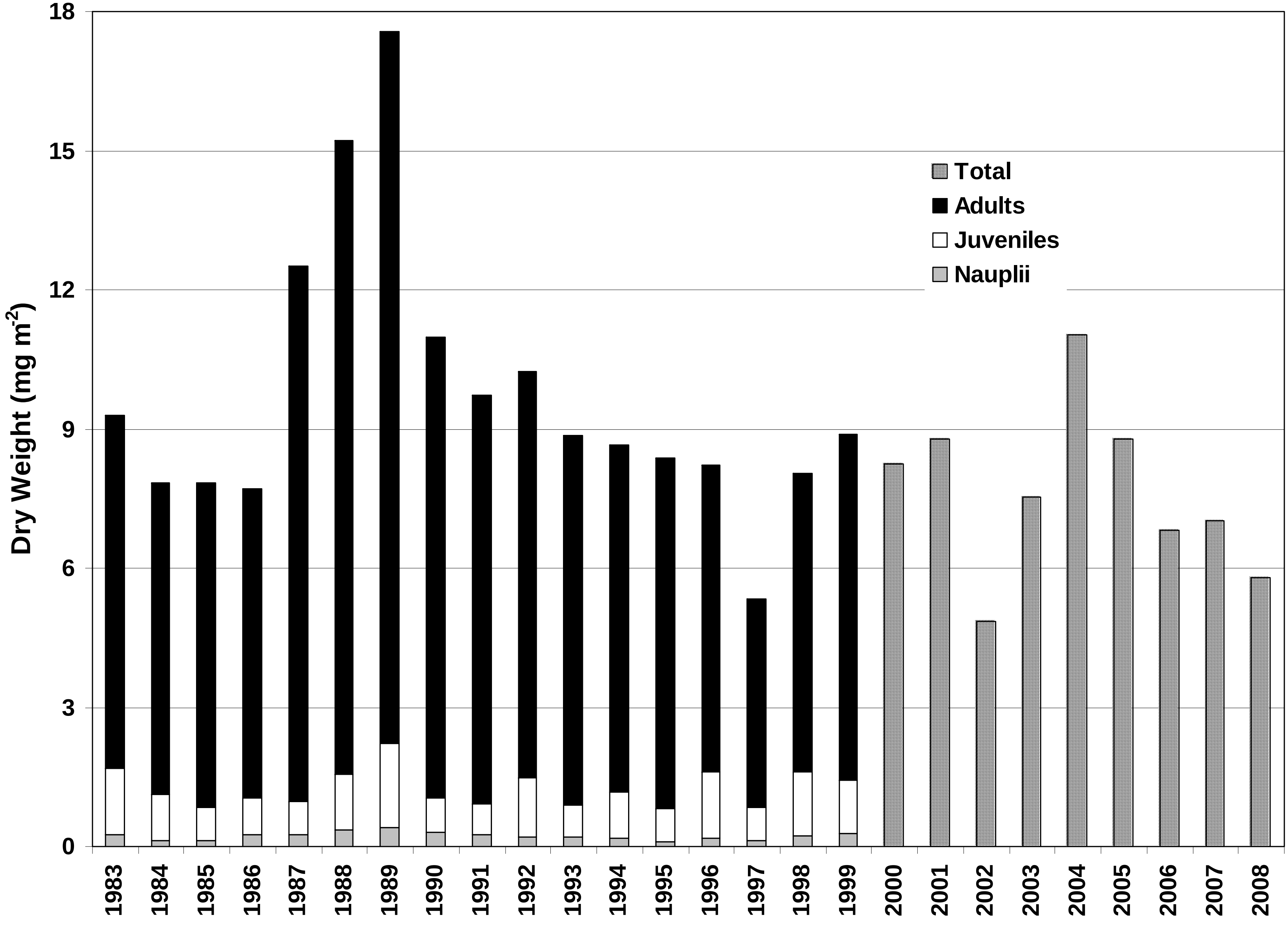

2000
1800
1600
1400
1200
1000
800
600
400
200
0
g C m^{-2} yr^{-1}
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Annual Primary Productivity

Figure 28



Mean Annual *Artemia* Biomass

Figure 29

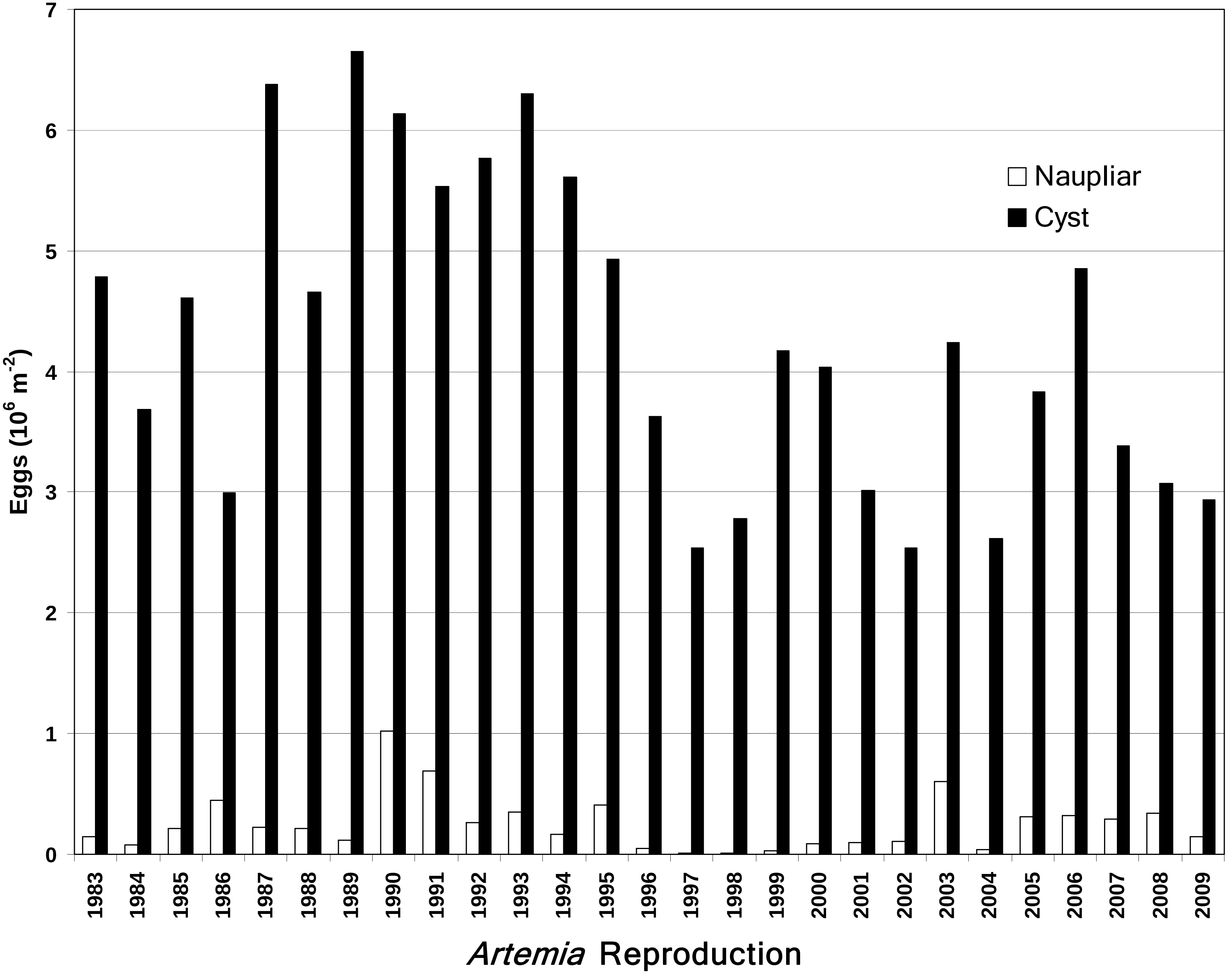

7
6
5
4
3
2
1
0
Eggs (10^6 m^{-2})
☐ Naupliar
■ Cyst
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Artemia Reproduction

Figure 30

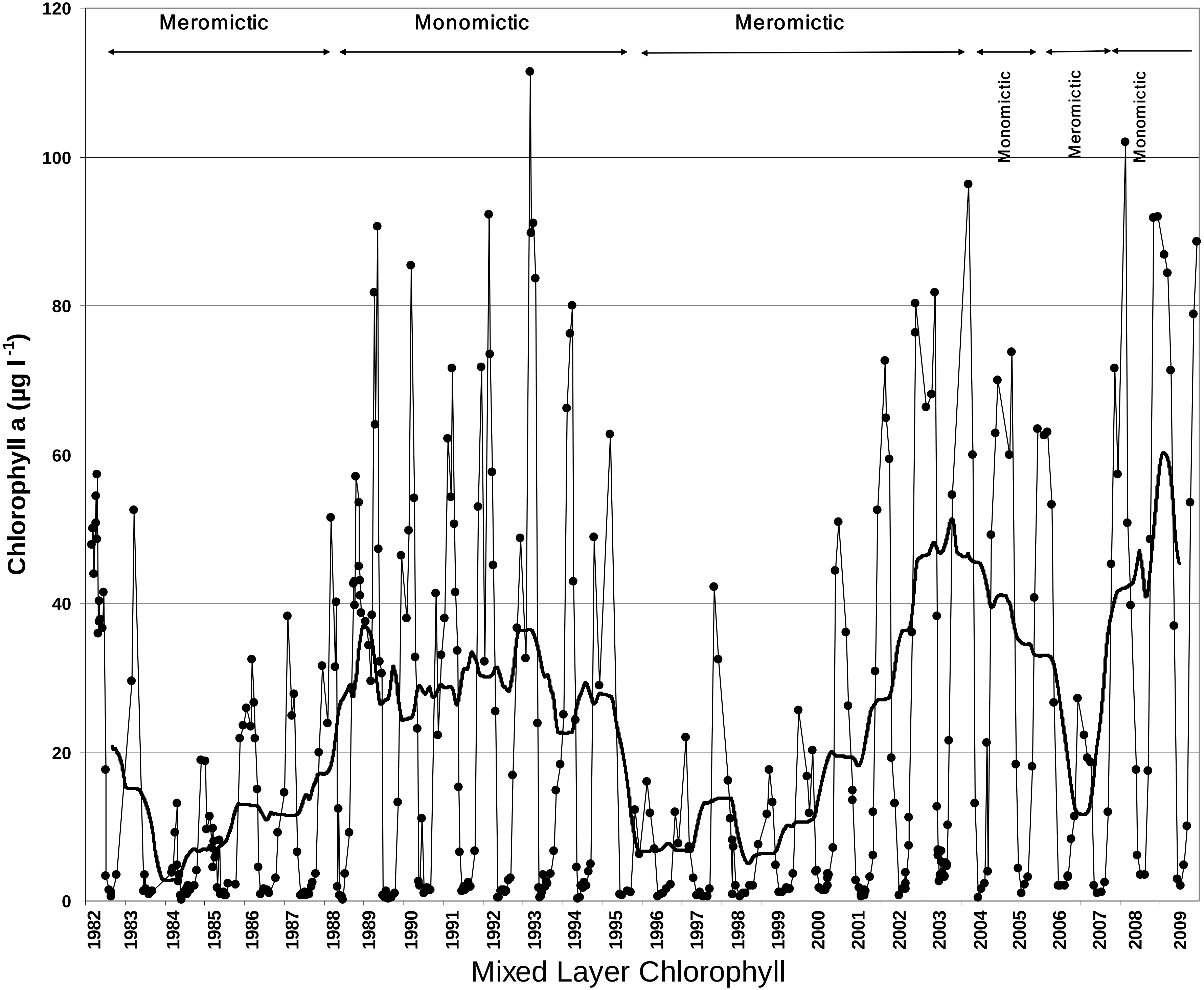
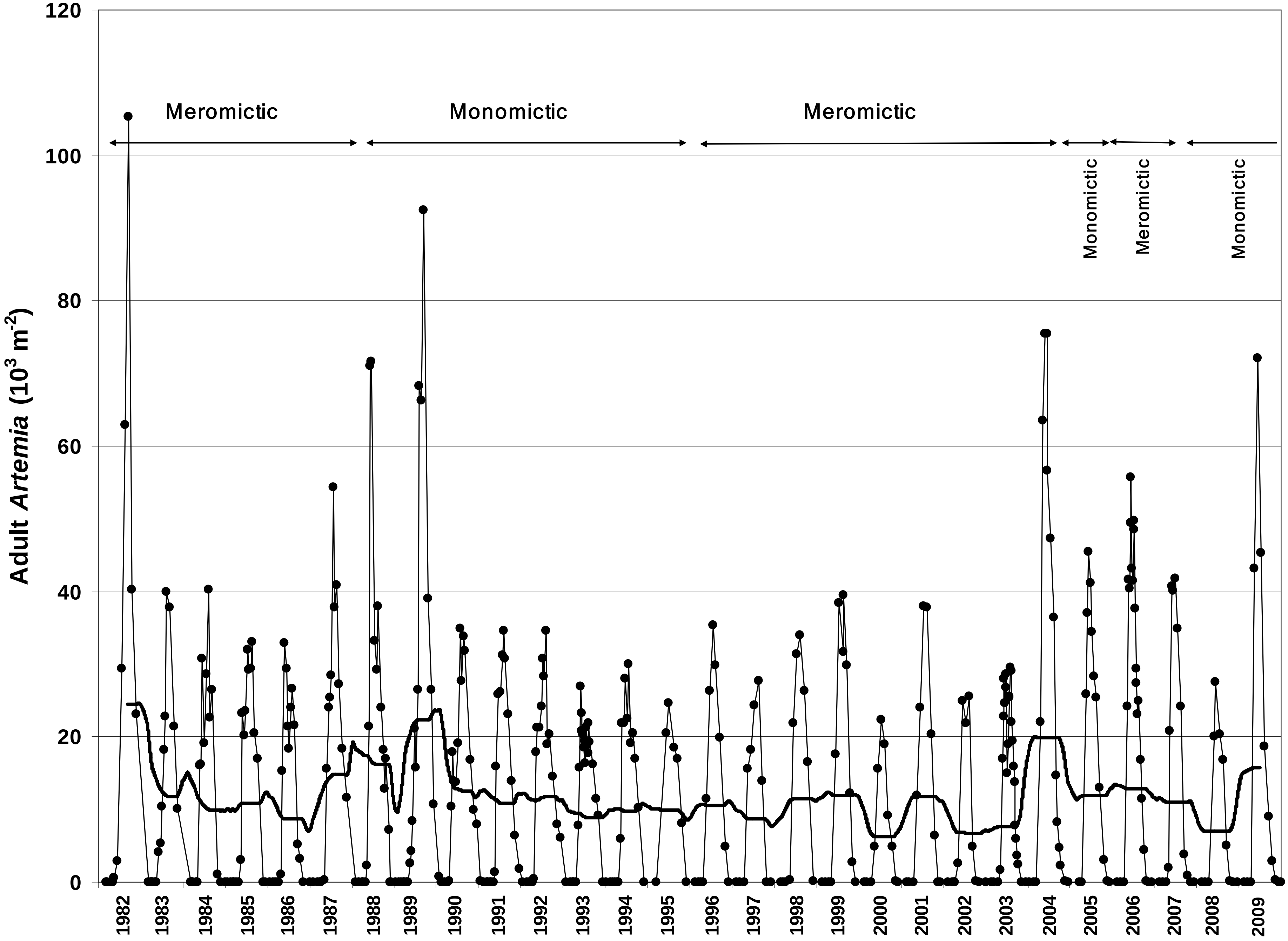

Chlorophyll a (µg l -1)
120
100
80
60
40
20
0
Meromictic
Monomictic
Meromictic
Monomictic
Meromictic
Monomictic
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Mixed Layer Chlorophyll

Figure 31

Figure 32



Adult *Artemia* Abundance

APPENDIX 2

Ornithology

MONO LAKE WATERFOWL POPULATION MONITORING

2009 Annual Report

09/28/2009

LOS ANGELES DEPARTMENT OF WATER AND POWER
PREPARED BY DEBBIE HOUSE
WATERSHED RESOURCES SPECIALIST
BISHOP, CA 93514
April 2009

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EXECUTIVE SUMMARY

Waterfowl populations were monitored in 2009 at Mono Lake, Bridgeport Reservoir, and Crowley Reservoir, as a component of the 1996 Mono Basin Waterfowl Habitat Restoration Plan. At Mono Lake, three summer ground surveys were conducted, documenting species composition, habitat use and brood production. Six fall aerial surveys were conducted at Mono Lake, Bridgeport Reservoir and Crowley Reservoir, providing an index of waterfowl numbers using each body of water during fall migration. The fall aerial surveys of Bridgeport and Crowley Reservoirs are being conducted in order to determine whether or not long-term trends observed at Mono Lake are mirrored at other Eastern Sierra water bodies or are specific to Mono Lake.

The elevation of Mono Lake has undergone annual variations in response to runoff conditions and precipitation regimes. Mono Lake has experienced a slow decline in elevation since the summer of 2007 from its most recent high point following two wet years. Many of the brackish lagoons and fresh water ponds that formed along the south shore during the period of increasing lake levels in 2006 and 2007 have contracted to a point that they no longer provide suitable habitat for nesting or brooding waterfowl.

The five species that used the Mono Lake shoreline habitats for brooding were Canada Goose, Gadwall, Green-winged Teal and Mallard. The number of broods detected along shoreline habitats at Mono Lake in 2009 (57) was similar to last year. The proportional use of lagoon habitats by summering waterfowl decreased, likely a function of the reduction in availability and quality of this habitat type. A total of eight broods of two species (Gadwall and Ruddy Duck) were observed at the Restoration Ponds in 2009.

A total of 27,861 individuals and eleven waterfowl species were recorded at Mono Lake during fall aerial surveys. Ruddy Ducks and Northern Shovelers were the dominant species during fall migration with Ruddy Ducks accounting for 43 % (11,991) of all detections, and Northern Shovelers accounting for 51% (14,202) of all detections. The peak one-day count of 7,920 waterfowl occurred on September 17 survey.

A total of 33,222 individuals and sixteen waterfowl species were recorded at Bridgeport Reservoir during fall aerial surveys. The most abundant species were Northern Shoveler and Gadwall. The peak number of waterfowl detected at Bridgeport Reservoir was 11,270, and occurred on September 17.

A total of 36,441 individuals and 20 waterfowl species were recorded at Crowley Reservoir during the six fall surveys. The most abundant species were Northern Pintail and Northern Shoveler. The peak number detected at Crowley Reservoir was 11,695 and occurred during the October 15 survey.

Data from the past eight years indicate that brood production has been significantly positively correlated with the surface elevation of Mono Lake. Total summer waterfowl use and waterfowl diversity have somewhat tracked changes in lake elevation also, but the relationships are not statistically significant. The use of Mono Lake by waterfowl during fall migration has shown no direct relationship to lake level since regular waterfowl surveys were initiated in 1996. There has been a significant positive trend in the peak number of waterfowl using Mono Lake during fall migration since 1996.

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 (SWRCB) 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 2009. Six comparative fall aerial counts were completed at Bridgeport and Crowley Reservoirs. Photos of shoreline habitats and the restoration ponds were taken from a helicopter on September 28, 2009.

2009 Mono Lake Waterfowl Population Monitoring
Los Angeles Department of Water and Power
Prepared by Debbie House
Watershed Resources Specialist
Bishop, CA

INTRODUCTION

In 1996, the Mono Basin Waterfowl Habitat Restoration Plan (Plan) was prepared by the Los Angeles Department of Water and Power (LADWP) for the SWRCB (LADWP 1996). 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.

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

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

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

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

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

All summer surveys were conducted by the author. Fall surveys were conducted by the author with assistance from Mr. Chris Allen, 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. All surveys were conducted as area counts, and locations were surveyed either by walking along the shoreline, along the creek corridor or by making observations from a stationary point. Ground surveys were completed over three or four day periods.

Shoreline locations surveyed were those identified in the Plan 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); and Lee Vining Creek bottomlands and delta (LVCR). Surveys were also conducted at the restoration ponds on the northwest shore: DeChambeau Ponds (DEPO) and County Ponds (COPO).

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

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

All summer ground surveys began within one hour of sunrise and were completed within approximately six hours. The order in which the various sites were visited was varied in order to minimize the effect of time-of-day on survey results. Total survey time was recorded for each area. The date and time of day for each survey during 2009 are provided in Appendix 1. The common name, scientific name, and four-letter code for species referenced in the document can be found in Appendix 2.

Surveys along the shoreline and in Rush and Lee Vining Creeks were conducted by walking at an average rate of approximately 1.5 km/hr, depending on conditions, and recording waterfowl species as they were encountered. Because waterfowl are easily flushed, and females with broods are especially wary, the shoreline was frequently scanned well ahead of the observer in order to increase the probability of detecting broods. The following was recorded for each waterfowl observation: 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”. Shorebirds were censused in the same manner, but shorebird data will not be presented in this document.

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

The habitat categories used generally follow the classification system found in the report entitled 1999 Mono Basin Vegetation and Habitat Mapping (LADWP 2000b). The habitat classification system defined in that report is being used for the mapping of lakeshore vegetation and the identification of changes in lake-fringing wetlands associated with changes in lake level. The specific habitat categories used in that mapping effort (and in this project) include: marsh, wet meadow, alkaline wet meadow, dry meadow/forb, riparian scrub, Great Basin scrub, riparian forest, freshwater stream, ria, freshwater pond, brackish lagoon, hypersaline lagoon, and unvegetated. Salinity measurements of ponds and lagoons were taken using an Extech EC400 Conductivity/TDS/Salinity probe in order to aid in the proper classification of fresh vs. brackish lagoons and ponds. Ponds with a salinity of less than 500 ppm were classified as fresh. Lagoons with vegetation present and a salinity of greater than 500 ppm were classified as brackish. Lagoons which lacked vegetation and freshwater inflow were classified as hypersaline. For reference, the definition of each of these habitat types is provided in Appendix 3. Representative photos of these habitats can be found in the report entitled Mono Lake Waterfowl Population Monitoring 2002 Annual Report (LADWP 2003).

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

Fall Aerial Surveys

Overview of Methodology

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

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

At Mono Lake, waterfowl and shorebirds were censused, with the primary emphasis on the censusing of waterfowl. The greater concentration and diversity of waterfowl at Bridgeport and Crowley Reservoirs prevents censusing of shorebirds at these locations. This report will only present waterfowl data. 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 and censused shorebirds. During the cross-lake transect counts, the second observer sat on the opposite side of the plane and counted Ruddy Ducks and phalaropes. At Bridgeport and Crowley, the second observer sat on the same side of the plane as the primary observer during the entire survey, and assisting in counting 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.

The cross-lake transects covered open water areas of 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 species occurring offshore. The beginning and ending points for each subsection were determined using landscape features, or, when over open water, by using a stopwatch, since the survey aircraft's airspeed was carefully controlled and the approximate length of each subsection was known.

LADWP contracted with Black Mountain Air Service to conduct fixed-winged aerial counts. Black Mountain Air Service has obtained a low-altitude flight waiver from the Federal Aviation Administration in order to conduct these flights. Aerial surveys were conducted in a Cessna 180 at a speed of approximately 130 kilometers per hour, and at a height of approximately 60 meters above ground. Perimeter surveys were conducted over water while maintaining a distance of approximately 250 meters from the shoreline. When conducting aerial surveys, the perimeter flight was conducted first, and 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. Adjustments were made as necessary depending on lighting, lake level and waterfowl distribution. The reservoir was circumnavigated twice during each survey to allow for a second count of often large concentrations of mixed species flocks.

Crowley Reservoir Aerial Surveys

The shoreline of Crowley Reservoir was divided into seven segments (Figure 4). Coordinates forming the beginning of each segment were generated from the 2000 aerial photo of Crowley

Reservoir (2000 aerial image taken by I. K. Curtis, and processed by Air Photo, USA) and can be found in Appendix 5, as well as the four-letter code used for each segment. Each survey began at the mouth of the Owens River (UPOW) and proceeded over water in a counterclockwise direction along the shoreline. The distance from shore, flight speed, and height above the water were the same as at Mono Lake during most of each flight. Temporary diversions of distance from shore or height above ground were made by the pilot as necessary to avoid direct or low flight over float-tubers or boats. Adjustments were also made as necessary depending on lighting, lake level and waterfowl distribution. The reservoir was circumnavigated twice during each survey to allow for a second count of often large concentrations of mixed species flocks.

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.

Photo Documentation

As required by the Order 98-05, photo documentation of lake-fringing waterfowl habitats was completed in 2009. Photos were taken from a helicopter at all bodies of water on September 28, 2009. In 2009, shoreline conditions were also documented using a helicopter-mounted, geo-referenced video camera. Photos depicting the condition and available habitats for each shoreline segment are described under Data Summary below.

Data Summary and Analysis

2009 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 habitat use observations except those of flyovers were included in this analysis. The waterfowl species for which habitat use data were analyzed were Canada Goose, Gadwall, and Mallard. 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.

2009 Fall Aerial Count Data

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

Evaluation of Trend in Waterfowl Populations

Simple linear regression analysis was used to evaluate trends in summer waterfowl detections, waterfowl diversity, the number of broods and total fall detections as a function of lake elevation. The reference elevations used for analyses were June for summer data, and September for fall data. Elevation data was obtained from the Mono Lake Committee’s website. Simple linear regression analysis was used to evaluate the trend in peak one-day waterfowl numbers 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. Regression equations were tested using ANOVA to determine the significance of the regression, (i.e. “Is the slope significantly different from zero?” Zar 1996).

RESULTS

Description of Shoreline Conditions in 2009

Mono Lake

The 2008-2009 water year in the Mono Basin was “Normal” year type with a predicted runoff of 88% of the 1941-1990 average runoff (see Order WR 98-05). At 6382.5 feet, the lake level was 0.7 feet lower in early summer (June) than it had been during the same time in 2008. The lake level remained stable through the summer survey period, and then decreased 0.6 feet to 6391.9 feet by the start of fall surveys in September. The decrease in lake elevation resulted in qualitative differences in lake-fringing habitats for waterfowl during the 2009 monitoring period, some of which are discussed below.

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

The drop in lake elevation resulted in an increase in exposed shoreline and a decrease in the size and extent of lake-fringing lagoons. The South Tufa area did not support any lake-fringing lagoons in 2009, as those that had formed at the east end of the area in 2006 had completely dried up. The western portion (near the South Tufa visitor area) continued to support mudflats due to spring outflow, while the shoreline area east of Navy Beach was dominated by exposed dry playa (Figure 5).

The numerous isolated lagoons along the length of the South Shore Lagoons area continued to contract as the lake level has declined over the last three years. The brackish lagoon at the west end of the South Shore Lagoons area (Figure 6), and the fresh water pond approximately 1.2 km farther east (Figure 7), had both contracted considerably and few waterfowl were observed in these areas in 2009. Sand Flat Spring outflow continued to be isolated from the lake (Figure 8). The main area of waterfowl use in 2009 along the South Shore Lagoons area was the Goose Springs outflow area (Figure 9). Although reduced in size, the Goose Springs outflow area continued to support an extensive brackish lagoon where most observations of waterfowl and shorebirds in the South Shore Lagoons shoreline segment occurred.

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

Warm Springs and Northeast Shore

The decrease in lake elevation resulted in further decreases in the size and extent of lagoons in the Warm Springs area. The “north lagoon” (Figure 12), which is supported by the outflow of Pebble and Twin Warm Springs, continued to retract in size. The north lagoon continued to be the primary area of waterfowl use on the east side of the lake. The south lagoon, supported by outflow from Warm Springs Marsh Channel, Warm B, and Bug Warm springs, was essentially dry in 2009. Since 2002, this south lagoon has been much smaller than the northern lagoon and less attractive to ducks and other waterbirds. In 2009 the Northeast Shore area was dominated by barren playa and did not support lagoons (Figure 13).

Bridgeport Creek, DeChambeau Embayment and Black Point

This area of the shoreline typically consists of several small lagoons with alkali meadow and or small areas of wet alkali meadow adjacent. Small isolated lagoons continued to persist in the shoreline area between Bridgeport Creek and Black Point (Figures 14 - 16) although the lagoons have contracted as the lake elevation has declined. These lagoons typically attract small numbers of waterfowl in the fall.

Northwest Shore (Wilson, Mill Creek and DeChambeau Creeks)

Qualitative changes were also noted along the northwest shore of the lake, from the Wilson Creek area to the DeChambeau Creek area. In the Wilson Creek area (Figure 17), the area east of Wilson Creek bay had dried considerably as compared to the previous two years, and supported little waterfowl use. At Mill Creek (Figure 18), the fresh water pond perched behind a gravel bar along the shoreline continued to persist, although it appeared slightly reduced in size as compared to the previous two years. In the DeChambeau Creek area (Figure 19), there were slight increases in the amount of exposed shoreline as compared to 2008. Due to the numerous springs in the area, the exposed shoreline creates extensive mudflats with fresh water outflow areas. Very small fresh water ponds existed near shore where spring outflow was retained behind small sandbars.

West Shoreline (West Shore, Lee Vining Creek, Ranch Cove and Rush Creek)

The West Shore area (Figure 20) with the presence of a few springs, supports primarily meadow and riparian scrub habitats, but lacks lagoons. No significant changes were noted in 2009. Also, no significant changes occurred at Lee Vining Creek (Figure 21), in 2009 as compared to the previous year with the exception of extensive willow recruitment noted in the delta of Lee Vining Creek. The Ranch Cove area (Figure 22) has limited fresh water input, and does not support lagoons due to the gradient. The area continued to be dominated by sandy beach and upland vegetation. At Rush Creek, flows at the delta continued to be deflected into the southern part of the bay by a sandbar (Figure 23). The decline in lake elevation appeared to expose more sandbars in the delta.

Restoration Ponds

Both County Ponds were flooded in 2009. There was little open water visible at County Pond West due to the extensive growth of emergent vegetation. All of the DeChambeau Ponds were flooded except DeChambeau Pond five, which remained dry all year.

Bridgeport Reservoir

Conditions at Bridgeport Reservoir appeared similar to those encountered in 2008. Figure 24 shows an overview of the reservoir as viewed from the south end looking north toward the dam. The south end of the reservoir, which includes the area referred to as “West Bay”, and part of the “East Arm” area, receives fresh water inflows from Buckeye and Robinson Creeks and the East Walker River, creating extensive mudflat areas adjacent to these creek inflow areas. The northern arm of the reservoir includes primarily sandy beaches bordered by upland vegetation. In early September there was evidence of heavy algal growth, however the water appeared much clearer by the end of September. The water level was fairly low as in September as the reservoir held 9,360 acre-feet (Department of Water Resources, California Data Exchange Center). As a point of reference, the storage capacity of Bridgeport Reservoir is 42,600 acre-feet.

Crowley Reservoir

Conditions at Crowley Reservoir appeared similar to those encountered in 2008. In September there was evidence of heavy algal growth, however the water appeared much clearer by the end of September. In early September, Crowley Reservoir held 114,800 acre-feet. As a point of reference, the storage capacity of Crowley Reservoir is 183,465 acre-feet. Figures 25-31 depict habitat conditions of each shoreline segment at Crowley Reservoir. The Upper Owens River delta area (Figure 25) includes large areas of exposed mudflats and reservoir bottom adjacent to the mouth of the Upper Owens River. Most of the length of Sandy Point area (Figure 26) is adjacent to elevated areas and upland vegetation. Small areas of meadow habitat occur in this area also. North Landing is largely bordered by meadows (Figure 27). The McGee Bay area (Figure 28) supports vast mudflat areas immediately adjacent to wet meadow habitats. Hilton Bay (Figure 29) is surrounded by meadow habitats, and receives some fresh water input from Hilton Creek. The Chalk Cliffs area (Figure 30) lacks fresh water inflow areas and wetland habitats, and is dominated by sandy beaches adjacent to steep, sagebrush-covered slopes. Layton Springs provides spring flow at the southern border of this lakeshore segment. The remainder of the area is bordered by upland vegetation and a large area of sandy beach in 2009 (Figure 31).

2009 Summer Ground Counts

The number of waterfowl detected in each shoreline area during each survey can be found in Table 1. Table 2 summarizes the summer survey data in terms of the number of detections of each species at each location, the total waterfowl detections at each location, and the percent of total detections for each shoreline area. A total of 9 species of waterfowl were detected during summer surveys. The total number of waterfowl using the shoreline (exclusive of dependent young) detected during summer surveys was highest (620) during the early June count and lowest (141) on the late-July survey. The highest proportion of detections was in the DeChambeau and Wilson Creek areas. The fewest number of waterfowl were at the South Tufa area.

The waterfowl species that brooded in the lake-fringing wetlands and creeks at Mono Lake in 2009 were Canada Goose, Gadwall, Green-winged Teal and Mallard. The number of broods of each species in each shoreline area can be found in Table 3. Figure 32 shows the locations of all of the broods detected in 2009. The number of broods detected in lake-fringing habitats (57) was similar to that seen in 2008 (58). Wilson Creek and Rush Creek were the most heavily used areas for brooding as 17 and 12 broods were detected in these areas respectively. Only five broods were seen in the South Shore Lagoon area, the area most heavily used by breeding waterfowl for the past three years.

Habitat Use

All three waterfowl species analyzed showed a disproportionate use of the various shoreline habitats in 2009. Table 4 provides the tabulated habitat use data, the chi-squared goodness-of-fit results, and the Bonferonni test results for the three species for which an adequate number of observations were obtained: Canada Goose, Gadwall, and Mallard. Figure 33 is a bar graph depicting the proportional use of habitats by each of these species. Canada Geese were observed using primarily unvegetated areas, meadow habitats, and open water areas near shore, with unvegetated areas used disproportionally more than other habitats. Gadwall were observed most frequently using ria, unvegetated areas, brackish lagoons, and freshwater ponds. Ria and unvegetated areas were used significantly more than other habitats. Mallard used unvegetated areas and fresh water ponds disproportionally, but were also seen observed using brackish lagoons and ria among other habitat types.

2009 Fall Aerial Surveys

Fall Aerial Survey Weather Conditions

At least three cold fronts affected the area during the fall survey period. At the end of September a rather strong cold front resulted in an approximate 20° F drop in local temperatures. In mid-October, a very wet system passed through resulting in close to three inches of rain in the Mono Basin, filling shore-fringing lagoons and depressions.

Mono Lake

A total of eleven waterfowl species and 27,861 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 7,920 and occurred on the September 17 survey (Table 5, Figure 34). Compared to the 2008 counts, the total number of detections was 27% lower than 2008 (27,861 vs 38,289 in 2008) while the one-day peak count in 2009 was approximately 43% less than that observed in 2008 (7,920 vs. 13,914 in 2008). The peak number of Northern Shoveler (6,708) occurred on September 17, and the peak number of Ruddy Ducks (5,534) occurred on October 15.

In terms of total detections, Ruddy Ducks and Northern Shovelers were the dominant species during fall migration with Ruddy Ducks accounting for 43 % (11,991) of all detections, and Northern Shovelers accounting for 51% (14,202) of all detections. Use of Mono Lake by Northern Shoveler was approximately half that observed in 2008 as evidenced by a comparison of the total detections. Use of Mono Lake by Ruddy Ducks in 2009 was approximately 23% greater than that observed in 2008.

Tables 6 through 11 provide the results of each of the six fall surveys in terms of the number of individuals of each species detected in each lakeshore segment. The main areas of waterfowl use during fall 2009 were Wilson Creek, Sammann's Spring and Mill Creek (Figure 35).

Bridgeport Reservoir

A total of 16 waterfowl species and 33,222 individuals were recorded at Bridgeport Reservoir during the 2009 fall aerial surveys (Table 12). The peak number of waterfowl detected on any single count at Bridgeport Reservoir was 11,270 individuals, which occurred on September 17 (Table 12, Figure 34). Tables 13-18 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment. The most heavily used area of the lake was the West Bay, accounting for 94% of all detections (Figure 37).

Crowley Reservoir

A total of 20 waterfowl species and 36,441 individuals were detected at Crowley Reservoir during the 2009 fall aerial surveys (Table 19). The peak number of waterfowl detected on any single count at Crowley Reservoir was 11,695 individuals and occurred on October 15 (Table 19, Figure 34). The most abundant species, in terms of total detections, were Northern Shoveler and Northern Pintail. Tables 20-25 provide the results of each of the six fall surveys in terms of number of each species detected by lakeshore segment. The primary areas of waterfowl use were McGee Bay, the Upper Owens and the Layton Springs area (close to the inflow of the Upper Owens River) (Figure 37).

Mono Lake Restoration Ponds

A total of five species and 55 waterfowl were detected at the Restoration Ponds during summer surveys (Table 26). The most abundant species were Gadwall and Ruddy Duck. A total of eight broods were seen, including seven Gadwall and one Ruddy Duck brood (Table 27).

A total of 111 individuals were detected at the DeChambeau and County Pond complexes during fall surveys (Table 28).

Trend Analysis – Mono Lake

Although the total number of summer waterfowl detections appears to have somewhat tracked changes in lake elevation (Figure 38), the data do not indicate a statistically significant relationship ($r = 0.585$, $p = 0.128$). Similarly, waterfowl diversity has also tracked changes in lake elevation (Figure 39), however the relationship is not significant ($r = 0.635$, $p = 0.091$). The number of broods, however has been positively correlated with lake elevation ($r = 0.85$, $p<0.05$) (Figure 40). In addition, the distribution of broods has varied as a function of lake elevation since 2002 (see Figure 41). From 2002-2005, the lake elevation was declining, and during this period, the northwest shoreline areas 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 decreased while the proportion increased along the south shore. Since declines in lake elevation starting in 2008, breeding waterfowl have shifted activity back towards the northwest shore area.

The total number of fall detections has varied independently of lake elevation based on waterfowl counts conducted since 1996 (r = - 0.46, p = 0.098), Figure 42. Figure 43 illustrates the trend in the peak number of waterfowl detected at Mono Lake from 1996-2009. There has been a significant positive trend in the peak number of waterfowl, exclusive of Ruddy Ducks (r = 0.576, p = 0.031, F = 5.971 df = 13).

DISCUSSION

Response of Waterfowl Populations to Restoration Efforts

Data from the summer surveys indicate that fluctuations in the elevation of Mono Lake have influenced the breeding waterfowl population. Variations in lake elevation explain 58% and 63% of the variability in the number and diversity of waterfowl for the time period 2002-2009. Brood production has been significantly positively correlated with the level of Mono Lake. Between 2002 and 2004, Mono Lake experienced a drop in elevation followed by a subsequent rise in elevation from 2004 to 2006, and then a decline from 2007 thru 2009. Increases in elevation, (at least within the elevation ranges observed), have resulted in increases in the number and extent of lake-fringing lagoons along the south shoreline, especially the South Shore Lagoons area. Based on field observations, these lagoons enlarged due either to an increase in the groundwater table or as a result of increased spring flow. The breeding population of waterfowl at Mono Lake has also responded to these changes with a shift in distribution. From 2002-2005, the lake elevation was declining. During this period, the Northwest Shore 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 subsequently decreased while the proportion detected along in the South Shoreline increased. Brooding waterfowl were observed using many of the ephemeral lagoons that had developed at the elevated lake level. As the lake declined further in 2008-2009, and lagoons along the south shore have continued to retract, breeding waterfowl have again shifted back towards the Northwest Shore areas.

Summering and breeding waterfowl have shown a great deal of annual variability with regard to the 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 habitat conditions that may explain waterfowl use and the spatial distribution of waterfowl at Mono Lake are not readily quantified during existing vegetation mapping efforts being conducted every five years.

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

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Table 1. 2009 Summer Ground Count Data

Survey 1	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Blue-winged Teal					2			1		3
Canada Goose	29		6						5	40
Cinnamon Teal	2		1		5			5		13
Gadwall	76	178	46	12	33	1	17	20	84	467
Green-winged Teal			4	2	12		2			20
Mallard	3	25	1	2	7		14	16	4	72
Redhead	1	1					2			4
Ruddy Duck			1							1
Total Waterfowl by Area	**111**	**204**	**59**	**16**	**59**	**1**	**35**	**42**	**93**	**620**

Survey 2	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Brant									1	1
Canada Goose	35									35
Cinnamon Teal	1									1
Gadwall	51	2	86	16	5		13	18	94	285
Green-winged Teal		1		2	1					4
Mallard	5	1		4	12		4		8	34
Unidentified Teal						2				2
Total Waterfowl by Area	**92**	**4**	**86**	**22**	**18**	**2**	**17**	**18**	**103**	**362**

Survey 3	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	Total
Canada Goose	30			10	16	10				66
Cinnamon Teal								1		1
Gadwall	8		9	6	5		3		20	51
Green-winged Teal				1						1
Mallard		1			6		1	1	3	12
Ruddy Duck									10	10
Total waterfowl by Area	**38**	**1**	**9**	**17**	**27**	**10**	**4**	**2**	**33**	**141**

Table 2. Summary of 2009 Summer Ground Count Data
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.

Species	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	**Total**
Blue-winged Teal					2			1		**3**
Brant									1	**1**
Canada Goose	94		6	10	16	10			5	**141**
Cinnamon Teal	3		1		5			6		**15**
Gadwall	135	180	141	34	43	1	33	38	198	**803**
Green-winged Teal		1	4	5	13		2			**25**
Mallard	8	27	1	6	25		19	17	15	**118**
Redhead	1	1					2			**4**
Ruddy Duck			1						10	**11**
Unidentified Teal						2				**2**
Total Detections	**241**	**209**	**154**	**55**	**104**	**13**	**56**	**62**	**229**	**1123**
% of Detections	21.4%	18.6%	13.7%	4.9%	9.3%	1.6%	5.0%	5.5%	20.4%	

Table 3. 2009 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**
Survey 1	Canada Goose			3							**3**
	Gadwall					1		1		1	**3**
	Green-winged Teal										**0**
	Mallard		1			1		1			**3**
	Total Broods	0	1	3	0	2	0	2	0	1	**9**
Survey 2	Canada Goose	1									**1**
	Gadwall					2		1		2	**5**
	Green-winged Teal		1		2						**3**
	Mallard				3	1					**4**
	Total Broods	1	1	0	5	3	0	1	0	2	**13**
Survey 3	Canada Goose										**0**
	Gadwall	4		5	6	2		1		14	**32**
	Green-winged Teal				1						**1**
	Mallard					1		1			**2**
	Total Broods	4	0	5	7	3	0	2	0	14	**35**
Total	Shoreline Segment	DECR	LVCR	MICR	RUCR	SASP	SOTU	SSLA	WASP	WICR	**Total**
	Canada Goose	1		3							**4**
	Gadwall	4		5	6	5		3		17	**40**
	Green-winged Teal		1		3						**4**
	Mallard		1		3	3		2			**9**
	Total broods per area	5	2	8	12	8	0	5	0	17	**57**

Table 4. Chi Square Goodness-of-Fit Results for Waterfowl Habitat Use Data

Grayed categories were excluded from analysis. The results of the Bonferroni Test are indicated in the "Sign" (= significance) column. NS indicates that there was no significant difference between expected and observed use of a habitat type at the $p < 0.05$ level.

	Canada Goose				Gadwall				Mallard			
Habitat	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign	Obs	Exp	χ^2	Sign
Great Basin Scrub					2	87.4	83.4	-				
Marsh					5	87.4	77.7	-	2	14.5	10.8	-
Wet Meadow	16	20.1	0.8	NS	6	87.4	75.8	-				
Alkali Wet Meadow	10	20.1	5.1	-								
Riparian Scrub									1	14.5	12.6	-
Freshwater Stream	2	20.1	16.3	-	19	87.4	53.5	-	4	14.5	7.6	-
Ria	2	20.1	16.3	-	382	87.4	993.0	+	17	14.5	0.4	NS
Fresh Water Pond	2	20.1	16.3	-	77	87.4	1.2	NS	28	14.5	12.6	+
Brackish Lagoon					47	87.4	18.7	-	21	14.5	2.9	NS
Hypersaline Lagoon												
Unvegetated	96	20.1	286.6	+	227	87.4	223.0	+	39	14.5	41.4	+
Open Water	13	20.1	2.5	NS	22	87.4	48.9	-	4	14.5	7.6	-
Total	141		343.9		787		1575.3		116		95.9	

Table 5. Summary of 2009 Mono Lake Fall Aerial Survey Count Data

Species	3-Sep	17-Sep	1-Oct	15-Oct	2-Nov	16-Nov	Total Detections	% Total
American Wigeon						1	1	<0.1%
Canada Goose		1		52	137	161	351	1.3%
Cinnamon Teal	1						1	<0.1%
Common Merganser						1	1	<0.1%
Gadwall	21	20	7		5		53	0.2%
Greater White-fronted Goose					2		2	<0.1%
Green-winged Teal	20	24		100	1	59	204	0.7%
Mallard	40	40	43	61		74	258	0.9%
Northern Pintail	8	29	48	48	96	190	419	1.5%
Northern Shoveler	5631	6708	1357	437	68	1	14202	51.0%
Ruddy Duck	490	1074	1937	5534	1506	1450	11991	43.0%
Unidentified Teal	260	24	10	49	25	10	378	1.4%
Total Waterfowl	6471	7920	3402	6281	1840	1947	27861	

Table 6. Mono Lake - Fall Aerial Survey, September 3, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
Cinnamon Teal							1									1		1
Gadwall													13		8	21		21
Green-winged Teal			20													20		20
Mallard					40											40		40
Northern Pintail													8			8		8
Northern Shoveler		20	190		15		5	2	80	4300	950	25	30	14		5631		5631
Ruddy Duck											2					2	488	490
Unidentified Teal				90	110							60				260		260
Total Waterfowl	**0**	**20**	**210**	**90**	**165**	**0**	**6**	**2**	**80**	**4300**	**952**	**85**	**51**	**14**	**8**	**5983**	**488**	**6471**

Table 7. Mono Lake - Fall Aerial Survey, September 17, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
Canada Goose												1				1		1
Gadwall	7				13											20		20
Green-winged Teal												4		20		24		24
Mallard											40					40		40
Northern Pintail				22								4	3			29		29
Northern Shoveler				3075						2500	750	350	18	15		6708		6708
Ruddy Duck											345	30	6			381	693	1074
Unidentified Teal			12		7									5		24		24
Total Waterfowl	**7**	**0**	**12**	**3097**	**20**	**0**	**0**	**0**	**0**	**2500**	**1135**	**389**	**27**	**40**	**0**	**7227**	**693**	**7920**

Table 8. Mono Lake - Fall Aerial Survey, October 1, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
Gadwall												5	2			7		7
Mallard				35	8											43		43
Northern Pintail				20						10	18					48		48
Northern Shoveler			60	405	17					750	85	40				1357		1357
Ruddy Duck	5	4					4				82	480	380	2	35	992	945	1937
Unidentified Teal			10													10		10
Total Waterfowl	**5**	**4**	**70**	**460**	**25**	**0**	**4**	**0**	**0**	**760**	**185**	**525**	**382**	**2**	**35**	**2457**	**945**	**3402**

Table 9. Mono Lake - Fall Aerial Survey, October 15, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
Canada Goose				3	28			21								52		52
Green-winged Teal				20						80						100		100
Mallard	4		12		10						35					61		61
Northern Pintail			18		30											48		48
Northern Shoveler			3	110				1		300		20		3		437		437
Ruddy Duck	159	123	67	37				13	157	50	53	105	448	15	46	1273	744	2017
Unidentified Teal					40							8				48	1	49
Total Waterfowl	**163**	**123**	**100**	**170**	**108**	**0**	**0**	**35**	**157**	**430**	**88**	**133**	**448**	**18**	**46**	**2019**	**4262**	**6281**

Table 10. Mono Lake - Fall Aerial Survey, November 2, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
Canada Goose	22			115												137		137
Gadwall	5															5		5
Greater White-fronted Goose				2												2		2
Green-winged Teal											1					1		1
Northern Pintail			95									1				96		96
Northern Shoveler									2			66				68		68
Ruddy Duck	25	102							97		135	87	148	20	147	761	745	1506
Unidentified Teal			25													25		25
Total Waterfowl	**52**	**102**	**120**	**117**	**0**	**0**	**0**	**0**	**99**	**0**	**136**	**154**	**148**	**20**	**147**	**1095**	**745**	**1840**

Table 11. Mono Lake - Fall Aerial Survey, November 16, 2009

Species	Lakeshore segment															**Shoreline Total**	**Offshore Total**	**Lakewide Total**
	RUCR	SOTU	SSLA	SASP	WASP	NESH	BRCR	DEEM	BLPO	WICR	MICR	DECR	WESH	LVCR	RACO			
American Wigeon								1								1		1
Canada Goose				120				41								161		161
Common Merganser	1															1		1
Green-winged Teal			40							7			12			59		59
Mallard	5			1				25		18				25		74		74
Northern Pintail			12	130						45			3			190		190
Northern Shoveler	1															1		1
Ruddy Duck	9	30	35	3					29	2	28	103	270	55	16	580	870	1450
Unidentified Teal										10						10		10
Total Waterfowl	**16**	**30**	**87**	**254**	**0**	**0**	**0**	**67**	**29**	**82**	**28**	**103**	**285**	**80**	**16**	**1077**	**870**	**1947**

Table 12. Summary of 2009 Bridgeport Reservoir Fall Aerial Survey Count Data

Species	3-Sep	17-Sep	1-Oct	15-Oct	2-Nov	16-Nov	**Total Detections**	**% Total**
American Wigeon			3				3	**<0.1**
Bufflehead		7		6	26	67	106	**0.3**
Canada Goose	221	112	180	425	75	75	1088	**3.3**
Cinnamon Teal	163						163	**0.5**
Common Merganser	7	12	18	1			38	**0.1**
Gadwall	4097	2520	1205	15	50	7	7894	**23.8**
Green-winged Teal	18	437	188	40	22	25	730	**2.2**
Lesser Scaup					3	60	63	**0.2**
Mallard	470	1058	750	2240	185	65	4768	**14.4**
Northern Pintail	304	954	951	1500	182	25	3916	**11.8**
Northern Shoveler	3065	5006	927	66	10	1	9075	**27.3**
Redhead	2	60	6		6	3	77	**0.2**
Ring-necked Duck					1		1	**<0.1**
Ruddy Duck	85	450	950	125	356	67	2033	**6.1**
Tundra Swan						13	13	**<0.1**
White-winged Scoter						1	1	**<0.1**
Unidentified Teal	1975	654	312	18	250	44	3253	**9.8**
Total Waterfowl	**10407**	**11270**	**5490**	**4436**	**1166**	**453**	**33222**	

Table 13. Bridgeport Reservoir Fall Survey, September 3, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
Canada Goose	6	183	32	221
Cinnamon Teal	28	120	15	163
Common Merganser	7			7
Gadwall	62	3810	225	4097
Green-winged Teal	14		4	18
Mallard	80	350	40	470
Northern Pintail	4	300		304
Northern Shoveler	65	3000		3065
Redhead		2		2
Ruddy Duck		20	65	85
Unidentified Teal		1950	25	1975
Total Waterfowl	266	9735	406	10407

Table 14. Bridgeport Reservoir Fall Aerial Survey, September 17, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
Bufflehead	7			7
Canada Goose		110	2	112
Common Merganser	12			12
Gadwall	45	2400	75	2520
Green-winged Teal	2	400	35	437
Mallard	8	700	350	1058
Northern Pintail	4	950		954
Northern Shoveler		5000	6	5006
Redhead		60		60
Ruddy Duck		450		450
Unidentified Teal	4	400	250	654
Total Waterfowl	82	10470	718	11270

Table 15. Bridgeport Reservoir Fall Aerial Survey , October 1, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
American Wigeon	3			3
Canada Goose		180		180
Common Merganser	2	10	6	18
Gadwall	7	1125	73	1205
Green-winged Teal	8	180		188
Mallard		680	70	750
Northern Pintail	1	950		951
Northern Shoveler	15	912		927
Redhead		6		6
Ruddy Duck		950		950
Unidentified Teal	12	300		312
Total Waterfowl	48	5293	149	5490

Table 16. Bridgeport Reservoir Fall Aerial Survey, October 15, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
Bufflehead	3	3		
Canada Goose		425		425
Common Merganser			1	1
Gadwall	5	1	9	15
Green-winged Teal		40		40
Mallard		2240		2240
Northern Pintail		1500		1500
Northern Shoveler	3	63		66
Ruddy Duck		125		125
Unidentified Teal	1		17	18
Total Waterfowl	12	4397	27	4436

Table 17. Bridgeport Reservoir Fall Aerial Survey, November 2, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
Bufflehead	4	7	15	26
Canada Goose		75		75
Gadwall	5	45		50
Green-winged Teal	2	20		22
Lesser Scaup	3			3
Mallard	8	175	2	185
Northern Pintail	20	150	12	182
Northern Shoveler	6		4	10
Redhead		4	2	6
Ring-necked Duck	1			1
Ruddy Duck	6	350		356
Unidentified Teal		180	70	250
Total Waterfowl	55	1006	105	1166

Table 18. Bridgeport Reservoir Fall Aerial Survey, November 16, 2009

Species	Lakeshore Segment			Total
	NOAR	WEBA	EASH	
Bufflehead	20	32	15	67
Canada Goose		75		75
Gadwall		7		7
Green-winged Teal		25		25
Lesser Scaup		60		60
Mallard		53	12	65
Northern Pintail		25		25
Northern Shoveler			1	1
Redhead			3	3
Ruddy Duck	2	65		67
Tundra Swan		13		13
Unidentified Teal		40	4	44
White-winged Scoter	1			1
Total Waterfowl	23	395	35	453

Table 19. Summary of 2009 Crowley Reservoir Fall Aerial Survey Count Data

Species	**3-Sep**	**17-Sep**	**1-Oct**	**15-Oct**	**2-Nov**	**16-Nov**	**Total Detections**	**% Total**
American Wigeon			35	96	40	22	193	**0.5**
Bufflehead				25	125	444	594	**1.6**
Canada Goose	111	170	256	145	25	77	784	**2.2**
Canvasback				14	8	40	62	**0.2**
Cinnamon Teal	74	132	20				226	**0.6**
Common Goldeneye						8	8	**0.02**
Common Merganser	2	12	24		1	5	44	**0.1**
Gadwall	1146	839	862	352	92	106	3397	**9.3**
Greater White-fronted Goose			29	92			121	**0.3**
Green-winged Teal	166	254	600	602	245	225	2092	**5.7**
Hooded Merganser						1	1	**0.00**
Lesser Scaup				20	92	35	147	**0.4**
Mallard	1269	470	840	691	67	469	3806	**10.4**
Northern Pintail	534	865	725	5200	420	94	7838	**21.5**
Northern Shoveler	2632	2265	1640	2258	210	366	9371	**25.7**
Redhead			35	11	8	12	66	**0.2**
Ring-necked Duck				12	6	10	28	**0.1**
Ruddy Duck		720	930	1507	557	907	4621	**12.7**
Snow Goose						30	30	**0.1**
Tundra Swan					2	14	16	**0.04**
Unidentified Teal	60	685	1175	670	400	6	2996	**8.2**
Total Waterfowl	**5994**	**6412**	**7171**	**11695**	**2298**	**2871**	**36441**	

Table 20. Crowley Reservoir Fall Aerial Survey, September 3, 2009

Species	Lakeshore Segment							Total
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Canada Goose	30			45			36	111
Cinnamon Teal				62	12			74
Common Merganser						2		2
Gadwall	120		20	1000	6			1146
Green-winged Teal	20			130	16			166
Mallard	100			1100	4		65	1269
Northern Pintail	80			454				534
Northern Shoveler	40		18	2500	24		50	2632
Unidentified Teal					20		40	60
Total Waterfowl	**390**		**38**	**5291**	**82**	**2**	**191**	**5994**

Table 21. Crowley Reservoir Fall Aerial Survey, September 17, 2009

Species	Lakeshore Segment							Total
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
Canada Goose				170				170
Cinnamon Teal	2				60		70	132
Common Merganser							12	12
Gadwall	80	9		750				839
Green-winged Teal	13	1		200	20		20	254
Mallard				450			20	470
Northern Pintail	65			800				865
Northern Shoveler	200			1800	220		45	2265
Ruddy Duck	550			100			70	720
Unidentified Teal		15		560			110	685
Total Waterfowl	**910**	**25**		**4830**	**300**		**347**	**6412**

Table 22. Crowley Reservoir Fall Aerial Survey, October 1, 2009

Species	Lakeshore Segment							Total
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
American Wigeon	15						20	35
Canada Goose				250			6	256
Cinnamon Teal							20	20
Common Merganser				20	1		3	24
Gadwall	300	20		500	12		30	862
Greater White-fronted Goose	27			2				29
Green-winged Teal	80			20	250		250	600
Mallard	30			750	10		50	840
Northern Pintail	60	30		600	20		15	725
Northern Shoveler	250	30		1200	40		120	1640
Redhead	4			4			27	35
Ruddy Duck	30	30		830			40	930
Unidentified Teal	20	30	5	620			500	1175
Total Waterfowl	**816**	**140**	**5**	**4796**	**333**		**1081**	**7171**

Table 23. Crowley Reservoir Fall Aerial Survey, October 15, 2009

Species	Lakeshore Segment							Total
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
American Wigeon	51			25			20	96
Bufflehead				23			2	25
Canada Goose	12			125			8	145
Canvasback				12			2	14
Gadwall	30	32	60	110	50		70	352
Greater White-fronted Goose				92				92
Green-winged Teal	200	12		280	60		50	602
Lesser Scaup				20				20
Mallard	80		6	500	25		80	691
Northern Pintail	510			4500	40		150	5200
Northern Shoveler	95	8	50	1785	20		300	2258
Redhead							11	11
Ring-necked Duck				12				12
Ruddy Duck	75		102	1200	80		50	1507
Unidentified Teal	150			520				670
Total Waterfowl	**1203**	**52**	**218**	**9204**	**275**		**743**	**11695**

Table 24. Crowley Reservoir Fall Aerial Survey, November 2, 2009

Species	Lakeshore Segment							Total
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
American Wigeon	20				20			40
Bufflehead	7	8	28	24	13	3	42	125
Canada Goose				25				25
Canvasback	5			3				8
Common Merganser		1						1
Gadwall	70					22		92
Green-winged Teal	170				70		5	245
Lesser Scaup	20			60	12			92
Mallard	20	4		8	20	5	10	67
Northern Pintail	70			110	20	220		420
Northern Shoveler	160			30			20	210
Redhead	5			3				8
Ring-necked Duck				6				6
Ruddy Duck	80	2		442	5	8	20	557
Tundra Swan					2			2
Unidentified Teal				300	10		90	400
Total Waterfowl	**627**	**15**	**28**	**1011**	**172**	**258**	**187**	**2298**

Table 25. Crowley Reservoir Fall Aerial Survey, November 16, 2009

Species	Lakeshore Segment							**Total**
	UPOW	SAPO	NOLA	MCBA	HIBA	CHCL	LASP	
American Wigeon	20		2					22
Bufflehead	23	18	85	210	54	29	25	444
Canada Goose	16			60	1			77
Canvasback	23			17				40
Common Goldeneye			5			3		8
Common Merganser							5	5
Gadwall	65		6	30			5	106
Green-winged Teal	43		6	75	30		71	225
Hooded Merganser							1	1
Lesser Scaup	15			20				35
Mallard	4	6	30	300	71		58	469
Northern Pintail	2		2	60		25	5	94
Northern Shoveler	105	15	12	200		30	4	366
Redhead	6						6	12
Ring-necked Duck					10			10
Ruddy Duck		15	7	600	10	14	261	907
Snow Goose				30				30
Tundra Swan				14				14
Unidentified Teal						6		6
Total Waterfowl	**322**	**54**	**155**	**1616**	**176**	**107**	**441**	**2871**

Table 26. Mono Lake Restoration Ponds - Total Summer Detections

Species	COPOE	COPOW	DEPO_1	DEPO_2	DEPO_3	DEPO_4	DEPO_5	**Total**
Cinnamon Teal			7	2				9
Gadwall	9	1	7	6		3		26
Green-winged Teal				1				1
Mallard	2			1				3
Ruddy Duck	6	1		1	1	7		16
Pond Totals	17	2	14	11	1	10	0	55

Table 27. Mono Lake Restoration Ponds - Total Waterfowl Broods

Species	County Ponds	**DeChambeau Ponds**
Gadwall	5	**2**
Ruddy Duck		**1**
Total Broods	**5**	**3**

Table 28. Mono Lake Restoration Ponds - 2009 Fall Survey Counts

County Ponds	3-Sep	17-Sep	1-Oct	15-Oct	2-Nov	16-Nov	**Total Fall Detections**
Gadwall			5				**5**
Common Merganser			2				**2**
Unidentified Teal	10	10			8		**28**
Total Waterfowl	**10**	**10**	**7**	**0**	**8**	**0**	**35**

DeChambeau Ponds	3-Sep	17-Sep	1-Oct	15-Oct	2-Nov	16-Nov	**Total Fall Detections**
Gadwall		12					12
Mallard				2			2
Northern Shoveler	8						8
Unidentified Teal		9	17	28			54
Total Waterfowl	8	21	17	30	0	0	76

Figure 1. Summer Ground Count Survey Areas

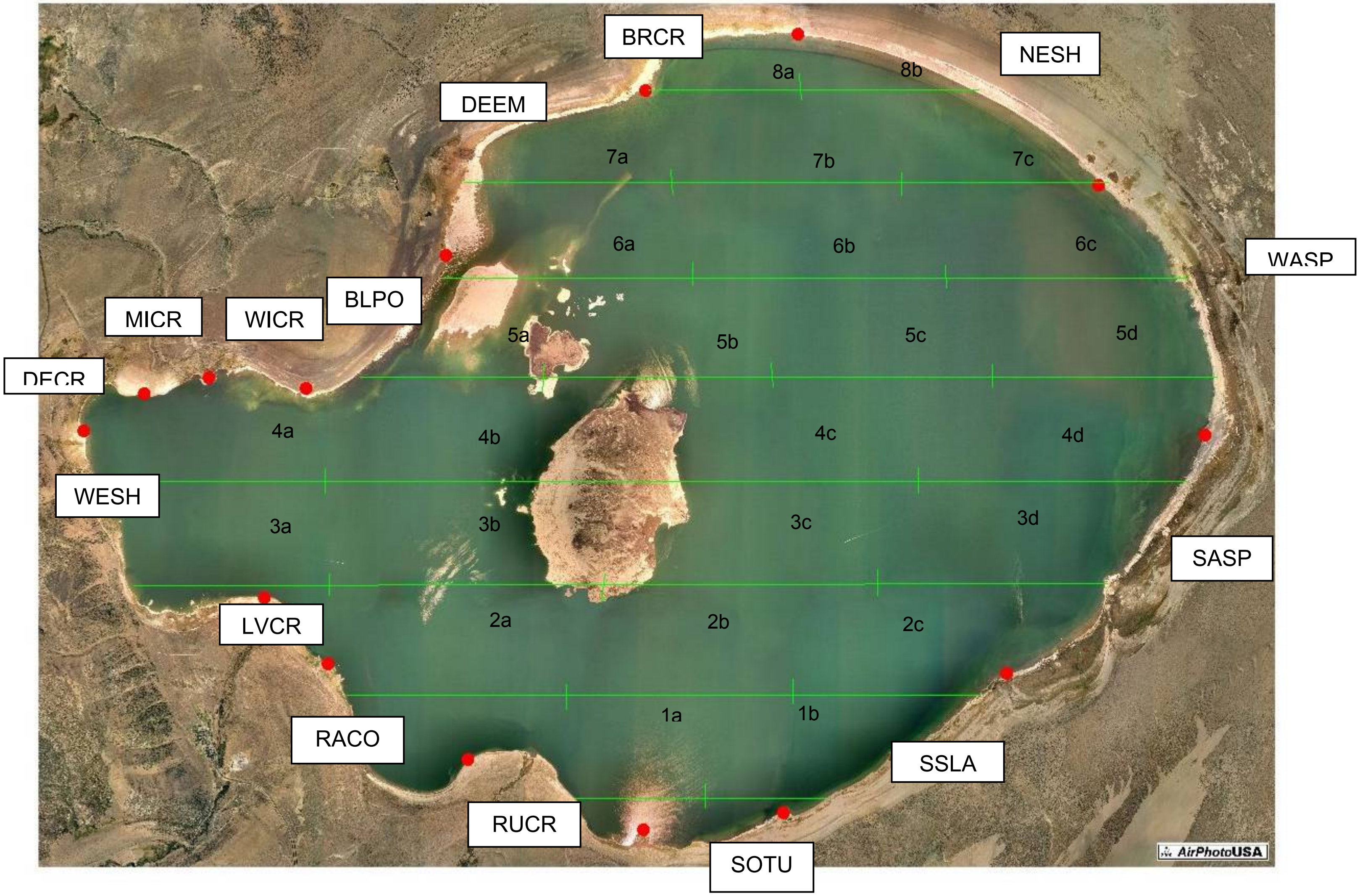


Figure 2. Mono Lake Fall Aerial Survey Lakeshore Segments, Boundaries, and Cross-Lake Transects

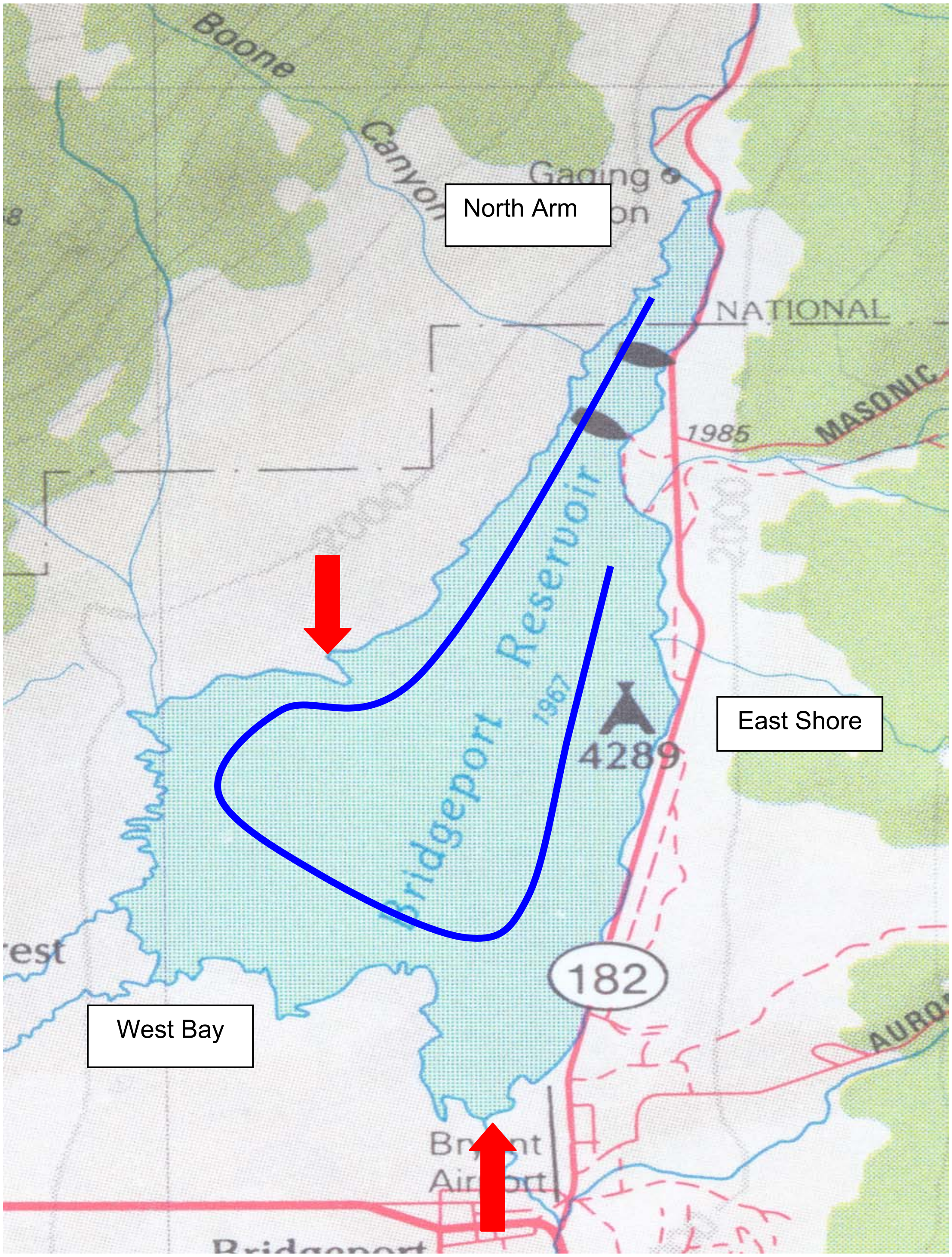


Figure 3. Bridgeport Reservoir Lakeshore Segments and Segment Boundaries

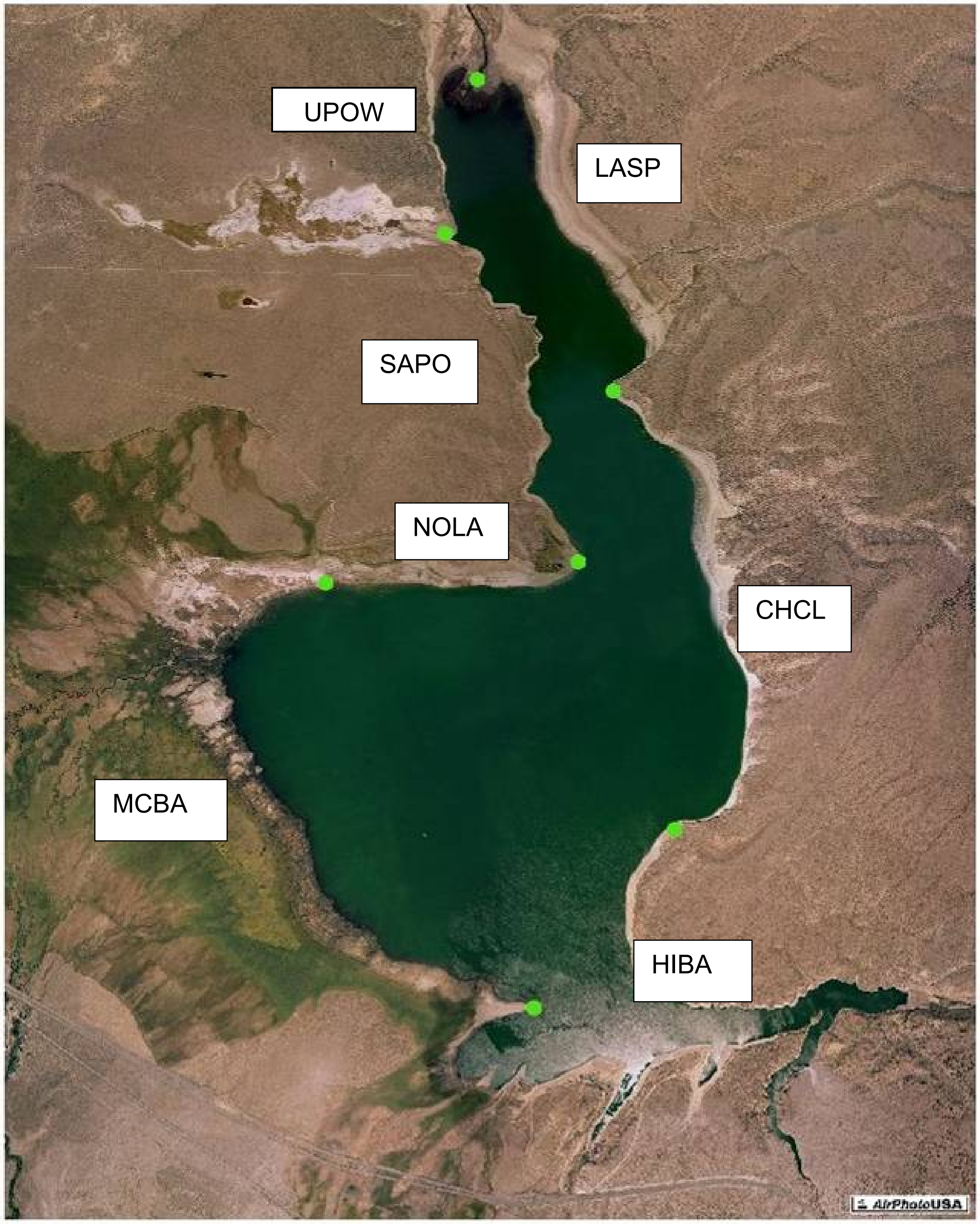


Figure 4. Crowley Reservoir Lakeshore Segments and Segment Boundaries

Figure 5. South Tufa, East of Navy Beach

Figure 6. South Shore Lagoons Area – First Lagoon

Figure 7. South Shoreline – Freshwater Pond

Figure 8. South Shore Lagoons – Sand Flat Spring

Figure 9. South Shore Lagoons Goose Springs Outflow Area

Figure 10. Sammann's Spring West of Tufa Grove

Figure 11. Sammann's Spring, east of Tufa grove

Figure 12. Warm Springs – North Lagoon

Figure 13. Northeast Shore

Figure 14. Bridgeport Creek Shoreline Area

Figure 15. DeChambeau Embayment

Figure 16. Black Point

Figure 17. Wilson Creek Shoreline Area

Figure 18. Mill Creek Delta

Figure 19. DeChambeau Creek Shoreline Area

Figure 20. West Shore

Figure 21. Lee Vining Creek Delta

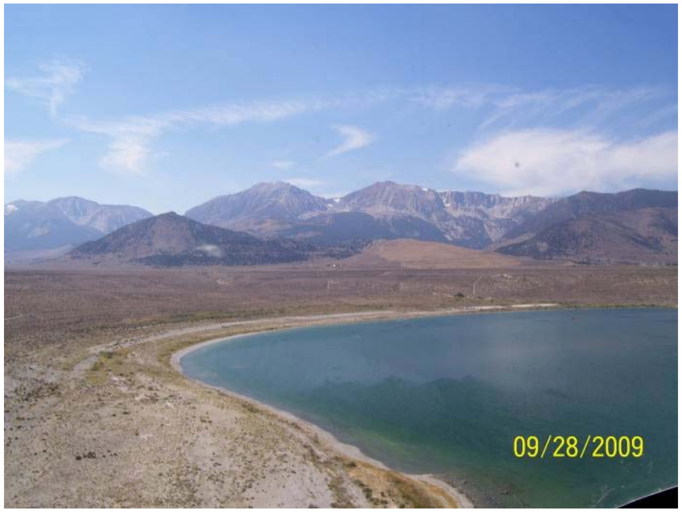


Figure 22. Ranch Cove Shoreline Area

Figure 23. Rush Creek Delta

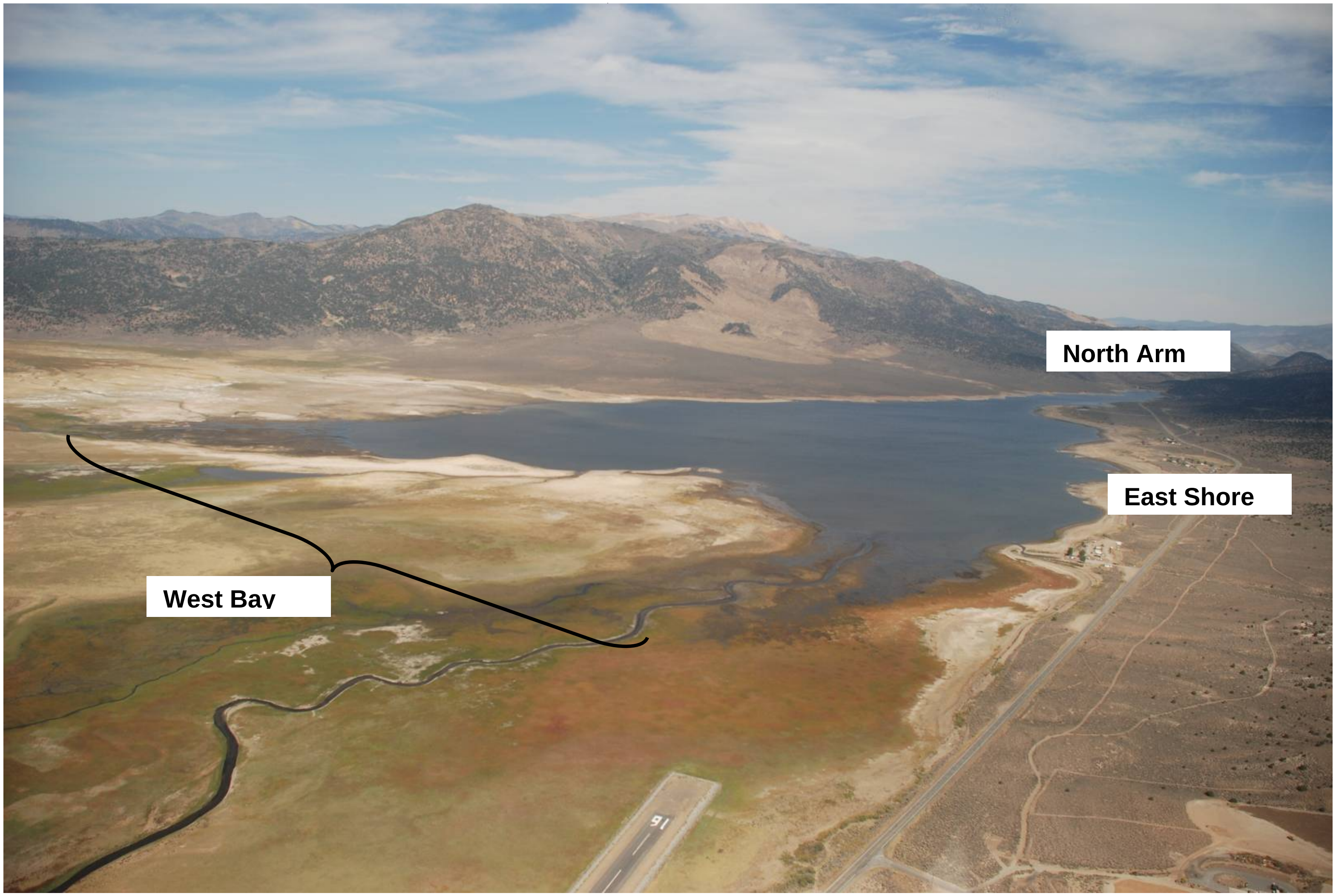


Figure 24 Photo of Bridgeport Reservoir, Looking North
Photo shows the West Bay area and the south end of the East Shore area. The majority of waterfowl that use Bridgeport Reservoir in the fall congregate in this southern end of the reservoir.

Figure 25. Upper Owens River Delta

Figure 26. Sandy Point Shoreline Area

Figure 27. North Landing Shoreline Area

Figure 28. McGee Bay

Figure 29. Hilton Bay

Figure 30. Chalk Cliffs

Figure 31. Hilton Bay

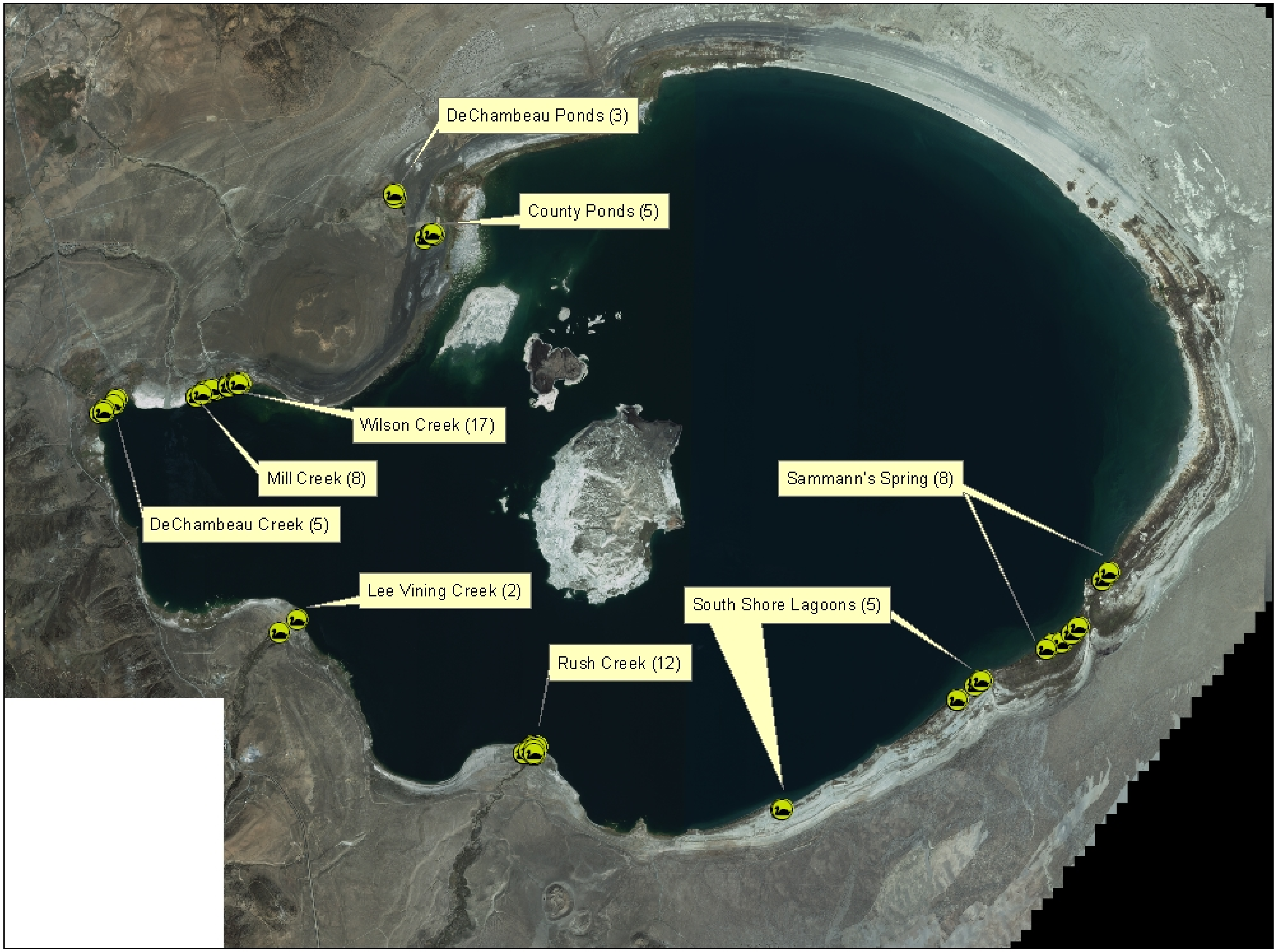


Figure 32. 2009 Brood Locations
The number in parentheses indicates the number of broods found in each area.

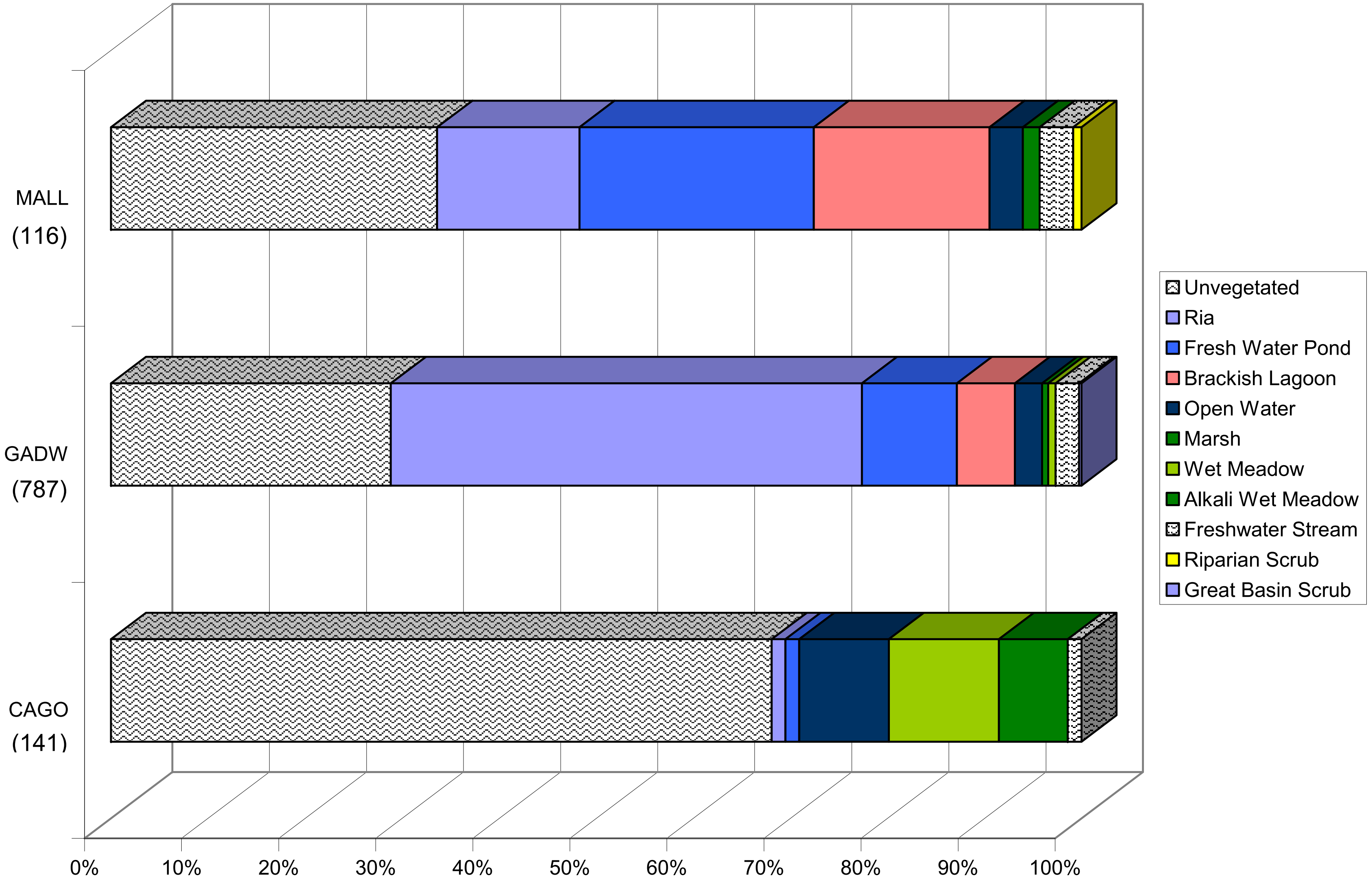


Figure 33. Waterfowl Habitat Use
The numbers in parentheses indicate sample size. The bars represent the percent of the total observations.

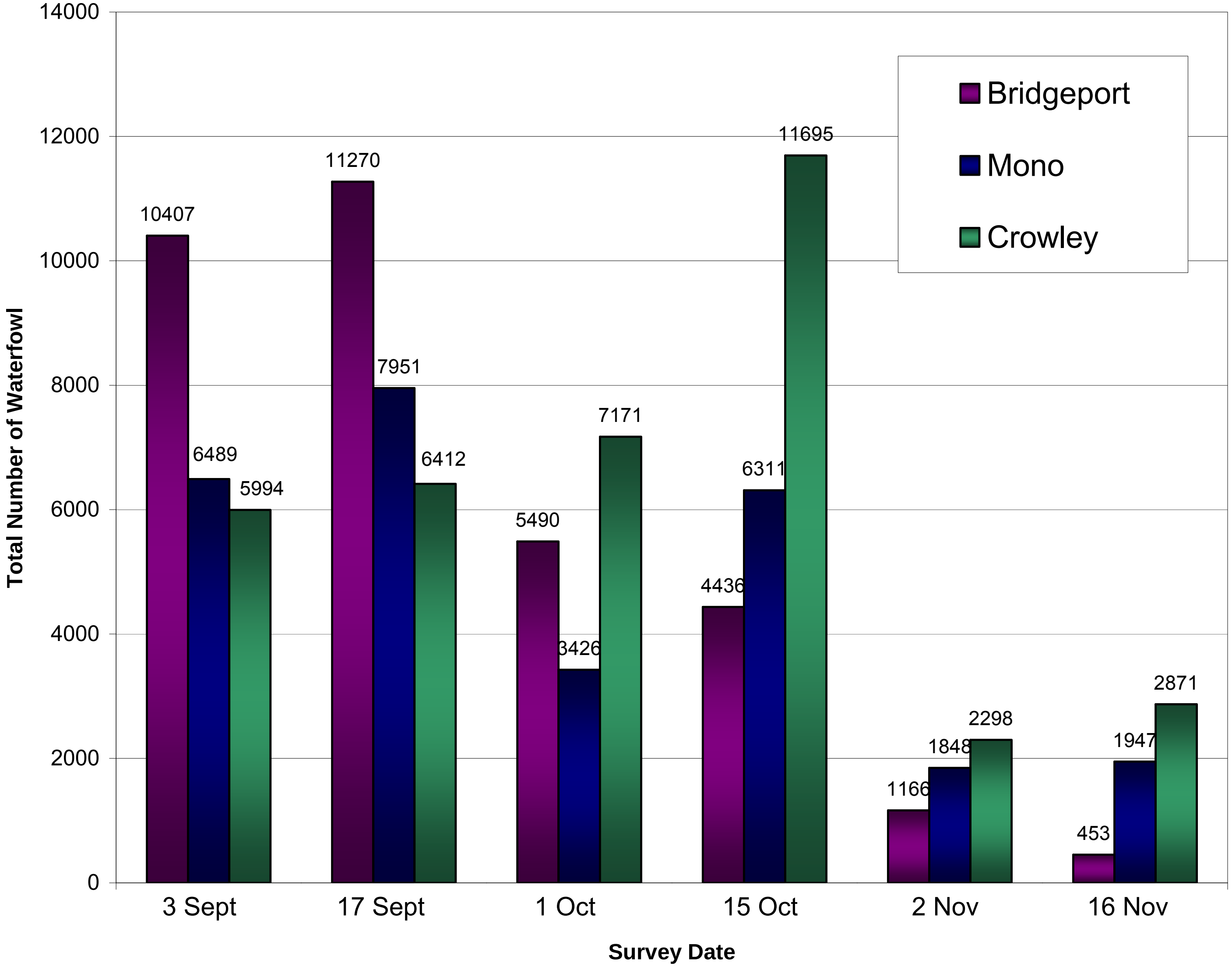


Figure 34. Total Fall Detections by Waterbody

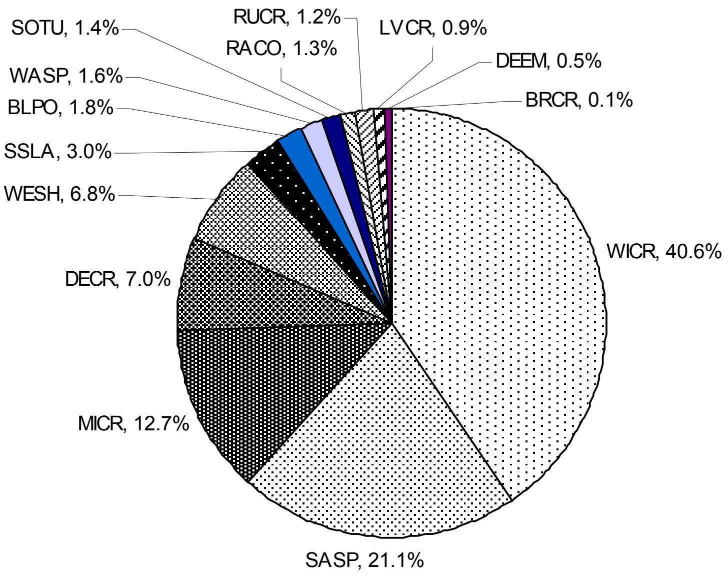


Figure 35. Spatial Distribution – Mono Lake

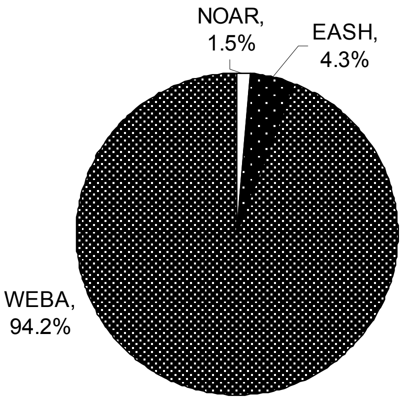


Figure 36. Spatial Distribution – Bridgeport Reservoir

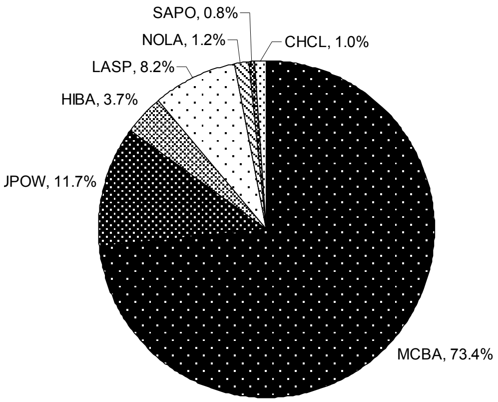


Figure 37. Spatial Distribution – Crowley Reservoir

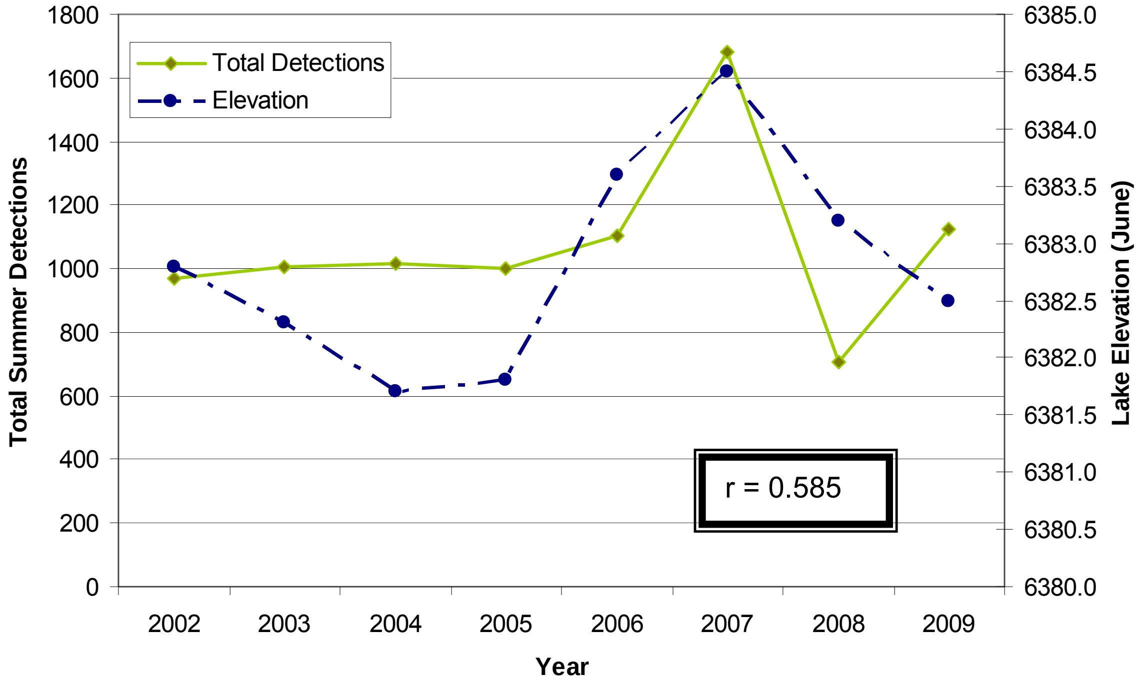


Figure 38. Total Summer Waterfowl Detections vs. Lake Elevation in June (2002-2009)

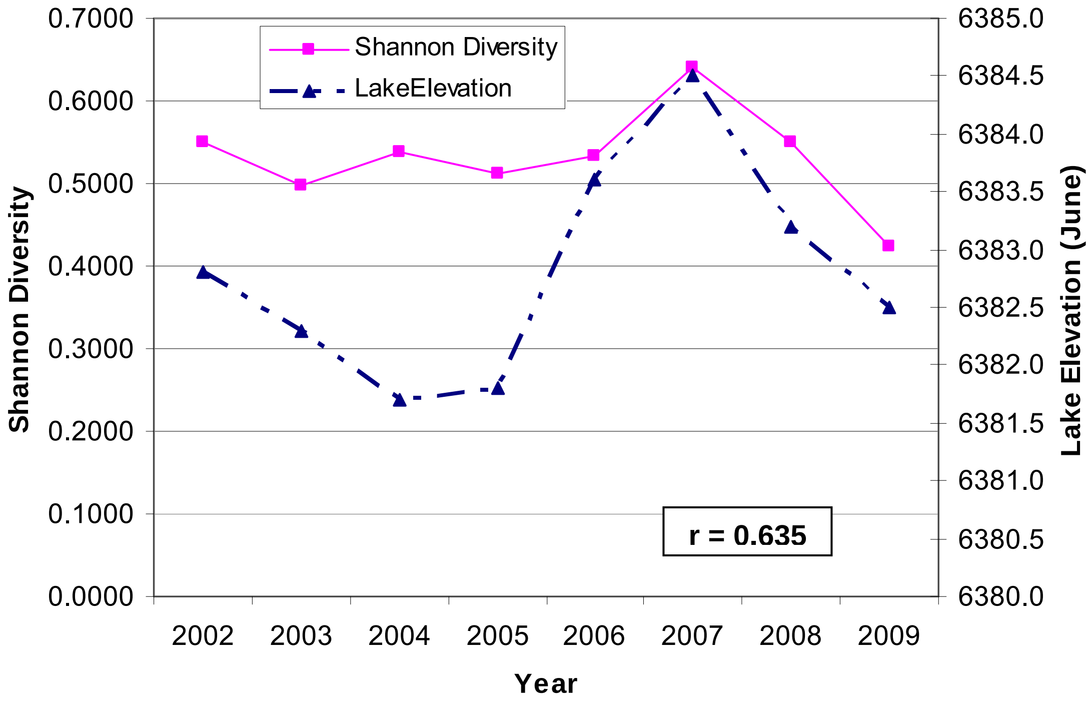


Figure 39. Summer Waterfowl Diversity vs. Lake Elevation (2002-2009)

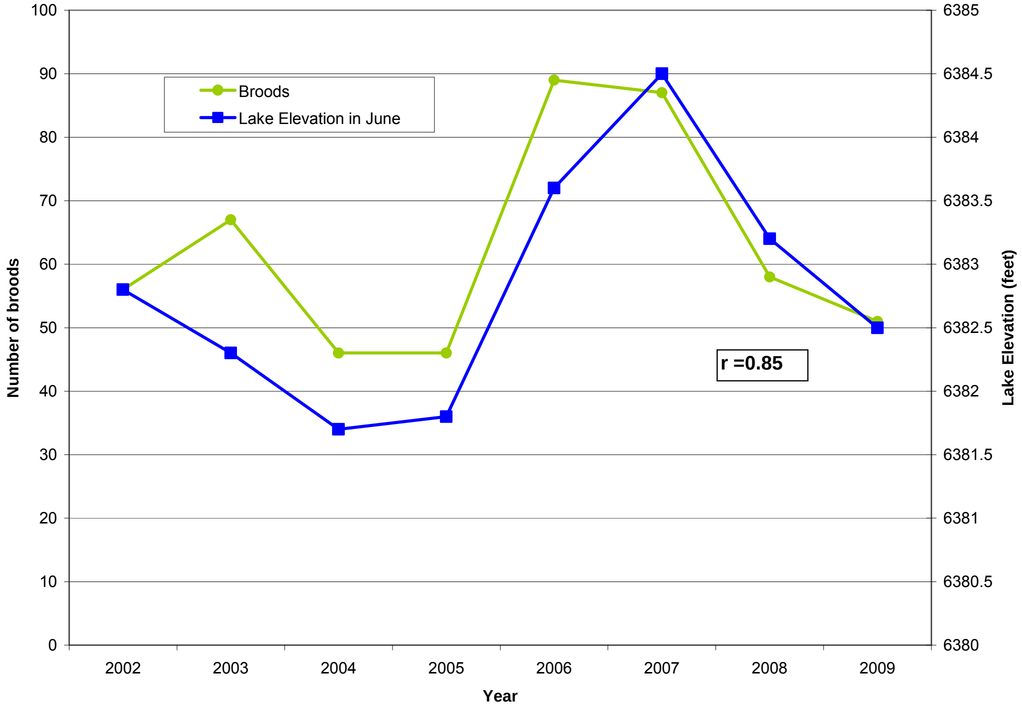


Figure 40. Number of Broods at Mono Lake vs. Lake Elevation 2002-2009

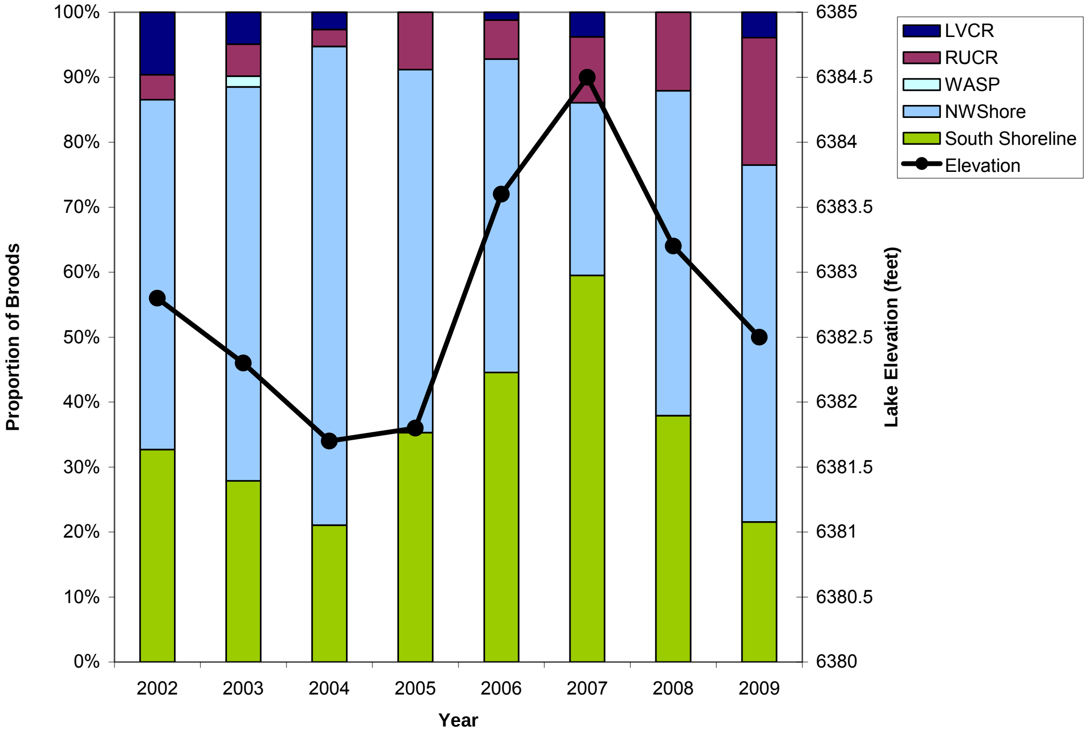
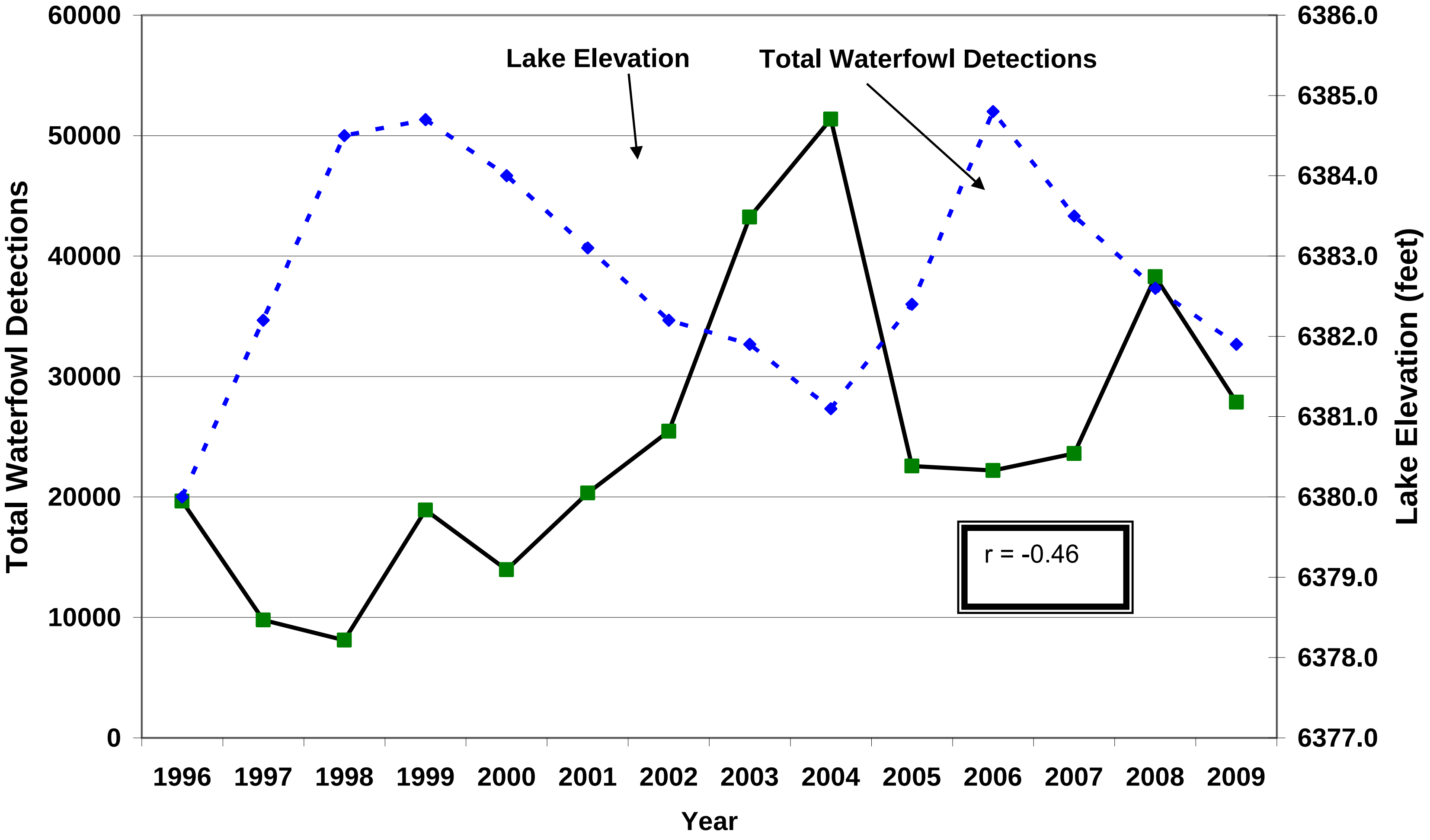


Figure 41. Proportional Use of Mono Lake Shoreline Areas for Brooding 2002-2009

Figure 42. Total Fall Waterfowl Detections vs. Mono Lake Elevation 2002-2009



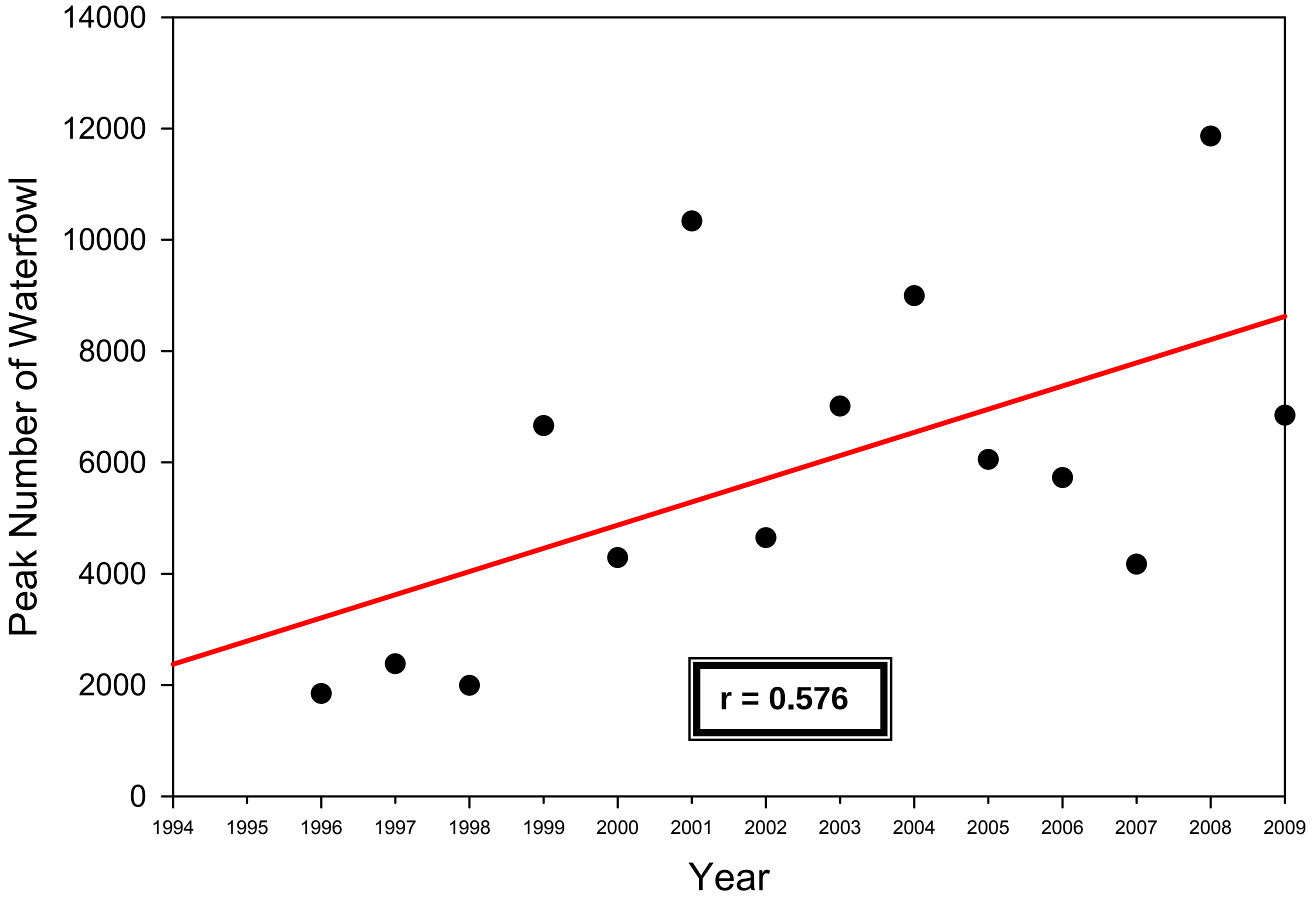


Figure 43. Trend in Peak Waterfowl Numbers (not including Ruddy Ducks) - Mono Lake 1996-2009

APPENDICES

Appendix 1. 2009 Ground Count Survey Dates and Times

Survey 1

Survey area	Survey Date and Time		
	9-Jun	10-Jun	11-Jun
RUCR	0549 - 0650 hrs		
SOTU	0737 - 0827 hrs		
SSLA	0828 - 1110 hrs		
SASP			0550- 0946 hrs
WASP			0947 – 1130 hrs
WICR		0745 – 0834 hrs	
MICR		0636 – 0744 hrs	
DECR		0540 – 0634 hrs	
LVCR		1009 – 1115 hrs	
DEPO		1154 – 1230 hrs	
COPO		1238 - 1248 hrs	

Survey 2

Survey area	Survey Date and Time			
	29-June	30-Jun	1-Jul	2-Jul
RUCR	0605 – 0710 hrs			
SOTU			0550 - 0642 hrs	
SSLA			0642 - 0900 hrs	
SASP				0612 – 0940 hrs
WASP		1120 - 1240 hrs		
WICR		0725 – 0803 hrs		
MICR		0634 – 0724 hrs		
DECR		0538 - 0634 hrs		
LVCR	0812 - 0922 hrs			
DEPO	1024 - 1042 hrs			
COPO	1045 - 1055 hrs			

Appendix 1. Continued. 2009 Ground Count Survey Dates and Times

Survey 3

Survey area	Survey Date and Time			
	20-July	21-July	22-July	23-July
RUCR	0602 – 0719 hrs			
SOTU	0758 - 0849 hrs			
SSLA	0850 - 1107 hrs			
SASP			0616 – 1010 hrs	
WASP				0636 - 0805 hrs
WICR		0754 – 0856 hrs		
MICR		0648 – 0754 hrs		
DECR		0544 – 0648 hrs		
LVCR		1220 – 1320 hrs		
DEPO		1109 – 1141 hrs		
COPO		1038 - 1102 hrs		

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

Common Name	Scientific Name	Code
American Wigeon	*Anas americanus*	AMWI
Blue-winged Teal	*Anas discors*	BWTE
Brant	*Branta bernicla*	BRAN
Bufflehead	*Bucephala albeola*	BUFF
Canada Goose	*Branta canadensis*	CAGO
Canvasback	*Aythya valisineria*	CANV
Cinnamon Teal	*Anas cyanoptera*	CITE
Common Goldeneye	*Bucephala clangula*	COGO
Common Merganser	*Mergus merganser*	COME
Eared Grebe	*Podiceps nigricollis*	EAGR
Lesser Scaup	*Aythya affinis*	LESC
Gadwall	*Anas strepera*	GADW
Greater White-fronted Goose	*Anser albifrons*	GWFG
Green-winged Teal	*Anas crecca*	GWTE
Hooded Merganser	*Lophodytes cucullatus*	HOME
Mallard	*Anas platyrhynchos*	MALL
Northern Pintail	*Anas acuta*	NOPI
Northern Shoveler	*Anas clypeata*	NSHO
Red-breasted Merganser	*Mergus serrator*	RBME
Redhead	*Aythya americana*	REDH
Ring-necked Duck	*Aythya collaris*	RNDU
Ruddy Duck	*Oxyura jamaicensis*	RUDU
Snow Goose	*Chen caerulescens*	SNGO
Tundra Swan	*Cygnus columbianus*	TUSW
White-winged Scoter	*Melanitta fusca*	WWSC
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. 2009 Fall Aerial Survey Dates

Survey Number	1	2	3	4	5	6
Mono Lake	3 Sept	17 Sept	1 Oct	15 Oct	2 Nov	16 Nov
Bridgeport Reservoir	3 Sept	17 Sept	1 Oct	15 Oct	2 Nov	16 Nov
Crowley Reservoir	3 Sept	17 Sept	1 Oct	15 Oct	2 Nov	16 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. Mono Lake Cross-Lake Transect Positions

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

2009

MONO LAKE VEGETATION MONITORING REPORT

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Mono Lake Vegetation Monitoring

The Los Angeles Department of Water and Power conducted vegetation-monitoring activities in lake fringing wetlands surrounding Mono Lake and in tributary stream deltas during the 2009 growing season. These efforts were undertaken to fulfill State Water Resources Control Board obligations as directed in Decision 1631 and Order No. 98-05. The objective of this monitoring effort is to determine changes to wetland communities with fluctuations in lake elevation. As of August 2009, the lake level was approximately 6,382 feet compared to 6,384 feet in 1999 when monitoring was initiated.

Woody Debris

On opportunistic basis, several times during this runoff year, LADWP staff placed large woody debris in both Lee Vining and Rush creeks' channels. Although there are still large woody debris along the channels of both creeks, every time staff remove wood for placement, they are disrupting other organisms that have been using the wood. It is recommended that this practice be discontinued.

Salt Cedar Control

Personnel from LADWP conducted surveys of the delta areas of both Rush and Lee Vining Creeks several times during the 2009 growing season. No plants were observed during these surveys and no treatment occurred.

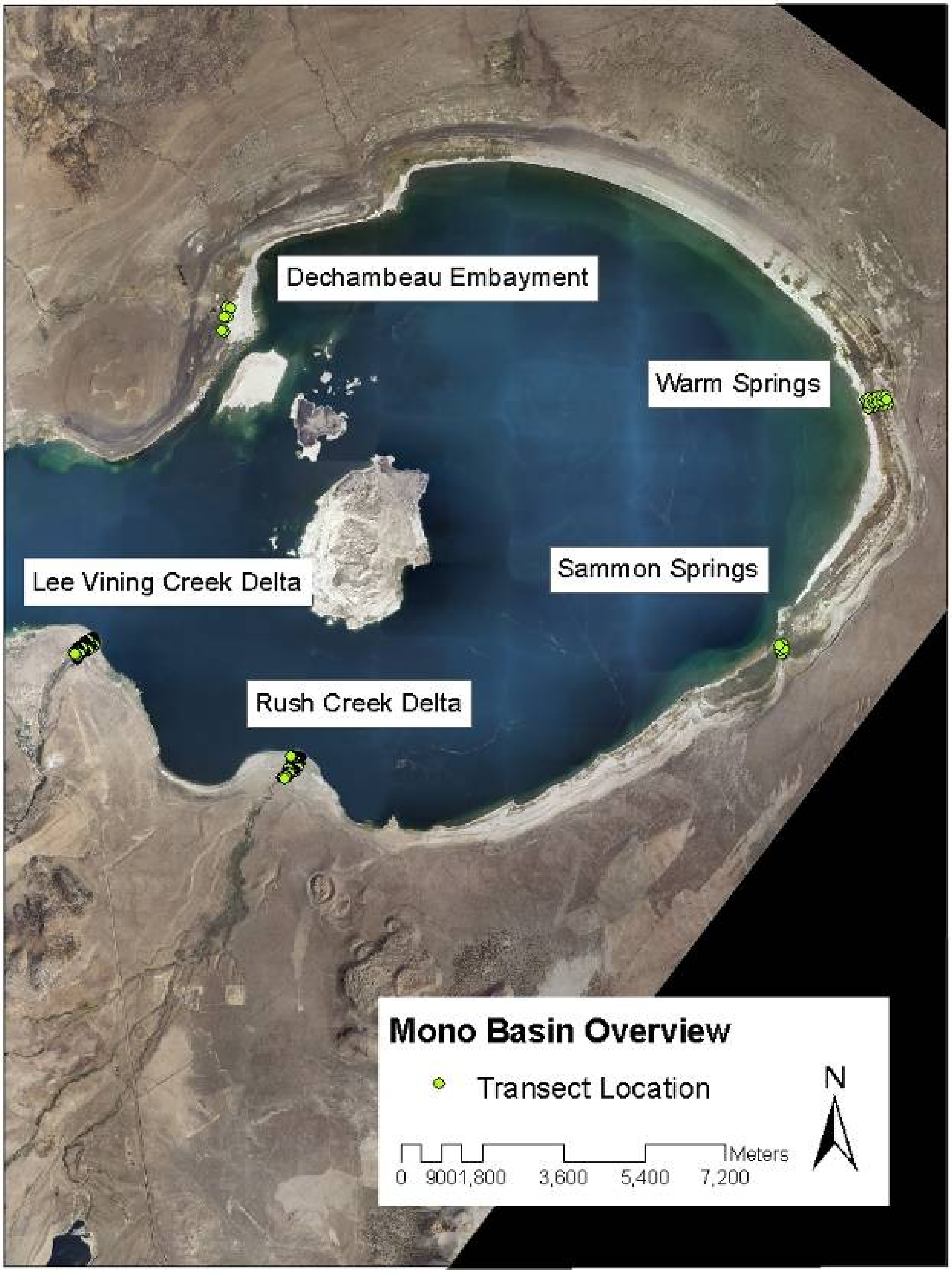
Grazing Moratorium

The grazing moratorium will continue in 2010.

Wetland Monitoring

Wetland monitoring sites were established in 1999 at three locations in the Mono Lake Basin; Dechambeau Embayment, Warm Springs, and Sammon Springs (Figure 1). Vegetation monitoring was conducted along permanent transects using the point intercept method to determine species composition and cover for each site (Mueller et al. 2002). Caution was taken to minimize disturbance to existing vegetation along the permanent transects. Horizontal coordinates of each monitoring site and permanent transects were determined with GPS. Photographs were taken for the monitoring transects and attached in Appendix 1.

Figure 1. Overview map of the Mono Basin.



Vegetation Monitoring Sites

Dechambeau Embayment

At Dechambeau Embayment, three permanent transects were randomly established perpendicular to the Mono Lake shoreline within the marsh areas extending approximately 100 meters from the current lake shore in 1999 (Figure 2). At each end, and the mid-point of each permanent transect, three 50 m long sampling transects were established. The bearing of each sampling transect was set randomly either north or south from each sampling point during the first sampling year. The same bearings have been used in subsequent sampling years. Average cover and species composition are presented in Table 1 as the average of the sampling points of approximately equal distance from the lake shore. Sampling was conducted on August 27th 2009.

Warm Springs

At Warm Springs, three permanent transects were established perpendicular to the Mono Lake shoreline in 1999 (Figure 3). Transects were randomly located within the marsh areas at each site. Transects extended from the 1999 lake elevation, 6382 feet, to approximately 6392 feet (~ 550 m*).* At 100 m intervals along each permanent transect, six 50 meter long sampling transects were established parallel to the lake shore. Sampling transects ran either north or south from the permanent transect. The direction was randomly chosen in 1999 and has remained the same. Average cover and species composition are presented in Table 2. Values are averages of the three sampling points of approximately equal distance from the lake shore. Sampling was conducted on August 26th 2009.

Sammon Springs

At Samman's Springs, three transects established by California State Parks biologists in 1999 were utilized to determine species composition and cover in order to minimize the number of permanent markers visible at this popular tufa viewing site (Figure 4). Transects varied in length as Transects 1 and 2 are 100 meters long while Transect 3 is 75 meters long. Average cover and species composition are presented in Table 3. Sampling was conducted on August 25th 2009.

Figure 2. Dechambeau Embayment transect locations.

Table 1. Species list and average percent cover for the Dechambeau Embayment Wetland Vegetation monitoring area. Values are averages of sampling points of approximately equal distance from the lake shore. Transect 1 is closest to the lake while Transect 3 is furthest from the lake.

Dechambeau Embayment	Transect 1			Transect 2			Transect 3		
Species	1999	2005	2009	1999	2005	2009	1999	2005	2009
Allenrofea occidentalis	0.7	--	--	--	--	--	--	--	--
Bassia hyssopifolia	0.7	0.7	--	6.0	--	--	1.3	--	--
Brassicaceae spp.	--	--	--	--	--	--	6.0	--	--
Carex rostrata	0.7	--	--	--	--	--	--	--	--
Chenepodaceae spp.	--	--	--	--	--	--	8.0	--	--
Chenopodium album	--	--	--	--	--	1.3	--	--	7.8
Descuriana pinnata	1.3	--	--	3.3	--	--	18.0	2.7	1.3
Distichlis spicata	22.0	10.7	12.4	14.7	3.3	2.6	6.0	--	--
Epilobium ciliatum ssp. *ciliatum*	--	--	--	--	0.7	2.6	--	4.7	3.3
Hordeum jubatum	1.3	6.0	4.6	44.0	14.7	7.8	17.3	0.7	--
Juncus arcticus	1.3	--	--	--	3.3	1.3	0.7	0.7	--
Lactuca seriola	--	--	--	--	--	--	--	--	3.3
Muhlenbergia asperifolia	2.0	4.0	--	--	--	--	--	--	--
Poa pratensis	--	--	5.2	--	--	0.6	--	--	--
Poa secunda	4.0	--	--	14.0	5.8	--	--	--	--
Poa sp.	--	6.7	--	--	8.7	--	--	--	--
Polypogon monospeliensis	--	--	--	1.3	--	--	4.7	5.3	0.7
Rumex salicifolius	--	--	--	--	--	0.6	--	--	0.7
Salix exigua	--	--	--	--	--	--	0.7	--	8.5
Salsola tragus	--	--	--	--	--	--	2.7	--	--
Sarcobantus vermiculatus	--	--	--	--	--	--	0.7	--	--
Schoenoplectus acutus	--	--	--	--	--	--	--	0.7	9.2
Schoenoplectus americanus	31.2	54.0	50.3	16.0	61.3	71.4	27.3	75.3	43.8
Schoenoplectus maritimus	--	--	13.1	--	--	--	--	--	--
Scirpus nevadensis	--	1.3	--	--	4.0	0.6	--	--	--
Triglogin concinna	4.7	--	--	--	--	--	--	--	--
Triglochin maritima	--	6.7	--	--	--	--	--	--	--
Typha latifolia	--	--	--	--	--	--	2.7	9.3	12.4
Veronica perigrina	--	--	--	--	--	--	1.3	--	--
Bare Ground	--	1.3	0.7	--	--	--	--	--	--
Litter	20.7	7.3	13.7	--	4.0	11.0	--	0.7	9.2
Tufa	--	1.3	--	--	--	--	--	--	--
Water	8.0	2.0	--	--	4.0	--	1.3	--	--

Figure 3. Warm Springs transect locations

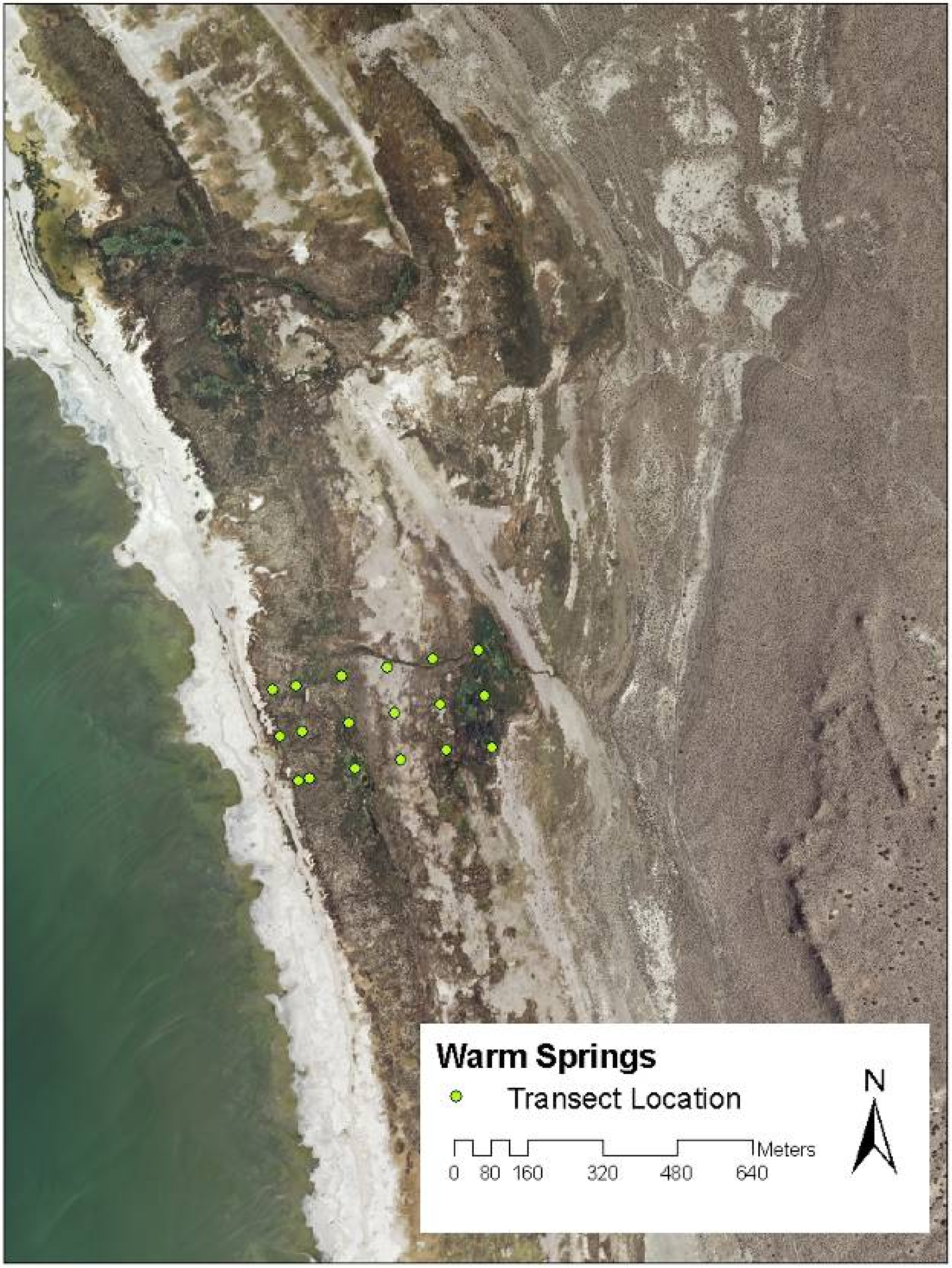


Table 2. Species list and average percent cover for the six sampling transects at the Warm Springs Wetland Vegetation monitoring area. Values are averages of sampling points. Transect 1 is closest to the lake while Transect 6 is furthest from the lake.

Warm Spring	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5			Transect 6		
Species	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009
Artriplex phylostegia	--	--	--	--	--	--	--	--	--	--	--	5.3	--	--	--	--	--	--
Atriplex truncata	--	--	--	--	--	--	--	--	--	--	--	--	--	1.3	--	--	--	--
Cleomella plocasperma	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	--	--	--
Distichlis spicata	--	--	--	--	--	--	--	--	--	15.3	15.3	3.3	2.0	1.3	0.7	--	--	--
Eriogonum sp.	--	--	--	--	--	--	--	--	--	--	--	5.9	--	--	--	--	--	--
Juncus arcticus	--	--	--	--	--	--	1.3	1.3	2.6	--	--	--	3.3	--	--	3.3	5.3	7.2
Muhlenbergia asperifolia	--	--	--	--	--	--	--	--	--	--	--	--	--	0.7	--	--	--	--
Nitrophilla occidentalis	--	--	--	--	--	--	--	--	--	--	--	7.2	--	2.7	4.6	--	1.3	--
Poa pretensis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3.3	--	--	--
Psathyrotes annua	--	--	--	--	--	--	--	--	--	--	--	1.3	--	--	--	--	--	--
Schoenoplectus acutus	--	--	--	--	--	--	16.7	5.3	2.6	--	--	2.0	--	--	--	2.7	--	2.6
Schoenoplectus americanus	--	--	0.7	18.0	16.0	7.9	5.3	55.3	39.7	--	--	1.3	13.3	14.0	9.3	74.0	78.0	48.0
Scirpus nevadensis	64.7	72.7	55.0	58.7	66.0	67.8	37.3	20.7	7.9	46.0	49.3	23.7	62.7	75.3	25.2	16.0	10.7	12.5
Triglochin maritima	--	--	--	--	--	--	--	--	--	--	--	--	--	1.3	--	--	--	--
Uknown annual forb	--	--	--	--	--	--	--	--	--	--	--	--	0.7	2.7	--	--	--	--
Uknown mustard	10.7	0.7	--	3.3	--	--	10.7	--	--	2.7	--	--	2.7	2.6	--	2.0	--	--
Bare Ground	10.7	--	--	3.3	--	--	6.7	--	2.6	20.7	16.7	21.1	1.3	--	3.3	2.0	--	1.3
Litter	10.7	27.3	44.4	16.0	18.0	24.3	11.3	12.7	37.1	15.3	18.7	27.6	7.3	3.3	52.3	--	3.3	25.7
Rock	--	--	--	--	--	--	--	--	--	--	--	1.3	--	--	--	--	--	0.7
Tufa	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.3	--
Water	3.3	--	--	0.7	--	--	10.7	4.7	7.3	--	--	--	--	--	0.7	--	--	2.0

Figure 4. Sammon Springs transect locations.

Table 3. Species list and average percent cover for the three sampling transects at the Sammon Springs Wetland Vegetation monitoring area.

Sammon Springs	Transect 1			Transect 2			Transect 3		
Species	1999	2005	2009	1999	2005	2009	1999	2005	2009
AAFF	--	1.3	--	--	--	--	--	--	--
Agrostis sp.	--	--	1.0	--	--	--	--	--	--
Brassica sp.	--	1.3	--	--	--	--	--	--	--
Casteleja spp.	--	--	--	2.0	--	--	--	--	--
Carex nebrascensis	--	--	1.0	--	--	--	--	--	--
Carex spp.	--	32.0	3.0	--	1.0	12.9	--	2.0	44.7
Distichlis spicata	10.7	6.7	5.9	3.0	--	--	7.0	4.0	3.9
Epilobium spp.	2.7	--	--	--	--	--	--	--	--
Eleocharis macrostachya	28.0	--	--	6.0	--	--	5.0	--	--
Ericameria nauseosa	--	2.7	3.0	--	1.0	--	6.0	7.0	1.3
Hordeum jubatum	--	--	1.0	--	--	--	2.0	--	--
Mimulus glabrata	--	--	--	2.0	--	--	--	--	--
Juncus arcticus	13.3	42.7	9.9	34.0	49.0	41.6	17.0	40.0	17.1
Muhlenbergia asperifolia	--	--	2.0	2.0	1.0	2.0	2.0	--	--
Poa pratensis	--	--	--	--	--	--	2.0	--	--
Schoenoplectus acutus	--	--	2.0	27.0	21.0	12.9	1.0	--	--
Schoenoplectus americanus	28.0	9.3	2.0	8.0	1.0	--	10.0	3.0	1.3
Scirpus nevadensis	5.3	2.7	4.0	--	3.0	--	23.0	17.0	--
Solidago spectabilis	--	--	2.0	3.0	--	--	4.0	8.0	--
Typha latifolia	--	--	1.0	7.0	12.0	7.9	2.0	1.0	--
Bare Ground	6.3	1.3	12.9	2.0	1.0	1.0	12.0	8.0	5.3
Litter	6.3	1.3	49.5	2.0	10.0	21.8	7.0	5.0	25.0
Tufa	--	--	--	--	--	--	--	5.0	--
Water	--	--	--	2.0	--	--	--	--	1.3

Tributary Delta Monitoring

Six transects were established within the delta areas of both Rush and Lee Vining Creeks in 1999 (Figures 1, 5, and 6). A seventh transect was added at the mouth of Rush Creek during the 2009 sampling season. The first transect, transect 1, was located near the mouth of each delta. Subsequent transects were established upstream of the deltas at approximately 100-meter intervals. Vegetation monitoring was conducted using the line-point intercept method to determine species composition and cover for each site. These data are presented in Tables 4 and 5. Horizontal coordinates of each sampling transect were determined with GPS. GPS readings were also taken at approximately 10-meter intervals along each sampling transect. With all sampling, caution was taken to not disturb existing monitoring areas. Transects varied in length, depending on the width of the floodplain, beginning from the top of the bank descending into the flood plain across the creek channel and up the opposite bank. The sampling interval was 20-25 steps in 1999 and 2009, and every other step in 2005.

Figure 5. Lee Vining Creek transect locations.

Table 4. Species list and average percent cover for each of the transects at the Lee Vining Delta vegetation monitoring area. Transect 1 is closest to the lake while Transect 6 is furthest from the lake.

Lee Vining Creek	**Transect 1**			**Transect 2**			**Transect 3**			**Transect 4**			**Transect 5**			**Transect 6**		
Species	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**
Achillea millefolium	--	0.8	--	--	--	--	--	2.1	6.7	--	0.7	--	--	--	--	--	--	--
Agrostis scabra	--	--	--	--	--	--	--	--	6.7	--	--	18.2	--	--	--	--	--	--
Agrostis stolonifera	4.4	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--
Annual Forb	--	0.4	--	--	0.3	--	--	--	--	--	--	--	--	0.4	--	--	0.4	--
Arnica longifolia	--	0.8	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Artemisia ludoviciana	--	0.8	3.1	2.9	--	6.5	3.9	2.8	--	3.6	0.7	9.1	1.7	0.4	8.3	1.9	1.7	5.3
Artemisia tridentata	4.3	0.4	--	1.0	--	--	--	--	--	0.7	0.7	--	2.3	1.8	--	0.6	2.1	10.5
Calamagrostis neglecta	--	--	--	--	1.0	--	--	2.4	--	--	2.2	--	--	--	--	--	--	--
Carex sp.	--	1.9	--	--	5.6	--	--	2.4	--	--	--	--	--	--	--	--	0.8	--
Carex utriculata	--	--	15.6	--	--	16.1	--	--	3.3	--	--	--	--	--	8.3	--	--	--
Casteleja sp.	--	--	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cirsium vulgare	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cyperus sp.	--	--	6.3	1.0	--	3.2	1.0	--	3.3	--	--	--	--	--	--	--	--	--
Distichlis spicata	--	--	--	1.0	--	--	--	--	--	--	--	--	4.5	--	--	1.8	--	--
Eleocharis sp.	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Epilobium ciliatum var. *ciliatum*	--	0.8	--	--	--	--	--	1.7	--	--	--	--	--	--	--	--	--	--
Ericameria nauseosa	--	1.5	--	--	0.4	--	--	--	3.3	--	--	--	--	0.4	--	--	0.8	--
Erigeron sp.	--	--	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Juncus arcticus	--	4.6	--	--	1.4	--	--	1.4	--	--	--	--	--	--	--	0.6	2.5	--
Juncus nevadensis	--	3.5	6.3	6.7	4.9	12.9	--	4.5	6.7	2.9	0.7	--	--	--	--	--	--	--
Juncus orthophyllus	--	--	--	--	0.7	--	--	--	--	--	--	--	--	--	--	--	--	--
Juncus sp.	--	--	3.1	--	--	3.2	--	--	--	--	--	--	--	--	--	--	--	--
Lupine sp.	4.3	3.5	9.4	3.8	2.8	9.7	5.8	6.6	6.7	2.2	--	9.1	1.1	0.9	--	3.7	10.1	21.1
Melilotus alba	8.7	--	--	4.8	--	--	1.0	--	--	--	--	--	--	--	--	1.8	--	--
Medicago lupulina	--	4.2	--	--	1.8	--	--	1.0	--	0.7	--	--	--	--	--	--	--	--
Melilotus officinalis	--	--	6.3	--	--	3.2	--	--	3.3	--	--	--	--	--	--	--	--	--
Mimulus floribundus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.4	--
Mimulus guttatus	--	--	--	--	--	--	--	--	3.3	--	--	--	--	--	--	--	--	--
Muhlenbergia spp.	4.3	3.9	9.4	--	1.1	9.7	--	0.3	3.3	2.2	--	9.1	--	0.4	--	2.5	--	--
Oenothera sp.	--	0.4	3.1	--	--	3.2	--	--	3.3	--	--	--	--	--	--	--	--	--

Lee Vining Creek	**Transect 1**			**Transect 2**			**Transect 3**			**Transect 4**			**Transect 5**			**Transect 6**		
Species	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**	**1999**	**2005**	**2009**
Penstemon sp.	--	--	--	--	--	--	--	1.4	--	--	5.1	--	--	2.2	--	--	0.4	--
Phlox sp.	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	--	--	--	--
Pinus contorta	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.3	--	--	--
Pinus jeffreyi	--	--	--	--	--	--	--	--	--	--	--	--	--	--	16.7	--	--	--
Poa pratensis	--	--	--	--	6.3	--	1.9	0.3	--	1.4	--	--	0.6	--	--	0.6	0.4	--
Poa secunda	--	--	--	--	--	--	--	--	--	--	0.7	--	1.7	--	--	--	--	--
Poa sp.	--	--	--	--	--	--	--	--	--	--	--	9.1	--	--	8.3	--	--	--
Populus balsamifera	--	0.4	--	--	0.4	--	--	0.7	13.3	--	4.4	--	--	2.2	16.7	--	2.1	21.1
Populus fremontii	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Populus trichocarpa	--	0.8	--	1.0	0.3	--	--	0.7	--	--	4.3	--	4.5	2.2	--	12.3	2.1	--
Purshia tridentata	--	--	--	--	--	--	--	0.3	--	--	0.7	9.1	2.3	2.7	16.7	--	4.6	15.8
Rosa woodsii	--	0.4	3.1	--	0.4	--	1.0	--	--	--	--	9.1	4.0	--	--	3.1	--	5.3
Rumex crispus	--	--	--	--	--	--	1.0	--	--	--	--	--	--	--	--	--	--	--
Salix sp.	4.4	--	--	--	--	--	--	2.4	--	--	2.9	--	--	--	--	--	--	--
Salix exigua	13.0	9.3	12.5	45.2	9.5	19.4	23.3	5.9	20.0	5.0	0.7	18.2	2.3	--	8.3	2.5	--	5.3
Salix exigua (dead)	17.4	0.4	--	--	0.3	--	2.0	0.7	--	--	--	--	--	--	--	--	--	--
Salix lutea	--	3.5	3.1	4.8	4.9	3.2	6.8	1.4	--	--	0.7	--	--	--	--	4.9	0.4	--
Saponaria officinalis	--	0.8	--	--	2.8	6.5	--	1.0	6.7	--	--	9.1	--	--	8.3	--	--	15.8
Schoenoplectus americanus	--	3.5	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Solidago spectabilis	--	9.3	6.3	1.9	5.6	3.2	--	1.7	3.3	--	--	--	--	--	--	--	--	--
Symphyotrichum spathulatum	--	--	--	--	--	--	--	0.3	--	--	--	--	--	--	--	--	--	--
Trifolium longipes	--	0.4	--	--	0.4	--	--	0.3	--	--	--	--	--	--	--	--	--	--
Trifolium sp.	--	--	--	--	--	--	--	--	3.3	--	--	--	--	--	--	--	--	--
Typha latifolia	--	0.8	3.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Verbascum thapsus	--	--	--	--	--	--	--	--	3.3	--	--	--	--	--	--	--	0.4	--
Valeriana californica	--	--	--	--	--	--	2.9	--	--	2.9	--	--	1.1	--	--	--	--	--
Bare Ground	17.4	2.7	--	9.6	4.9	--	29.1	3.8	--	51.8	5.1	--	57.6	5.8	--	42.9	8.4	--
Litter	8.7	9.3	--	9.6	12.0	--	12.6	19.4	--	5.0	10.3	--	8.5	7.1	--	14.7	15.6	--
Moss	--	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--
Rock	--	9.3	--	--	21.8	--	--	26.4	--	--	57.4	--	--	66.7	--	--	38.8	--
Water	13.0	9.3	--	6.7	11.6	--	6.8	11.1	--	21.6	8.8	--	7.3	9.3	--	6.1	10.1	--

Figure 6. Rush Creek sampling locations.

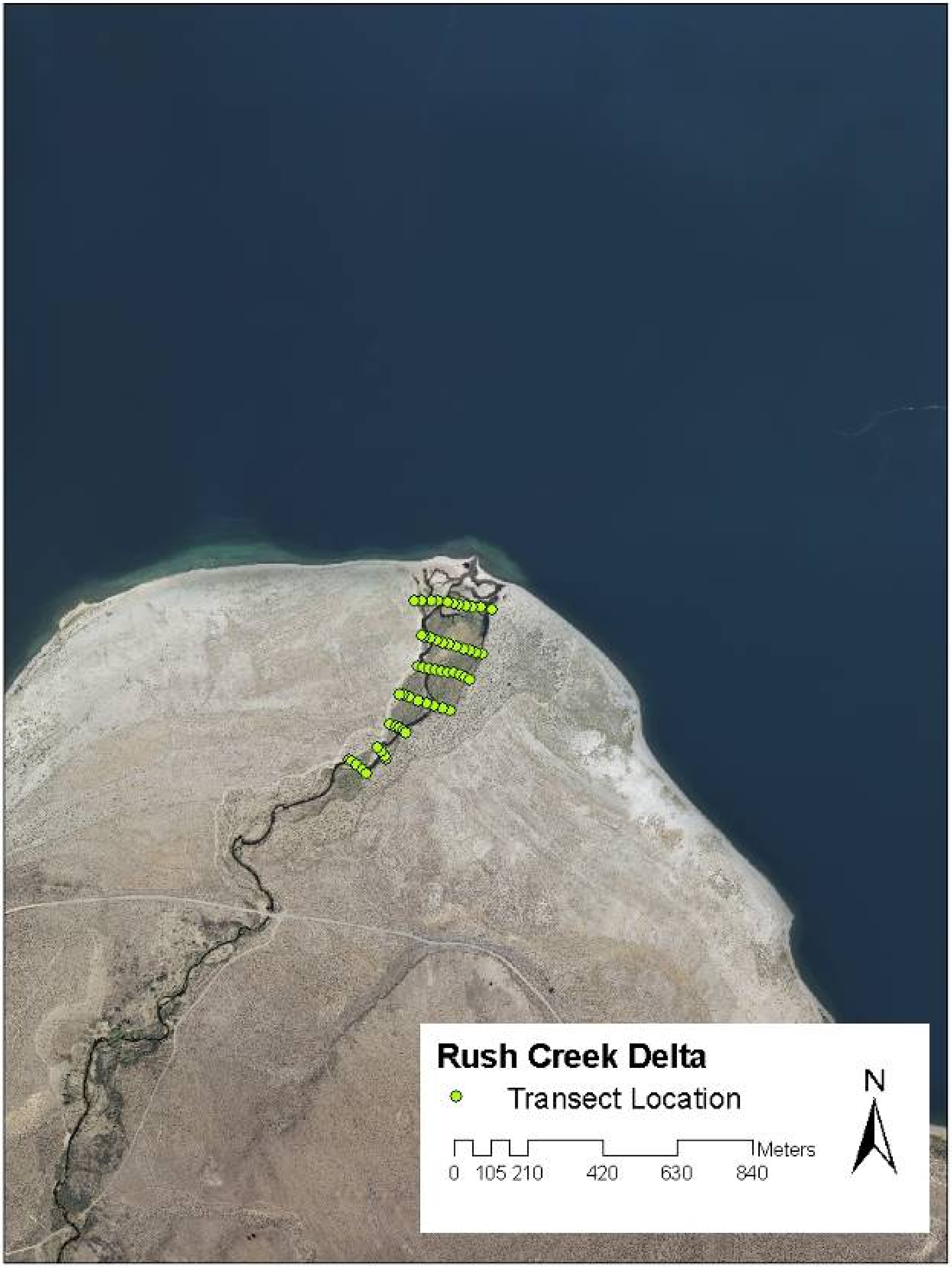


Table 5. Species list and average percent cover for each of the transects at the Rush Creek Delta Vegetation monitoring area. Transect 7 is closest to the lake followed by Transects 1 trough 6.

Rush Creek	Transect 1			Transect 2			Transect 3			Transect 4			Transect 5			Transect 6			Transect 7
Species	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009	1999	2005	2009	2009
Annual Forb	0.5	1.1	--	--	1.1	--	--	2.1	--	--	--	--	--	3.0	--	--	--	--	--
Achillea millefolium	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--
Achnatherum hymenoides	--	--	--	--	--	--	--	--	8.3	--	--	--	--	--	--	--	--	--	--
Arnica longifolia	--	--	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--
Artemisia ludoviciana	--	0.4	--	--	--	--	--	--	8.3	--	--	--	--	--	--	1.4	2.4	--	--
Artemisia tridentata	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	14.3	--
Aster sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.1
Astragalus canadensis	--	--	--	--	--	--	--	0.5	--	--	--	--	--	3.2	--	--	--	--	--
Berula erecta	--	--	--	--	--	--	--	--	8.3	--	--	--	--	--	--	--	--	--	--
Carex aquatilis	--	--	--	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Carex douglasii	--	--	--		--	--	--	1.9	--	--	--	--		--	--	--	--	--	--
Carex nebrascensis	0.5	1.9	--	--	0.9	--	--	4.2	--	--	--	--	3.9	--	--	2.4	3.6	--	--
Carex praegracilis	0.5	--	--	--	--	--	0.6	--	--	--	--	--	5.9	--	--	--	--	--	--
Carex sp.	--	--	--	--	--	--	--	6.0	--	--	5.1	--	--	--	--	--	--	--	--
Carex utriculata	--	--	--	--	--	7.7	--	--	--	--	--	--	--	--	--	--	--	--	--
Castilleja sp.	--	--	7.7	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--
Chrysothamnus nauseosus	--	--	--	--	--	--	1.1	--	--	1.6	--	--	2.0	--	--	--	--	--	--
Deschampsia cespitosa	2.0	--	--	--	0.4	7.7	--	--	8.3	--	--	--	--	--	--	--	--	--	--
Distichlis spicata	--	0.4	--	--	--	--	--	--	--	--	2.5	--	--	--	--	2.4	1.2	--	7.1
Eleocharis sp.	--	1.9	--	--	--	--	--	1.4	--	--	--	--	--	--	--	--	--	--	--
Epilobium ciliatum ssp. *ciliatum*	--	0.4	--	--	--	--	--	0.5	--	--	--	--	--	--	--	--	--	--	--
Epipactis gigantea	--	--	--	--	--	--	--	--	8.3	--	--	--	--	--	--	--	--	--	--
Equisetum arvense	--	0.4	7.7	--	--	--	--	--	--	--	--	--	--	1.6	50.0	--	1.2	42.9	--
Ericameria nauseosa	--	--	7.7	--	--	--	--	--	--	--	2.5	16.7	--	3.2	--	--	1.2	--	--
Eriognum sp.	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Iris sp.	--	--	--	--	--	7.7	--	--	--	--	--	--	--	--	--	--	--	--	--
Juncus balticus	11.0	20.2	15.4	23.8	29.6	7.7	14.7	18.6	25.0	12.7	16.5	16.7	13.7	15.9	--	8.4	2.4	--	--
Juncus bufonis	1.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Juncus longistylus	3.5	--	--	3.3	--	--	2.8	--	--	1.6	--	--	--	--	--	--	--	--	--
Juncus nevadensis	--	9.0	--	--	11.7	--	--	14.9	--	--	--	--	--	--	--	--	--	--	--
Lupinus sp.	--	8.6	--	0.6	--	--	1.1	0.5	16.7	17.5	11.4	--	--	--	--	--	--	--	--

Mentzelia laevicaulis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.1
Mimulus guttatus	--	1.1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Muhlenbergia asperifolia	--	2.2	7.7	--	1.3	15.4	0.6	3.7	--	--	6.3	--	--	11.1	--	--	--	--	7.1
Muhlenbergia spp.	3.0	--	--	1.1	--	--	1.2	--	--	--	--	--	--	--	--	--	--	--	--
Poa pretensis	--	--	--	--	--	--	--	--	--	--	--	--	--	--	25.0	--	--	--	--
Poa secunda	--	--	--	--	--	--	2.3	--	--	--	--	--	--	--	--	--	--	--	--
Potentilla biennis	0.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Purshia tridentata	--	--	--	--	2.2	7.7	0.6	2.8	8.3	--	2.5	16.7	--	--	--	--	--	14.3	--
Rosa woodsii	--	--	--	--	--	--	--	--	--	--	1.3	16.7	--	3.2	--	--	--	--	--
Rumex crispus	--	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix exigua	32.5	7.9	23.1	27.8	14.3	15.4	39.5	9.3	8.3	39.7	1.3	--	19.6	1.6	--	28.9	3.6	--	7.1
																			--
Salix exigua (dead)	6.0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Salix lutea	--	14.6	15.4	2.8	9.0	15.4	6.2	17.2	--	--	8.9	--	3.9	1.6	--	--	3.6	14.3	--
Schoenoplectus americanus	--	4.9	--	--	0.4	7.7	--	--	--	--	--	--	--	--	--	--	--	--	21.4
Scirpus microcarpus	--	--	7.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Scirpus nevadensis	--	1.1	--	--	--	--	--	0.9	--	--	--	--	--	--	--	--	--	--	21.4
Senecio hydrophilus	--	--	--	--	0.4	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Sheperdia argentea	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.2	--	--
Solidago spectabilis	0.5	--	7.7	--	--	7.7	--	0.9	--	--	5.1	--	3.9	--	--	--	--	--	--
Tamarix rammosisima	0.5	--	--	0.6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Triglochin maritimus	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Unk Boraginaceae	--	--	--	--	0.4	--	--	--	--	--	--	16.7	--	--	25.0	--	--	--	--
Verbascum thapsus	--	--	--	--	--	--	--	--	--	--	1.3	16.7	--	--	--	--	--	--	--
Veronica anagallis-aquatica	--	0.7	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
																			--
Bare ground	17.0	4.1	--	13.8	5.4	--	16.9	0.9	--	9.5	3.8	--	17.6	3.2	--	21.7	10.7	--	--
Litter	3.0	7.5	--	2.7	5.4	--	3.4	4.2	--	--	7.6	--	--	12.7	--	3.6	4.8	--	--
Rock	--	7.1	--	--	8.1	--	--	4.7	--	--	5.1	--	--	15.9	--	--	14.3	--	--
Water	17.5	5.6	--	22.2	9.9	--	8.5	5.6	--	15.9	19.0	--	29.4	27.0	--	31.3	50.0	14.3	21.4

Analysis

For each monitoring site, average cover by species was calculated for all three sampling years (1999, 2005, and 2009) by combining all the sampling points of approximately equal distance from the lake shore. These values were then used to calculate indices of community similarity to compare how similar the communities were between the sampling periods. Three sets of similarity indices were calculated between two sampling years (1999 and 2005, 2005 and 2009, and 1999 and 2009). Two different indices were selected, the Proportional Similarity Index (PS) (Brower et al. 1990) and Morisita's Index (MI) (Brower et al. 1990). The Proportional Similarity Index is based on differences of percent covers of the same species in two communities (in this study two sampling years) the higher the index value for the two communities of interest, the greater the similarity is between species cover values. Morisita's index is based on the probability that two randomly selected individuals from a community will be the same species. Thus, the index value will be higher when the same species are found dominant or common in the two communities. For both indices, values can range from 0.0 to 1.0, with an index of 0.0 indicating the species composition between two sampling periods are completely different and a index of 1.0 indicating they are identical.

Results

Comparisons among sampling sites show that changes between sampling years have occurred at some sites while very little change has occurred at others. The similarity indices show that there have been minimal changes in the plant communities at Dechambeau Embayment and Warm Springs between 2005 and 2009 as PI values are greater than 0.78 and MI values are greater than 0.90. However, at Dechambeau Embayment there has been a decrease in *Hordeum jubatum* and an increase of *Schoenoplectus americanus* across all transects suggesting that the community composition is beginning to move to a later seral state. Larger changes were observed at Sammon Springs as both indices are lower than the previous two sites (PI = 0.75 and MI = 0.82), and *Schoenoplectus americanus* and *Scripus nevadensis* are decreasing in percent cover while *Carex* spp. and *Juncus arcticus* are increasing in percent cover. In Warm Springs, both indices are high (PI = 0.85 and MI = 0.93) even comparing between 1999 and 2009 indicating plant communities have changed very little since 1999. The dominant species there are *Schoenoplectus americanus* and *Scirpus nevadensis*. Analyses of Rush and Lee Vining Creeks show that the community composition has changed as most of PI and MI values are below 0.6. Notable changes observed at Rush Creek are an increase in the percent cover of *Salix lutea*, a decrease in percent cover of *Salix exigua*, and colonization of *Solidago spectablis*. Also, along transect 7 there is an abundance of *Schenoplectus americanus* and *Scirpus microcarpus*, two late seral species that are indicative of a wetland environment. Results are displayed in table 6.

Table 6. Indices of community similarity for the Mono Basin Lake fringing wetlands and tributary deltas.

Site	**Index***	**1999/2005**	**2005/2009**	**1999/2009**
Dechambeau Embayment	PI	0.51	0.78	0.48
	MI	0.66	0.98	0.68
Warm Spring	PI	0.90	0.82	0.85
	MI	0.98	0.92	0.93
Sammon Spring	PI	0.63	0.75	0.64
	MI	0.72	0.82	0.58
Rush Creek	PI	0.68	0.59	0.46
	MI	0.56	0.59	0.44
Lee Vining Creek	PI	0.80	0.54	0.57
	MI	0.57	0.44	0.61

** PI indicates Proportional Similarity Index. MI indicates Morisita's Index.*

Discussion

Succession is a natural process describing the sequential changes in plant and animal communities. Succession is affected by both exogenous processes, such as a change in water levels and endogenous processes such as competition and facilitation in which each new community creates an environment favorable for colonization by other plant and animal species. During succession, the diversity of plant species generally decrease, the height and the size of the dominant plant species generally increases and the size of the plant seeds generally increases. Wetlands are dynamic with species and community composition reflecting changing water levels. Part of the diversity of the wetlands is dependent on dynamic change. During the course of this study, the elevation of Mono Lake has fluctuated giving no particular advantage to a specialist species, unless adapted to a fluctuating lake level. During years of a receding lake level, 1999-2004 and 2006-2009, it is plausible that the hydrologic effect on the wetland and tributary delta areas will be less than during years that the lake level is rising and that the salinity should decrease. With a declining lake level and subsequently lesser hydrologic effect, this might be beneficial for the expansion of freshwater spring and wetland systems. On the other hand, with an increased lake level increasing the hydrologic affect, this should favor species that are adapted to a more saline environment and restrict the expansion of springs and wetland environments. Because the elevation of Mono Lake has been fluctuating over the course of this study, and similarity indices indicate changes among some but not all of the wetland and tributary delta study areas, it is hard to address the effect that the lake is having on these communities.

At Dechambeau Embayment, the community composition is heading towards a more stable, or climax community. This can be observed with the change in percent cover of both *Hordeum jubatum* and *Schoenoplectus americanus. Hordeum jubatum,* an early seral species, being replaced by *Schoenoplectus americanus*, a later successional species. With a decrease in the lake level, the lake is having less of an effect on the site and allowing for the development of a marsh habitat type. This can be observed on transect 3, which is farthest from the lake shore and closest to the spring head. Both *Schoenoplectus acutus* and *Typha latifolia*, indicators of a marsh habitat, are increasing in percent cover. Meanwhile *Hordeum jubatum* is no longer a component along transect 3 in 2009. Also, on transect 1, *Distichlis spicata* has decreased across years, suggesting that there is a possible decrease in the salinity along that transect.

There has been little in the way of disturbance at Warm Springs since the initial sampling year. The site is dominated by few species, which are later successional species such as *Schoenoplectus americanus* and *Scirpus nevadensis*. Early seral species, such as *Hordeum jubatum*, have not been a component of the site since the initial sampling year. The community composition is stable, and without disturbance will likely persist as a climax community.

The changes observed at Sammon Springs suggest that the community composition is changing. Along with a fluctuating lake level, State Parks commenced a prescribed burning program prior to the initial sampling conducted in 1999. The site was burned for two consecutive years. When the transects were established in 1999, the site was composed of an ash layer and burned stobs of *Schoenoplectus americanus* and *Typha latifolia*. Therefore, some vegetation changes are a result of the sampling area recovering from those burns. In 2009, with a decreased lake level, the transects can be broken into zones following a gradient of fresh to saline conditions across the site. Transect 1 is the lake zone, Transect 2 is the intermediate zone, and Transect 3 is the spring zone. Along transect 3 there is greater spring influence increasing the percent cover of *Carex* spp. Also, litter is increasing.

Transect 2 is moving towards a stable community composition of both *Juncus arcticus* and *Schoenoplectus acutus* suggesting that it is the driest area of the site. Transect 1 is closest to the lake and is exhibiting an overall decrease in species composition and an increase in percent cover of litter. It is plausible that the amount of decadence along Transect 1 is consuming available space for the establishment of *Schoenoplectus americanus* and *Juncus arcticus*. As litter increases, it is expected that recruitment and overall percent cover of the site will continue on a downward trend.

The results observed at both Rush and Lee Vining Creeks can be attributed to multiple factors. Some of the changes are most likely attributable to changing delta areas between sampling periods. The changes are most evident in the Rush Creek delta and displayed on (Figures 7, 8, and 9). In 2000 there is a lack of a delta area. Sediment deposition is noticeable, however the lake elevation was approximately 6,384 ft above msl which covered the deposits and held back the creek channel. The creek channel is to the far left of the flood plain against the upland vegetation. *Salix exigua* is a large component of the site. In 2005, with a decreased lake level, the creek channel is beginning to braid and delta deposits are beginning to be exposed. There is a decrease in the percent cover of *Salix exigua* and an increase in *Juncus arcticus* indicating the presence of a wetter, fresh water environment. Also, *Salix lutea* is beginning to colonize the site suggesting that delta deposits are increasing the available space for recruitment and establishment of the species. In 2009 the delta area is considerably different from that of 2000 (Figure 9). There is a highly developed delta with littoral bar formation at the mouth. The lake level has receded to 6382 feet above msl which has promoted movement of the creek channel to the center of the flood plain. The creek channel has become less braided and incised within the newly exposed delta deposits. Also, with the decreased lake level, the flood plain has expanded in width increasing the area of exposed flood plain with colonization of *Solidago spectablis* and decrease in the percent cover of *Salix exigua*.

The observed changes in the vegetation composition may also be attributed to the fact that permanent transect markers were not established. Therefore, when sampling was conducted, a GPS unit was utilized to locate the transects and follow the sampling route. Utilizing this same method in 2005 and 2009 likely resulted in some "straying" from the original course which could have resulted in some of the differences. Also, there is unevenness in the sampling interval across years. The sampling interval for 1999 and 2009 is consistent with a point read every 20-25 steps. In 2005, the sampling interval was closer to 1-1.5 meters, or every other step. This has lead to an increase in species richness and a more even distribution of species across transects compared to 1999 and 2009 (Figures 10 and 11). For example, in 2009, Rush Creek Transects 5 and 6 had more than a 40% cover of *Equisetum arvense* due to the limited number of sampling points along the transects (Table 5). The percent cover of *E. arvense* does not accurately represent the composition of those particular transects. Because of the inconsistencies with the sampling methodology it is difficult to infer the PI and MI values for plant communities' changes overtime.

Figure 7. 2000 Imagery of Rush Creek delta.

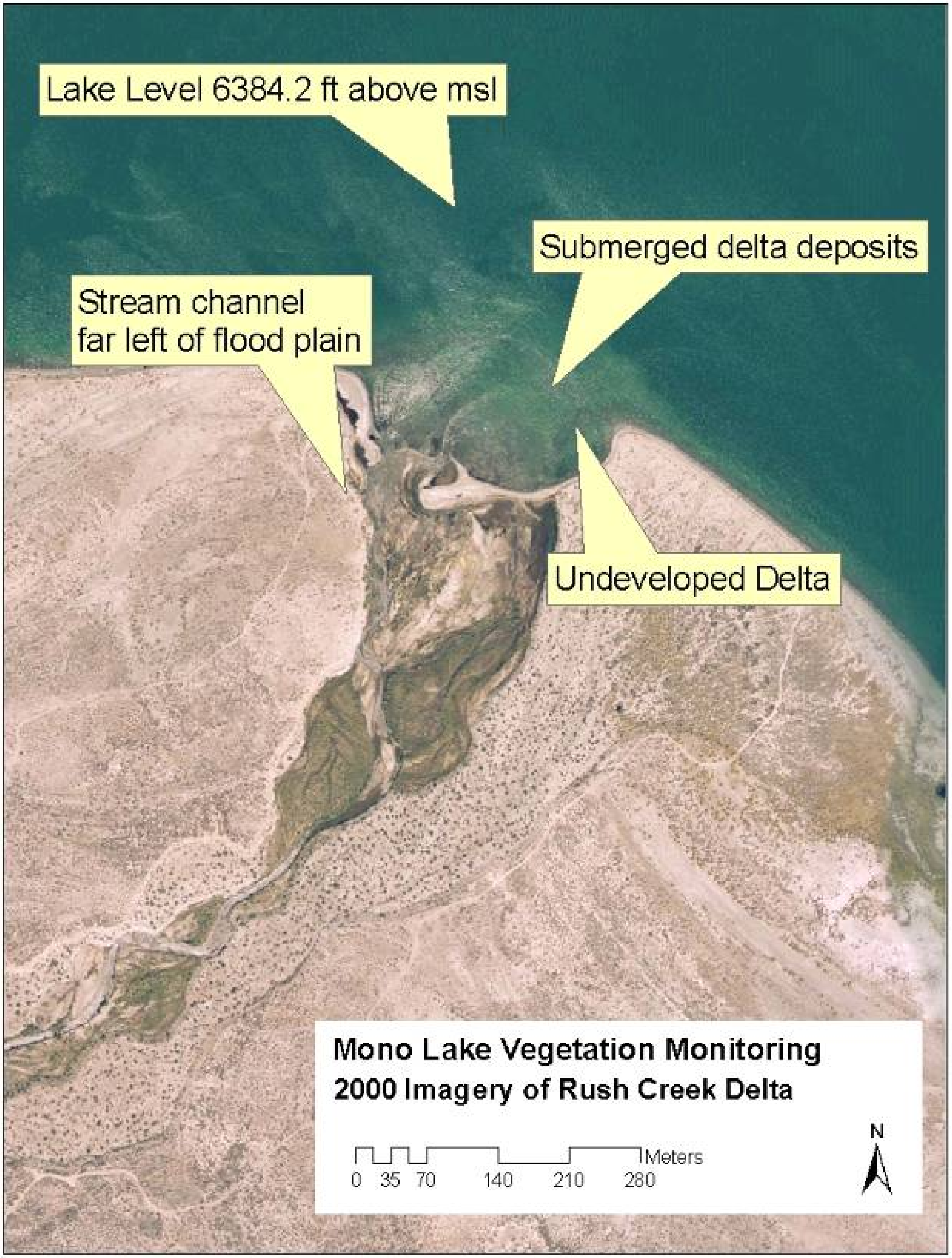


Figure 8. 2005 imagery of Rush Creek delta.

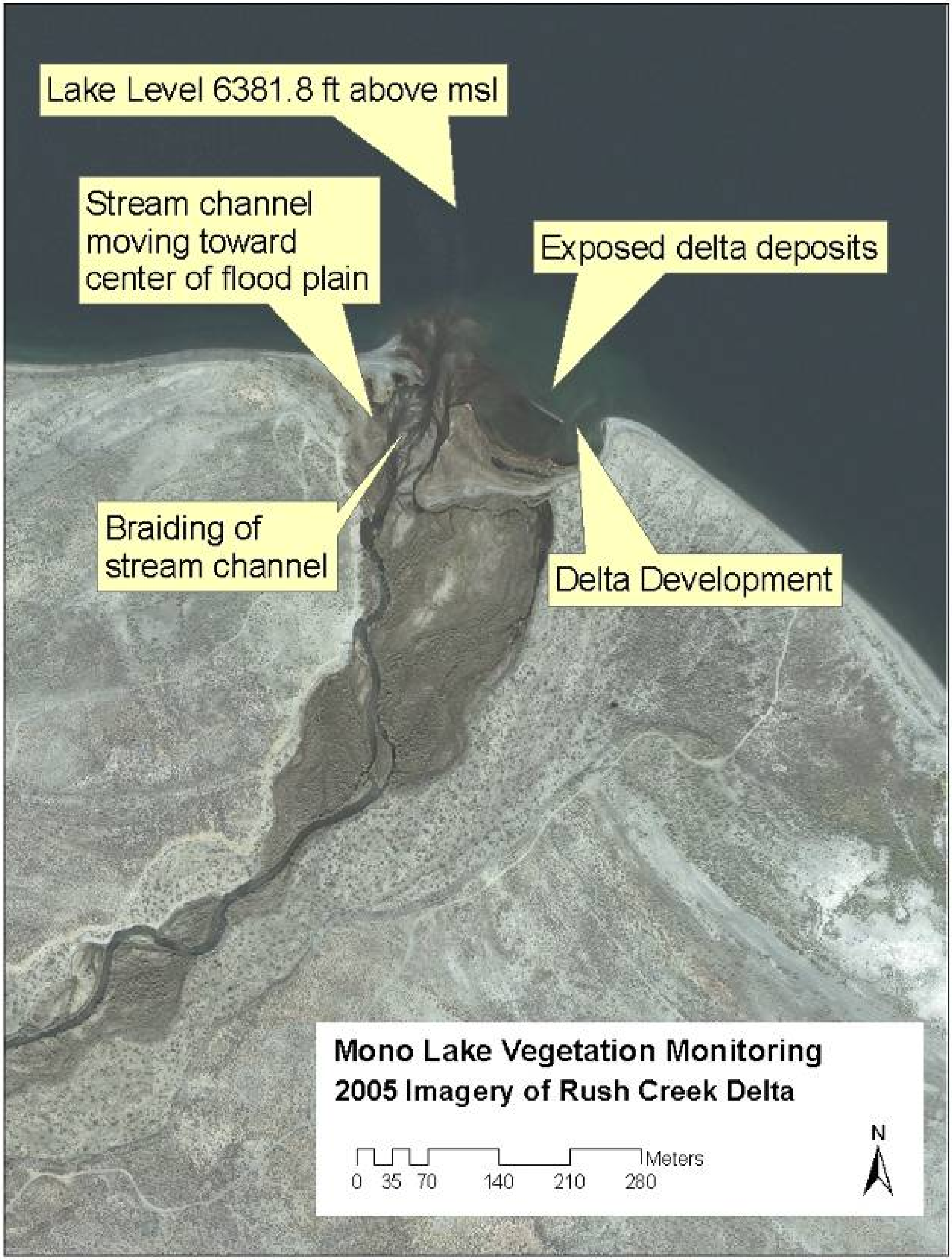


Figure 9. 2009 imagery of Rush Creek delta.

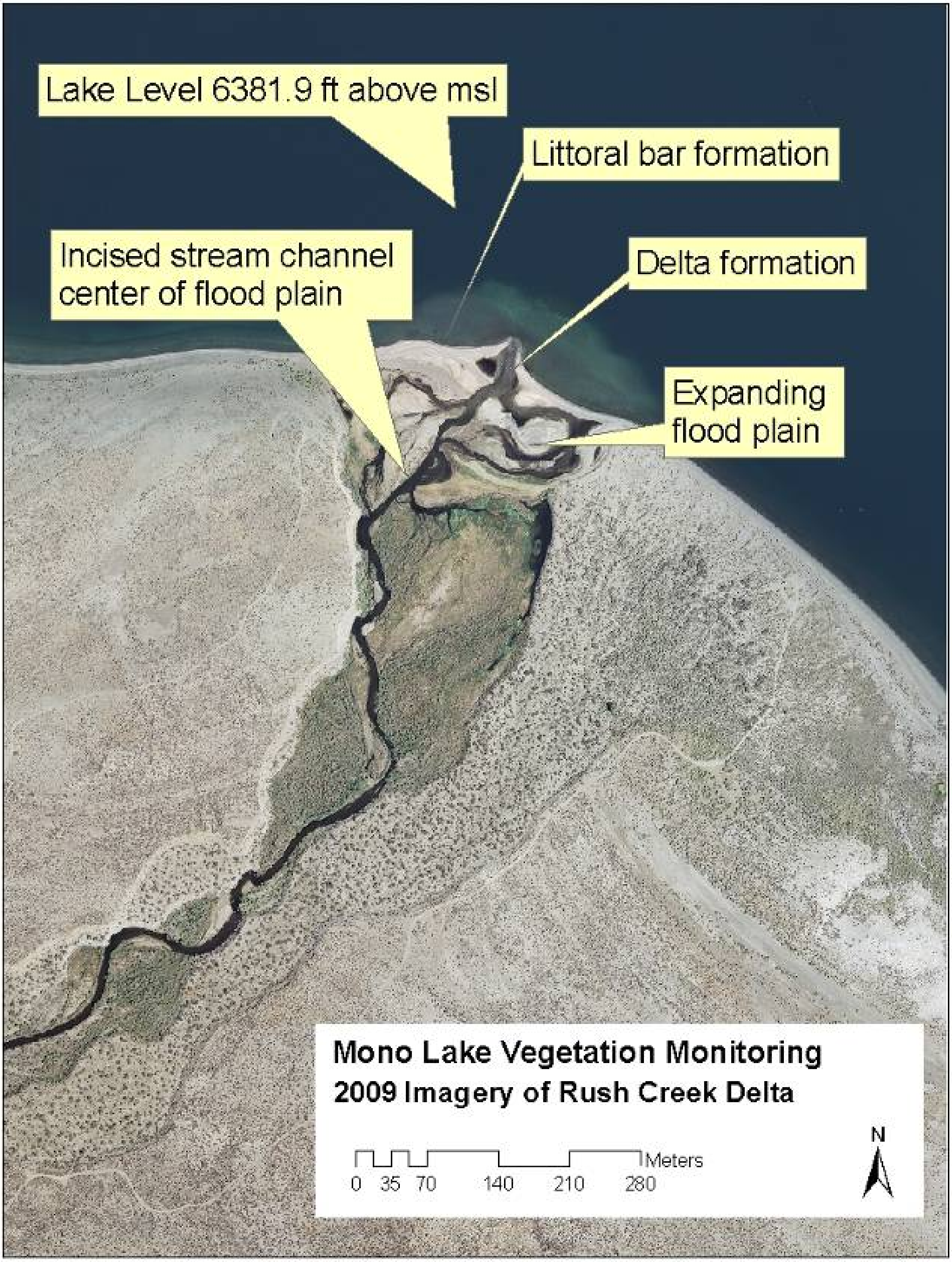


Figure 10. Lee Vining Species Richness across years.

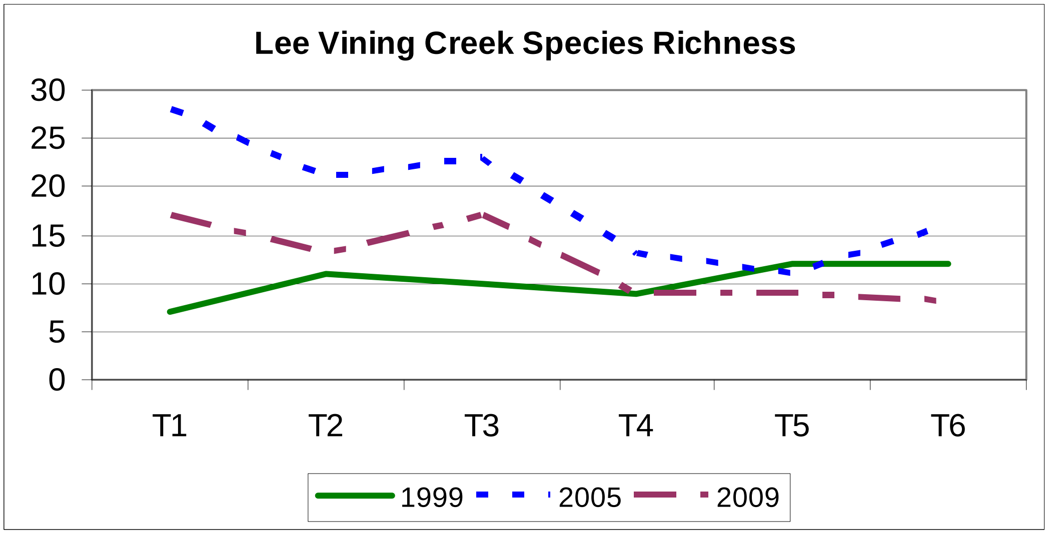
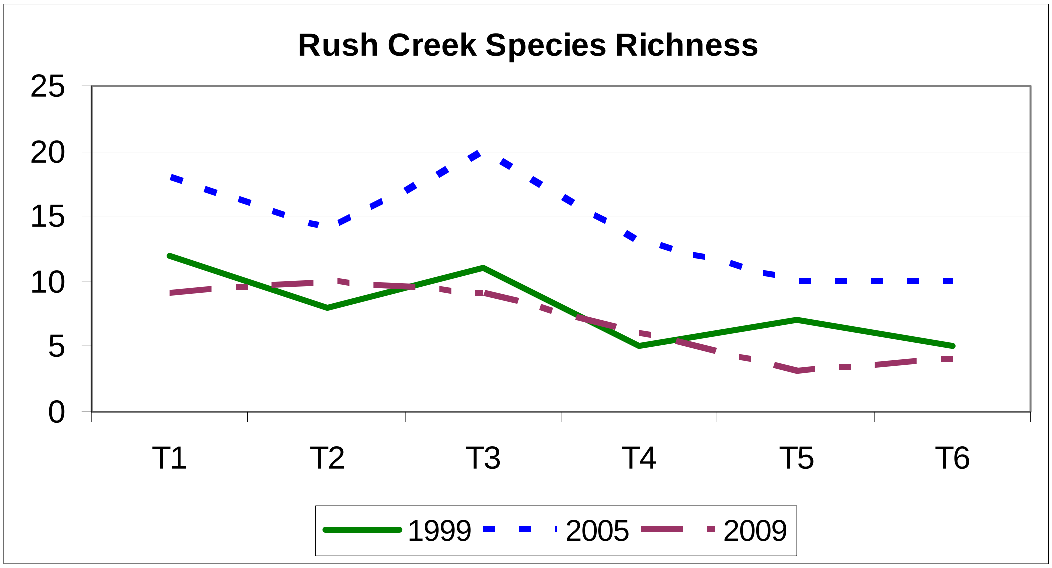
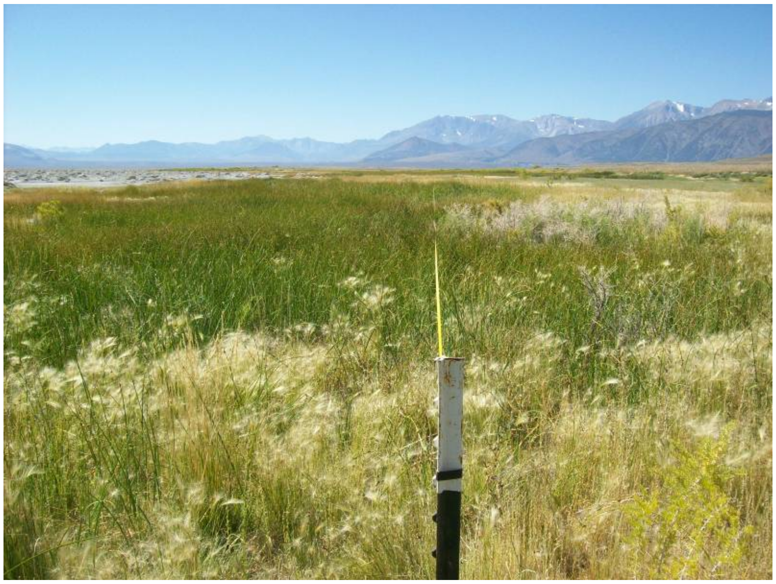


Figure 11. Rush Creek species richness across years.



Appendix 1.

Dechambeau Embayment Transect 1



Dechambeau Embayment Transect 1 Cont

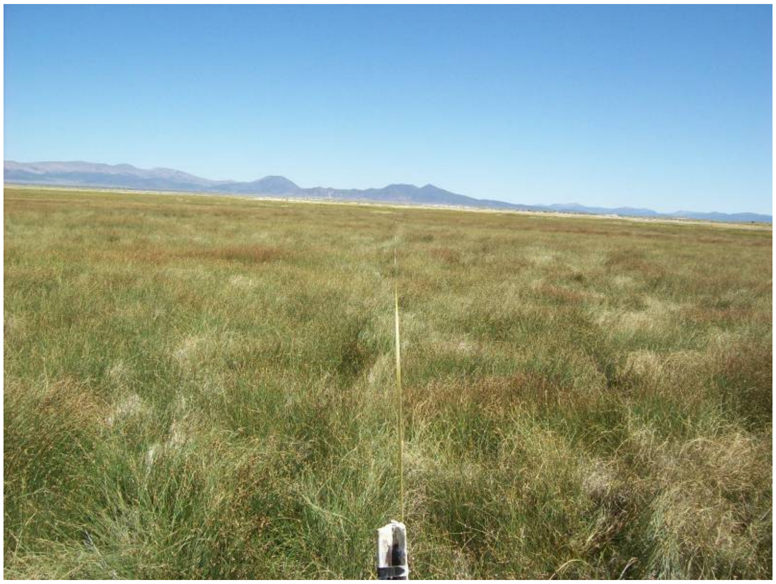
Dechambeau Embayment Transect 2

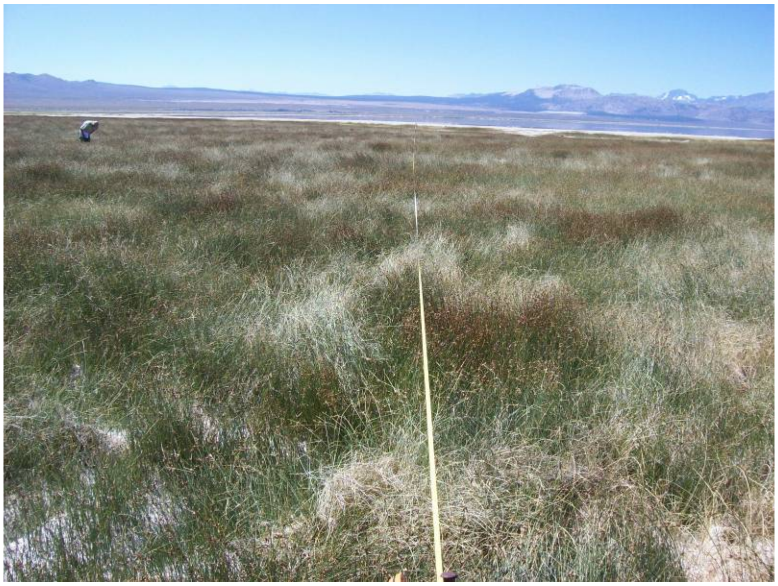
Dechambeau Embayment Transect 2 Cont

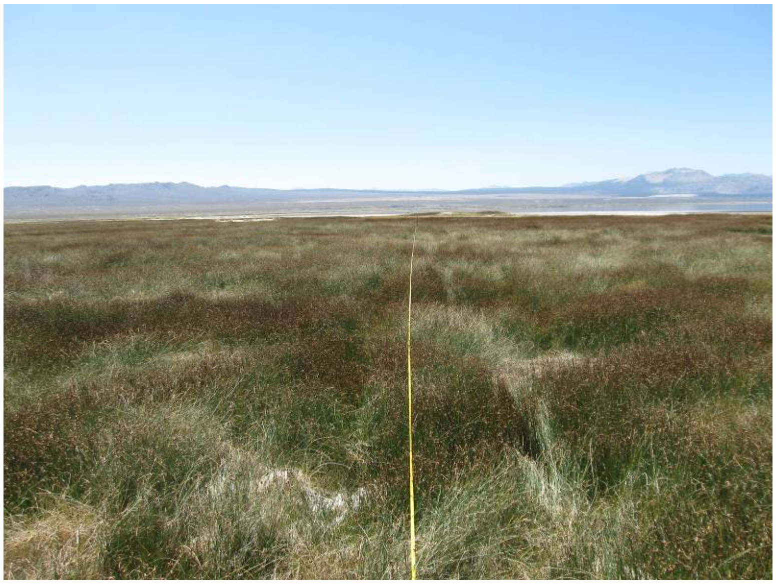
Dechambeau Embayment Transect 3

Dechambeau Embayment Transect 3 Cont

Warm Springs Transect 1







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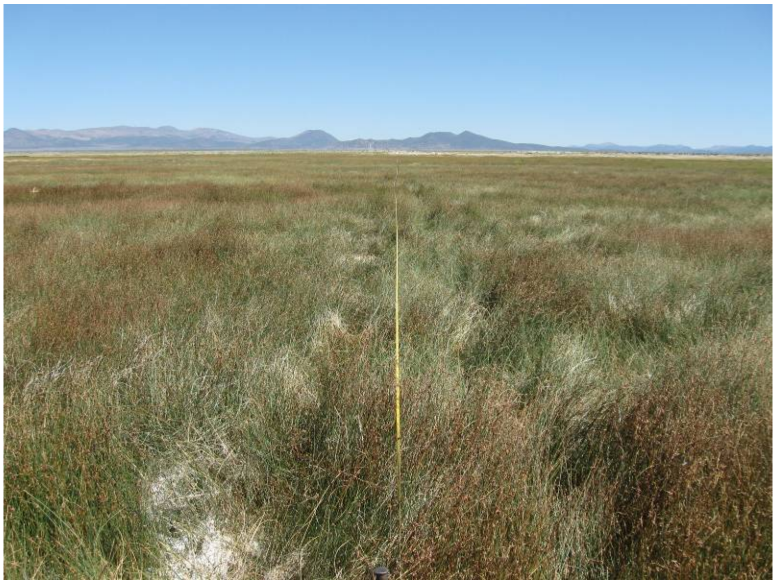
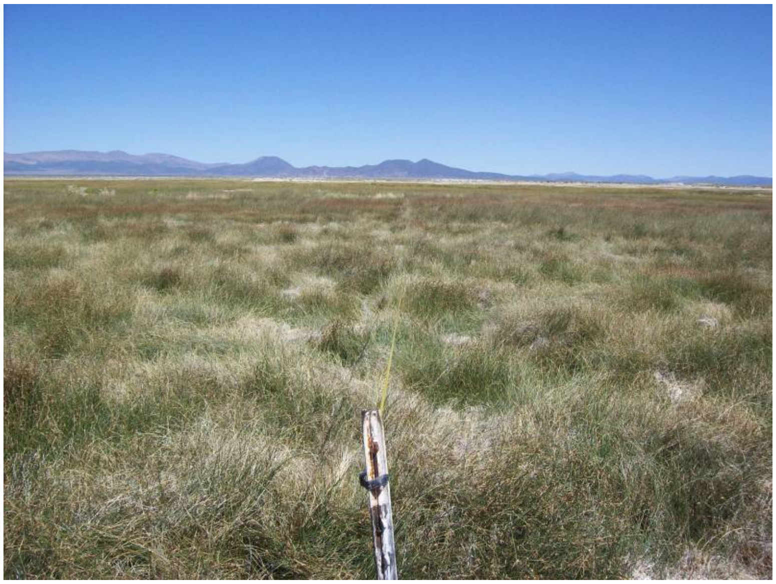
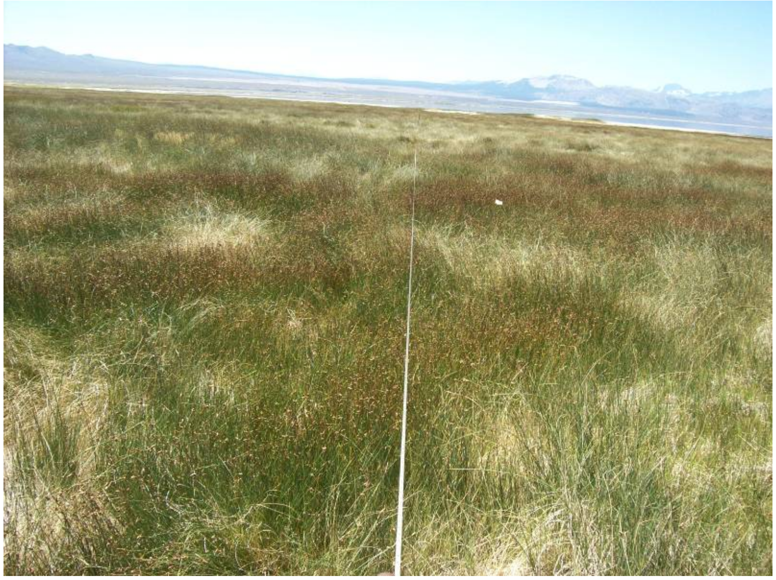


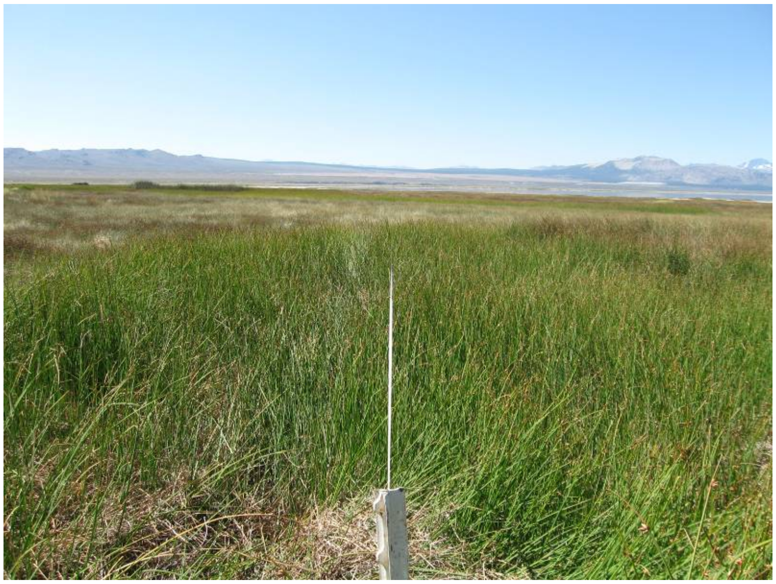
Warm Springs Transect 2

Warm Springs Transect 2 Cont





Warm Springs Transect 3



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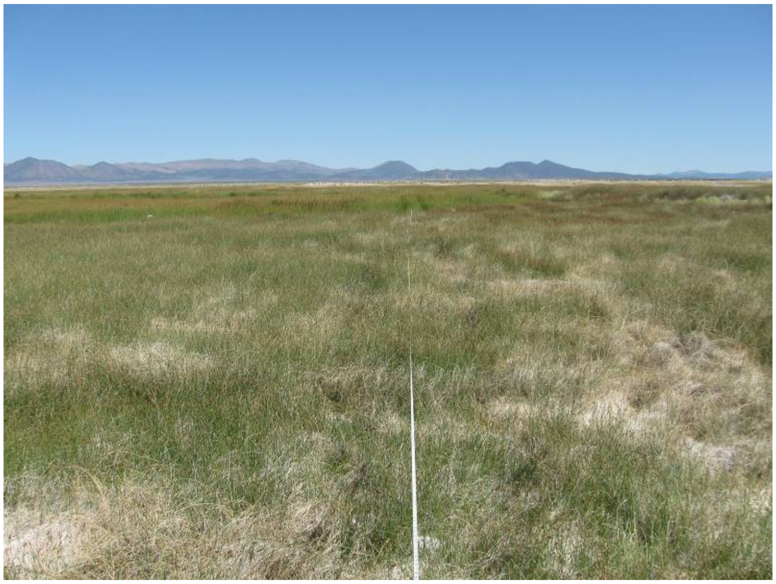
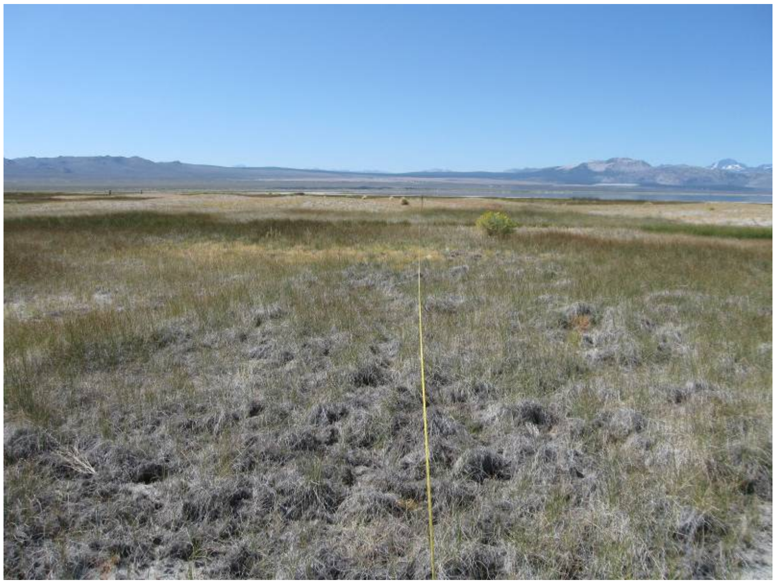


Warm Springs Transect 4



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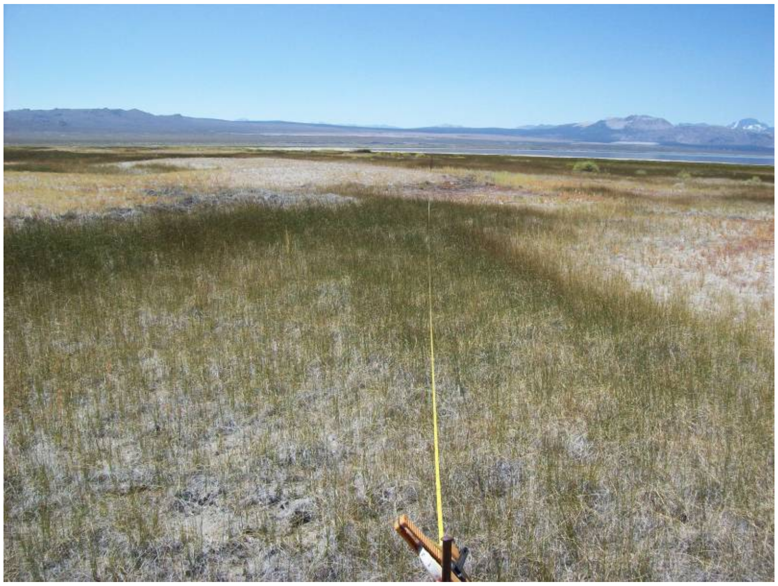
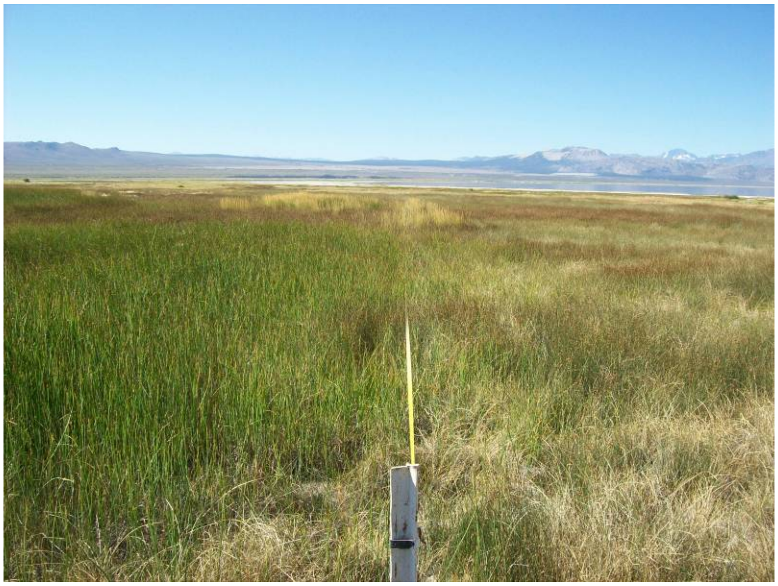
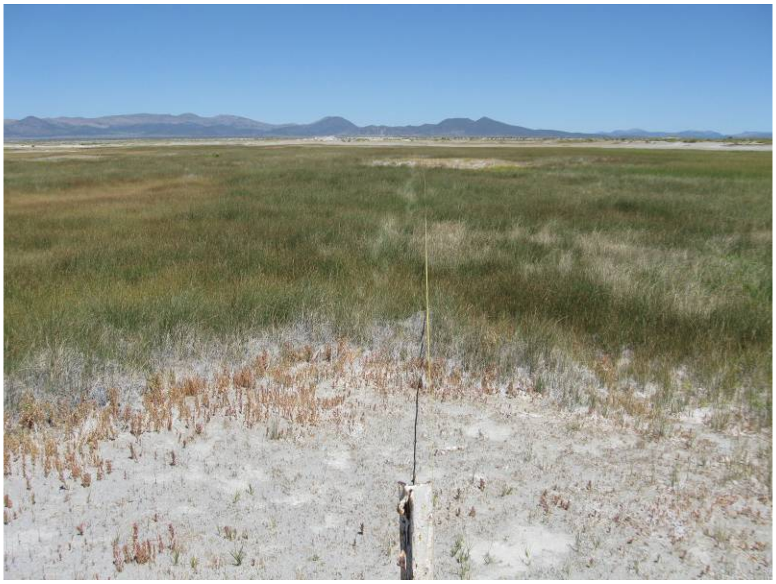
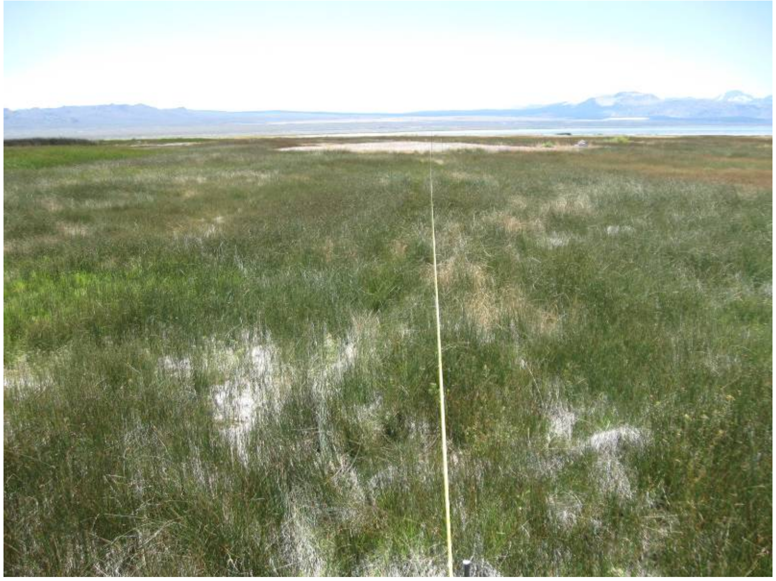


Warm Springs Transect 5







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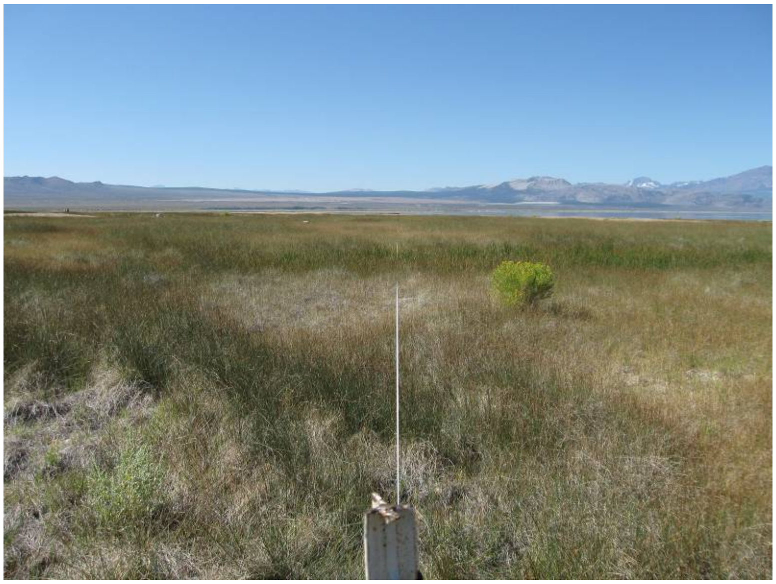
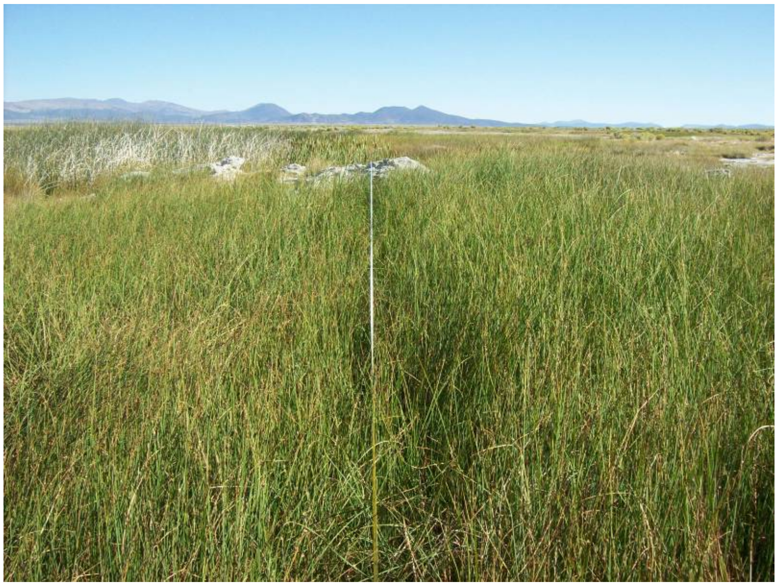
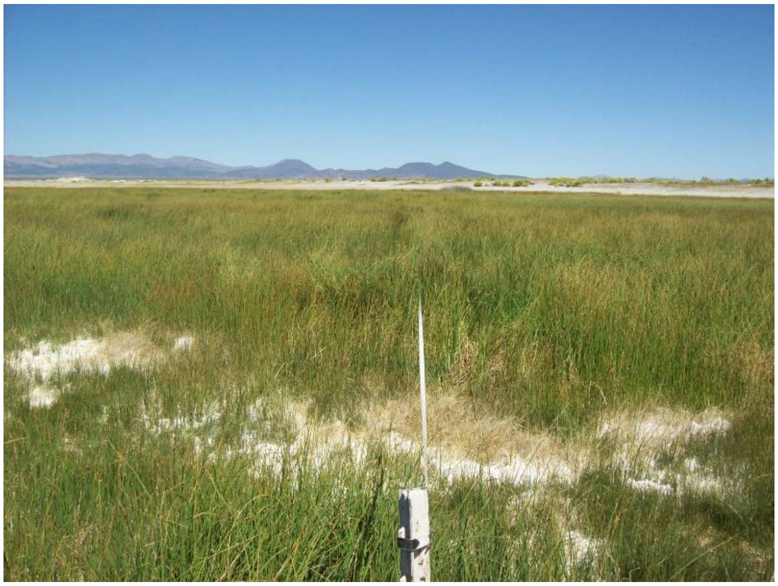


Warm Springs Transect 6



Warm Springs Transect 6 Cont



Samman’s Springs Transect 1

Samman’s Springs Transect 2

Samman's Springs Transect 3

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Brower, J. E., J. H. Zar, and C. N. von Ende, 1990. Field and Laboratory Methods for General Ecology. Third addition. Wm. C. Brown Publishers, Dubuque, Iowa.

Mueller-Dombois, D. and H. Ellenberg, 2002. Aims and Methods of Vegetation Ecology. The Blackburn Press, Caldwell, New Jersey.

2009
Mono Lake Vegetation Mapping Report

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Lake Fringing Wetland Vegetation Mapping

Introduction

The Los Angeles Department of Water and Power (LADWP) conducted vegetation-mapping activities in lake fringing wetlands surrounding Mono Lake and in tributary stream deltas during the 2009 growing season. These efforts were undertaken to fulfill State Water Resources Control Board obligations as directed in Decision 1631 and Order No. 98-05. The objective of these monitoring efforts is to determine changes that occur in the lake fringing wetlands as lake levels rise and how those changes may relate to waterfowl activity in the region. The lake elevation was 6384.2 ft above mean sea level (msl) in September 1999 and 6381.9 ft above msl in August of 2009. The approximate 2.3 ft difference in lake elevation during this mapping period as compared to 1999 resulted in the exposure of as much as 295 feet of lake shore in some areas.
The aerial imagery and examination of vegetation mapping of Mono Basin waterfowl habitat was comprised of three separate steps. Methods of each step were fully described in the 1999 Mono Basin Vegetation and Habitat Mapping Report (LADWP 1999).

Methods

In 1999, a GIS database was developed from the 1999 imagery using ESRI ArcView software. Polygons were mapped by subarea, which roughly correspond to the set of subareas used for ongoing waterfowl surveys (Figure 1).

For the 2005-2006 effort, satellite imagery was utilized in place of the aerial photography used in 1999. The satellite imagery had a resolution of 0.8 meters in true color as a single 4-band (red, green, blue, near infra-red). These four bands were collected simultaneously with identical look angles, and were precisely registered. The scale of the photography was 1:24000 or 1 inch equaling 2000 feet. For a discussion related to comparisons between the 1999 and 2005 mapping see the 2006 Mono Lake Vegetation Monitoring Report.

For the 2009 mapping effort, digital aerial imagery was collected between August 1st and August 7th 2009 using an aircraft occupied with a multi-spectral digital camera. The imagery had a resolution of 1 foot in true color as a single 4-band (red, green, blue, near infra-red). These four bands were collected simultaneously with identical look angles, and were precisely registered.

The imagery was delivered as separate Geo-Tiff files with one USGS quad composed of 16 files. The files were merged together utilizing the Mosaic Tool in ERDAS Imagine 9.3., creating one composite image of the entire Mono Basin. The Mono Basin image was then split into subareas. A spectral classification was performed on all of the subareas followed by a supervised classification to identify habitat types.

Following the classification of the subareas, the habitat types delineated utilizing ERDAS Imagine were converted to polygons using ArcMap 9.3, converting them into shapefiles. A post classification clean up was performed to eliminate pixel inclusion and overall roughness of the classified subareas. After completing the post classification clean up, the habitat type polygons were merged together and acreages of habitat types were calculated and exported into Microsoft Excel.

Classification

The selection of the vegetation classes, or habitat types, used for the 2009 mapping effort was based on previous years vegetation classes. These classes were developed based on three basic criteria. First, the classification used for monitoring should be compatible with previous vegetation mapping. Secondly, the cover classes needed to distinguish structurally different habitat types utilized differently by waterfowl. Thirdly, the cover classes used for monitoring habitat changes needed to be individually discriminated using the newly acquired imagery. The classes used in the mapping, and brief descriptions of each of the classes are as follows:

Marsh

Areas with surface water usually present all year and dominated by tall emergent species such as hard-stem bulrush (*Schoenoplectus acutus*), cattail (*Typha latifolia*), three square (*Schoenoplectus americanus*), alkali bulrush (*Juncus arcticus*) 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 minor*]). Wet meadow vegetation was in areas where alkaline or saline soils did not appear to be present.

Alkaline Wet Meadow

This class 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 (S*cirpus nevadensis*), Baltic rush (*Juncus arcticus*), and/or salt grass (*Distichlis spicata*). The high density and lushness of the vegetation indicated that it had relatively high water table with at least seasonal inundation that 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*).

Riparian Wetland Scrub

Areas dominated by willows (*Salix* spp.), comprised most of this vegetation class. Small amounts of buffalo berry (*Shepardia argentea*) and Wood's rose (*Rosa woodsii*) usually mixed with willow were also included.

Great Basin Scrub

Scattered dense stands of sagebrush (*Artemisia tridentata*), rabbit brush (*Ericameria nauseosa*), and/or bitterbrush (*Purshia tridentata*) made up this class.

Riparian Forest Woodland

Aspen (*Populus tremuloides*), and black cottonwood (*Populus balsamifera*) were the two tree species most common in this class.

Freshwater Stream

This class included the channels of streams that had flowing water at the time of the imagery acquisition.

Freshwater Ria

Surface water at the mouths of streams that likely had some salt/fresh water stratification.

Freshwater Pond

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

Ephemeral Brackish Lagoon

If an extensive area of marsh or wet meadow indicating the presence of springs was present landward, lagoons along the shoreline created by the formation of littoral bars were mapped.

Ephemeral Hypersaline Lagoon

If an extensive area of marsh or wet meadow was not present landward, lagoons along the shoreline created by the formation of littoral bars were mapped. These areas contain concentrated brine due to evaporation.

Unvegetated

Barren to sparsely vegetated (<15 percent cover) were classified as unvegetated. This class included sandy areas, alkaline flats, tufa, and delta outwash deposits. Man made features were sometimes included into this class.

Man Made

Areas classified as man made included buildings, parking areas, and roads. Stands of horticulturally established tree species (e.g. black locust, Siberian elm) were also mapped.

Results and Discussion

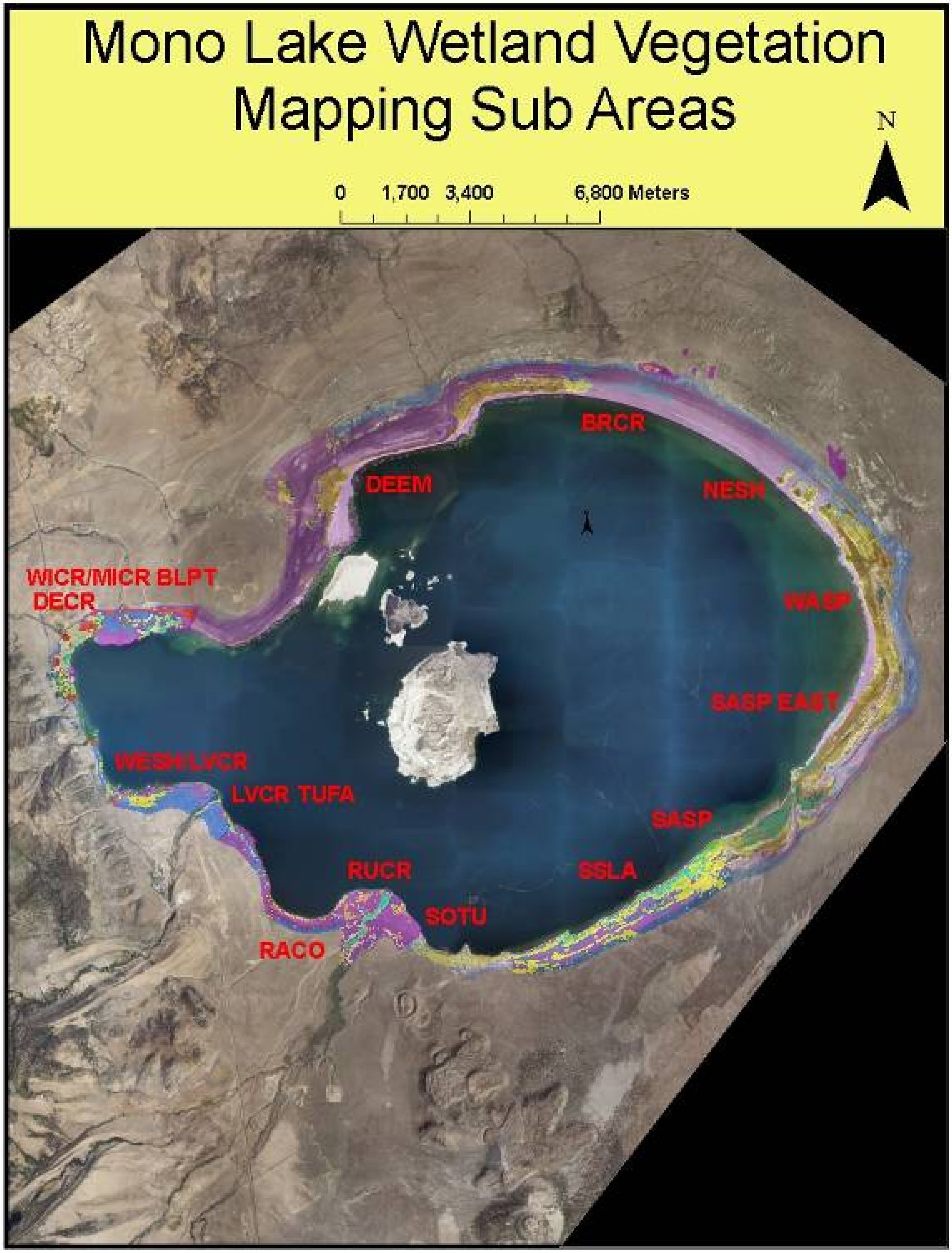
The classification and mapping of habitat types presented here documents areas of different waterfowl habitat types at Mono Lake in 2009 and the differences between these habitat types as originally mapped in 1999 and 2005. Also included is a comparison of an ERDAS based classification of both Lee Vining and Rush creeks to an on the ground vegetation map compiled by McBain and Trush.

Accuracy of Cover Type Classification

To evaluate the accuracy of the vegetation classification, five sources of ground truth information were utilized. This consisted of ground truth points established in 2006, transect data of vegetation composition within lake fringing wetlands, transect data of vegetation composition within Lee Vining and Rush Creek deltas, photographs taken during vegetation monitoring and waterfowl monitoring, and a comparison of previous years mapping efforts to the current year.

Figure 1 illustrates the subareas that were utilized for this mapping effort. The specific areas are; Sammann's Springs (SASP), Sammann's Springs East (SASP East), Warm Springs (WASP), Northeast Shore (NESH), Bridgeport Creek Delta (BRCR), Dechambeau Embayment (DEEM), Black Point (BLPT), Mill/Wilson Delta (MICR/WICR), Dechambeau Creek Delta (DECR), West Shore/Lee Vining Creek Delta (WESH/LVCR), Ranch Cove (RACO), Rush Creek Delta (RUCR), South Tufa (SOTU), and South Shore Lagoons (SSLA).

Figure 1. Mapping subareas.



Observed Change

Table 1 illustrates the acreage and percent of total area of each habitat type for 1999, 2005, and 2009.

Table 1. Acreage of each habitat type for 1999, 2005, and 2009

Habitat Type	1999		2005		2009	
	Acreage	% total Area	Acreage	% total Area	Acreage	% total Area
Marsh	300.00	2.43	408.80	3.11	849.31	6.19
Alkaline Wet Meadow	582.40	4.72	1293.10	9.85	1123.99	8.19
Dry Meadow Forb	1921.70	15.57	1355.20	10.32	935.05	6.81
Riparian Wetland Scrub	333.60	2.70	204.40	1.56	191.14	1.39
Great Basin Scrub	3819.40	30.95	3662.10	27.89	3042.16	22.16
Riparian Forest Woodland	8.40	0.07	21.30	0.16	25.32	0.18
Unvegetated	4993.30	40.47	5948.60	45.30	7430.18	54.13
Man Made	56.30	0.46	126.40	0.96	62.40	0.45
Freshwater Ria	2.90	0.02	5.50	0.04	1.06	0.01
Freshwater	10.20	0.08	8.50	0.06	11.76	0.09
Ephemeral Brackish Lagoon	108.60	0.88	17.20	0.13	5.51	0.04
Ephemeral Hypersaline Lagoon	110.70	0.90	38.40	0.29	0.41	0.00
Wet Meadow	83.00	0.67	29.40	0.22	39.32	0.29
Freshwater Pond	8.70	0.07	12.00	0.09	9.39	0.07
Total Mapped Acreage	12339.20		13130.90		13726.98	

Table 2 illustrates the differences between the sampling periods for all of the subareas and the total differences. Due to a decline in the lake elevation from 6,384.2 ft above msl to 6381.9 ft above msl, there was an increase of 1,387.78 total acres mapped between 1999 and 2009. Also, because of the enhanced mapping through the use of ERDAS, subtleties within habitat types that were undifferentiated with the previous mapping efforts can now be delineated. For example, areas that were classified as Great Basin scrub in 2005 also contained unvegetated areas which could be classified separately in 2009.

Table 2. Comparison of vegetation acreage by habitat type for sampling years 1999, 2005, and 2009

Habitat Type	**Sammann's Springs/Sammann's Springs East**					**Northeast Shore/Warm Springs**					**Bridgeport Creek Delta/Dechambeau Embayment/Black Point**				
	1999	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**
Marsh	180.80	147.70	411.62	-33.10	230.80	67.20	88.30	124.28	21.10	21.50	35.20	88.20	232.19	53.00	207.61
Alkaline Wet Meadow	285.30	351.70	250.69	66.40	-34.60	253.40	206.20	406.31	-47.20	189.73	9.70	566.50	353.60	556.80	345.17
Dry Meadow Forb	387.90	291.10	80.37	-96.80	-307.50	584.10	575.40	212.01	-8.70	-372.09	551.10	231.80	344.67	-319.30	-205.59
Riparian Wetland Scrub	1.70	17.80	0.00	16.10	-1.70	0.00	0.00	0.00	0.00	0.00	7.00	0.10	0.00	-6.90	-7.00
Great Basin Scrub	397.20	360.10	262.49	-37.10	-134.70	565.40	570.90	762.80	5.50	202.43	1072.10	931.50	885.75	-140.60	-184.80
Riparian Forest Woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unvegetated	311.50	545.10	805.99	233.60	494.50	2021.30	2383.20	2525.11	361.90	505.99	1676.70	1867.80	2161.49	191.10	563.39
Man Made	0.00	4.60	0.00	4.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.40	0.00	11.40	0.00
Freshwater Ria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ephemeral Brackish Lagoon	12.20	0.10	1.27	-12.10	-12.20	51.20	11.60	3.62	-39.60	-51.20	18.60	2.80	0.00	-15.80	-18.60
Ephemeral Hypersaline Lagoon	0.00	1.00	0.29	1.00	2.00	105.50	0.00	0.00	-105.50	-105.50	5.20	0.50	0.00	-4.70	-5.20
Wet Meadow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.30	0.00	0.00	-18.30	-18.30
Freshwater Pond	0.50	0.80	0.29	0.30	-0.50	0.40	0.40	0.00	0.00	-0.40	7.70	10.80	4.37	3.10	6.22
Total Acres	**1577.10**	**1720.00**	**1813.02**	**142.90**	**236.10**	**3648.50**	**3836.00**	**4034.13**	**187.50**	**390.46**	**3401.60**	**3711.40**	**3982.06**	**309.80**	**682.89**

Habitat Type	**WillsonCreek/Mill Creek Deltas**					**Ranch Cove**					**Rush Creek**				
	1999	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**
Marsh	0.00	12.10	11.60	12.10	11.60	0.00	0.00	1.26	0.00	1.26	0.00	8.40	4.22	8.40	4.32
Alkaline Wet Meadow	0.40	18.60	14.60	18.20	14.20	0.00	13.70	9.04	13.70	9.04	0.00	18.10	7.99	18.10	7.99
Dry Meadow Forb	24.40	23.90	30.40	-0.50	6.00	0.00	0.00	3.96	0.00	3.96	0.00	8.50	8.96	8.50	8.96
Riparian Wetland Scrub	70.30	10.60	9.81	-59.70	-60.49	49.30	21.70	27.37	-27.60	-21.93	44.90	29.40	31.41	-15.50	-13.45
Great Basin Scrub	192.70	212.30	225.04	19.60	32.34	123.80	148.10	123.83	24.30	0.03	517.30	450.80	219.98	-66.50	-297.31
Riparian Forest Woodland	2.10	4.70	4.18	2.60	2.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unvegetated	135.30	129.90	152.32	-5.40	17.02	31.40	24.80	51.20	-6.60	19.80	81.10	131.40	403.77	50.30	322.37
Man Made	29.70	42.30	35.27	12.60	5.57	0.00	1.00	0.00	1.00	0.00	3.70	9.60	0.00	5.90	-3.70
Freshwater Ria	0.00	4.20	0.00	4.20	0.00	0.00	0.00	0.00	0.00	0.00	2.40	1.30	0.64	-1.10	-0.62
Freshwater	2.60	0.10	2.61	-2.50	0.01	0.00	0.00	0.00	0.00	0.00	5.90	6.50	7.49	0.60	0.92
Ephemeral Brackish Lagoon	2.00	0.00	0.00	-2.00	-2.00	0.80	0.00	0.00	-0.80	-0.80	0.20	0.10	0.00	-0.10	-0.20
Ephemeral Hypersaline Lagoon	0.00	34.60	0.00	34.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet Meadow	20.60	0.00	22.84	-20.60	2.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater Pond	0.10	0.00	0.00	-0.10	-0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00
Total Acres	**480.20**	**493.30**	**508.66**	**13.10**	**28.46**	**205.30**	**209.30**	**216.66**	**4.00**	**11.36**	**655.50**	**664.10**	**684.87**	**8.60**	**29.28**

Table 2 continued.

Habitat Type	**South Shore Lagoon**					**South Tufa**					**Lee Vining Creek Tufa**				
	1999	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**
Marsh	0.00	14.20	10.04	14.20	11.10	1.90	2.60	2.88	0.70	0.98	4.20	4.60	3.07	0.40	-1.13
Alkaline Wet Meadow	7.70	71.20	62.36	63.50	55.45	0.00	7.20	4.80	7.20	4.80	1.50	0.00	0.00	-1.50	-1.50
Dry Meadow Forb	239.80	116.00	101.51	-123.80	-138.53	0.00	18.80	16.92	18.80	16.92	5.20	8.60	9.84	3.40	4.64
Riparian Wetland Scrub	2.60	0.30	0.49	-2.30	-2.28	0.00	0.00	0.31	0.00	0.31	16.60	16.30	17.22	-0.30	0.62
Great Basin Scrub	267.70	348.00	223.70	80.30	-43.43	246.00	220.60	91.22	-25.40	-154.78	79.00	77.60	73.67	-1.40	-5.33
Riparian Forest Woodland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unvegetated	627.00	678.80	832.62	51.80	206.04	44.50	51.20	161.14	6.70	116.64	4.90	4.60	20.04	-0.30	15.14
Man Made	3.40	11.00	0.00	7.60	-3.40	6.40	10.40	0.00	4.00	-6.40	0.00	1.50	0.00	1.50	0.00
Freshwater Ria	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ephemeral Brackish Lagoon	23.60	2.40	0.62	-21.20	-23.60	0.00	0.20	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Ephemeral Hypersaline Lagoon	0.00	2.30	0.10	2.30	3.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wet Meadow	0.00	0.30	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Freshwater Pond	0.00	0.00	4.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Acres	**1171.80**	**1244.50**	**1235.75**	**72.70**	**64.41**	**298.80**	**311.00**	**277.27**	**12.20**	**-21.53**	**111.40**	**113.20**	**123.85**	**1.80**	**12.45**

Habitat Type	**Dechambeau Creek Delta**					**West Shore/Lee Vining Creek Delta**					**All Sub Areas**				
	1999	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**	**1999**	**2005**	**2009**	**99-05 Change**	**99-09 Change**
Marsh	0.00	3.90	11.32	3.90	11.32	10.70	38.80	36.84	28.10	26.96	300.00	408.80	849.31	108.80	549.31
Alkaline Wet Meadow	0.00	0.00	0.00	0.00	0.00	24.40	39.90	14.62	15.50	-8.84	582.40	1293.10	1123.99	710.70	541.59
Dry Meadow Forb	28.20	50.10	51.11	21.90	22.91	101.00	31.00	75.29	-70.00	-25.32	1921.70	1355.20	935.05	-566.50	-986.65
Riparian Wetland Scrub	61.80	46.50	48.78	-15.30	-13.02	79.40	61.70	55.74	-17.70	-21.20	333.60	204.40	191.14	-129.20	-142.46
Great Basin Scrub	41.50	39.60	35.25	-1.90	-6.25	316.70	302.60	138.42	-14.10	-175.13	3819.40	3662.10	3042.16	-157.30	-777.24
Riparian Forest Woodland	1.20	0.00	0.01	-1.20	-1.20	5.10	16.60	21.13	11.50	14.34	8.40	21.30	25.32	12.90	16.92
Unvegetated	7.60	9.10	17.25	1.50	9.65	52.00	122.70	299.25	70.70	259.81	4993.30	5948.60	7430.18	955.30	2436.88
Man Made	6.60	22.20	19.83	15.60	13.23	6.50	12.40	7.30	5.90	0.80	56.30	126.40	62.40	70.10	6.10
Freshwater Ria	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.42	-0.50	-0.50	2.90	5.50	1.06	2.60	-1.84
Freshwater	0.00	0.00	0.00	0.00	0.00	1.70	1.90	1.66	0.20	-0.04	10.20	8.50	11.76	-1.70	1.56
Ephemeral Brackish Lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	108.60	17.20	5.51	-91.40	-103.09
Ephemeral Hypersaline Lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.45	110.70	38.40	0.41	-72.30	-110.29
Wet Meadow	44.10	29.10	16.47	-15.00	-27.63	0.00	0.00	0.00	0.00	0.00	83.00	29.40	39.32	-53.60	-43.68
Freshwater Pond	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.70	12.00	9.39	3.30	0.69
Total Acres	**191.00**	**200.50**	**200.02**	**9.50**	**9.01**	**598.00**	**627.60**	**650.70**	**29.60**	**71.34**	**12339.20**	**13130.90**	**13726.98**	**791.70**	**1387.78**

The difference in acreage for each subarea between 1999 and 2009 ranged from a decrease of 21.53 acres at South Tufa to an increase of 580.46 acres at Bridgeport Creek Delta/Dechambeau Embayment/Black Point (Table 3). All of the differences represent 11.25 percent difference compared to the total acreage mapped in 1999.

Table 3. Acreage of each of the mapping sub areas and the differences between sampling years.

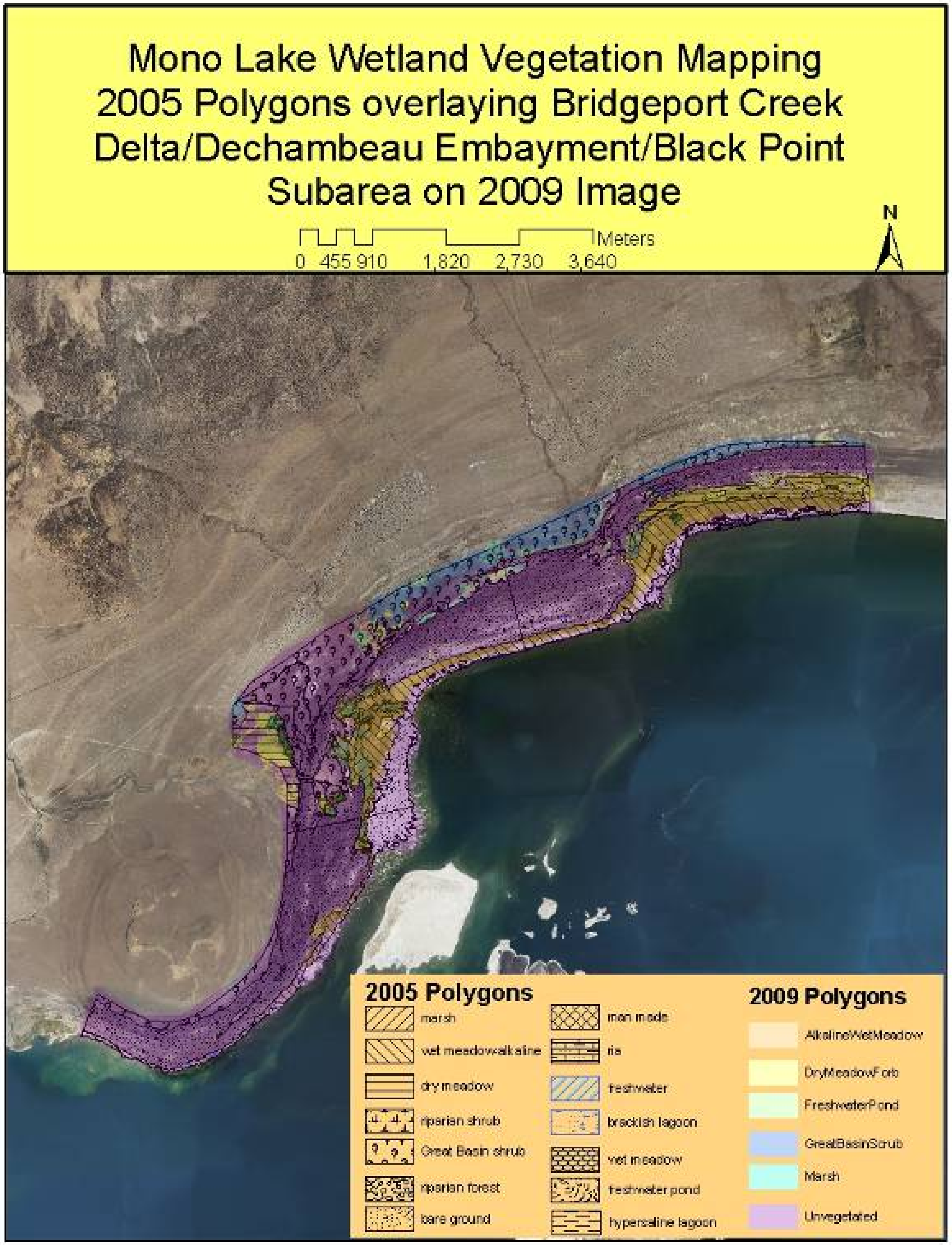
Sub Area	1999	2005	2009	99-05 diff	99-09 diff
Sammann's Springs/Sammann's Springs East	1577.10	1720.00	1813.02	142.90	235.92
Northeast Shore/Warm Springs	3648.50	3836.00	4034.13	187.50	385.63
Bridgeport Creek Delta/Dechambeau Embayment/Black Point	3401.60	3711.40	3982.06	309.80	580.46
Willson Creek/Mill Creek Deltas	480.20	493.30	508.66	13.10	28.46
Ranch Cove	205.30	209.30	216.66	4.00	11.36
Rush Creek	655.50	664.10	684.87	8.60	29.37
South Shore Lagoon	1171.80	1244.50	1235.75	72.70	63.95
South Tufa	298.80	311.00	277.27	12.20	-21.53
Lee Vining Creek Tufa	111.40	113.20	123.85	1.80	12.45
Dechambeau Creek Delta	191.00	200.50	200.02	9.50	9.02
West Shore/Lee Vining Creek	598.00	627.60	650.70	29.60	52.70
All Sub Areas	12339.20	13130.90	13853.42	791.70	1387.78

Overall, the greatest increase in habitat type was observed within the Unvegetated class (Table 4). This increase in acreage can be directly related to the decrease in lake elevation between the mapping periods increasing the amount of exposed alkaline flats, tufa, and delta outwash deposits. This change is best illustrated in the Bridgeport Creek/Dechambeau Embayment/Black Point subarea which had the largest increase in the Unvegetated class (563.39 acres). When the polygons developed in 2005 are superimposed on the 2009 image, the change is easily observed (Figure 2).

Table 4. Acreage change for each habitat type.

Habitat Type	All Sub Areas				
	1999	2005	2009	99-05 Change	99-09 Change
Marsh	300.00	408.80	849.31	108.80	549.31
Alkaline Wet Meadow	582.40	1293.10	1123.99	710.70	541.59
Dry Meadow Forb	1921.70	1355.20	935.05	-566.50	-986.65
Riparian Wetland Scrub	333.60	204.40	191.14	-129.20	-142.46
Great Basin Scrub	3819.40	3662.10	3042.16	-157.30	-777.24
Riparian Forest Woodland	8.40	21.30	25.32	12.90	16.92
Unvegetated	4993.30	5948.60	7430.18	955.30	2436.88
Man Made	56.30	126.40	62.40	70.10	6.10
Freshwater Ria	2.90	5.50	1.06	2.60	-1.84
Freshwater	10.20	8.50	11.76	-1.70	1.56
Ephemeral Brackish Lagoon	108.60	17.20	5.51	-91.40	-103.09
Ephemeral Hypersaline Lagoon	110.70	38.40	0.41	-72.30	-110.29
Wet Meadow	83.00	29.40	39.32	-53.60	-43.68
Freshwater Pond	8.70	12.00	9.39	3.30	0.69
Total Acres	12339.20	13130.90	13726.98	791.70	1387.78

Figure 2.


Mono Lake Wetland Vegetation Mapping
2005 Polygons overlaying Bridgeport Creek
Delta/Dechambeau Embayment/Black Point
Subarea on 2009 Image
0
455
910
1,820
2,730
3,640
Meters
N
2005 Polygons
marsh
wet meadowalkaline
dry meadow
riparian shrub
Great Basin shrub
riparian forest
bare ground
man made
ria
freshwater
brackish lagoon
wet meadow
freshwater pond
hypersaline lagoon
2009 Polygons
AlkalineWetMeadow
DryMeadowForb
FreshwaterPond
GreatBasinScrub
Marsh
Unvegetated

The increase in the Unvegetated class and the decrease in the Man Made class are partly due to the inclusion of man made features into the Unvegetated class. Obvious man made features were quickly classified but some of the smaller roads that abutted unvegetated areas were included into the Unvegetated class.

The second greatest increase in habitat type was in the Marsh class which increased by 549.31 acres. Subarea Sammann's Springs/Sammann's Springs East accounted for 230.80 acres of that change compared to only 108.80 acres in 2005 (Figure 3).

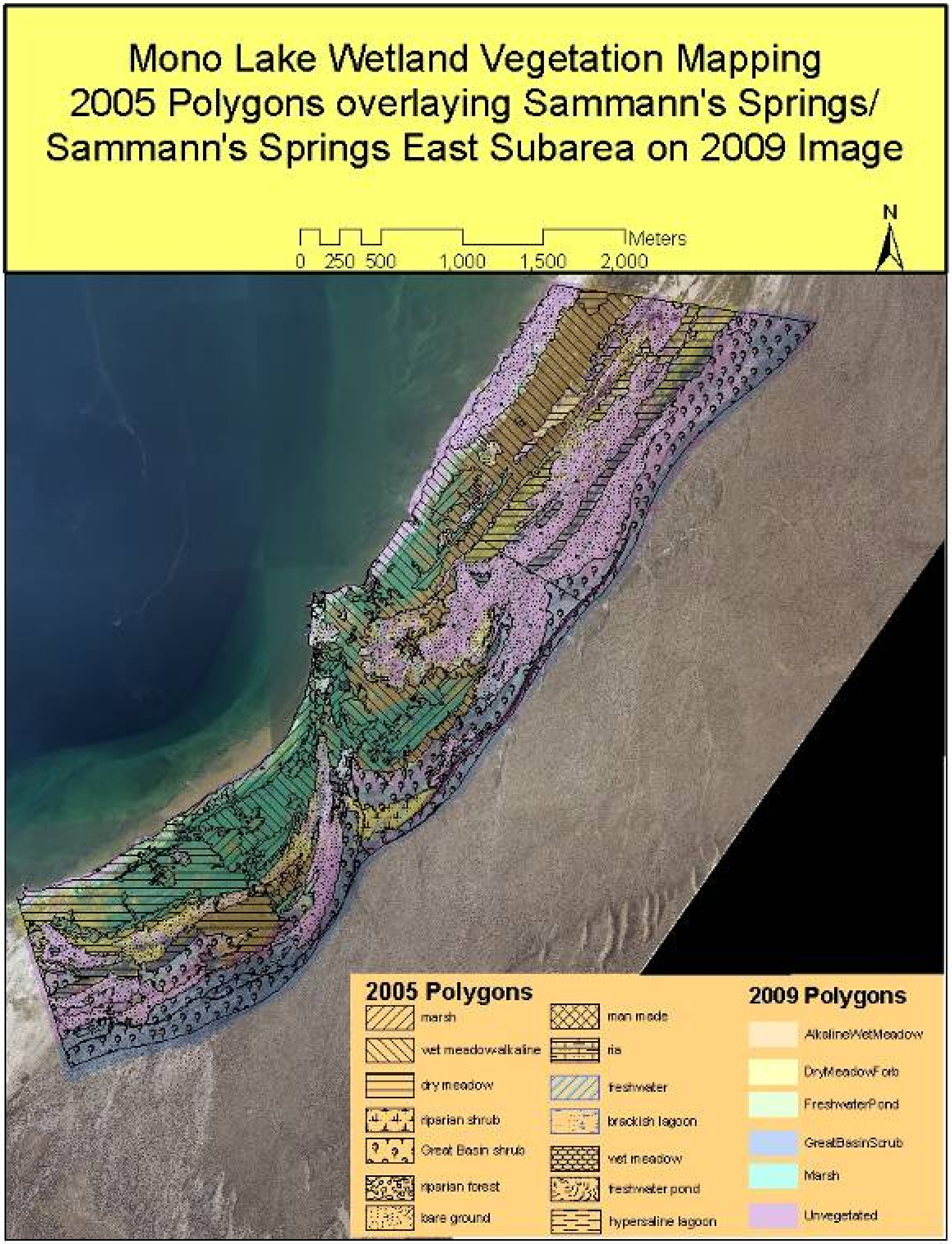
The increase in Marsh is mostly the result of areas previously mapped as Alkaline Wet Meadow being reclassified as Marsh. The area previously mapped as Alkaline Wet Meadow has a fresh water input from springs above with a fault blocking the input of lake water from below. Because the area is more fresh than alkaline, it has been classified as Marsh.

The third greatest increase in habitat type was in the Alkaline Wet Meadow class which increased by 541.59 acres. Subarea Bridgeport Creek/Dechambeau Embayment/Black Point accounted for over half (345.17 acres) of this change. The increase observed at Bridgeport Creek/Dechambeau Embayment/Black Point can be attributed to the resolution of the newly acquired imagery making it easier to discern the transition from a fresh water system to a more alkaline system (Figure 2).

The decreases in the areas mapped as Ephemeral Brackish Lagoon (-103.09) and Ephemeral Hypersaline Lagoon (-110.29) also likely resulted in the lowering of the lake elevation.

The decreases observed in areas mapped as Dry Meadow Forb (-986.65 acres), Great Basin Scrub (-777.24 acres), and Riparian Wetland Scrub (-142.46) can be attributed to the refined mapping technique. Earlier mapping efforts delineated polygons by hand that included overlapping habitat types. The 2009 effort utilizing ERDAS 9.3 enabled the delineation of habitat types that previously were overlooked because they were smaller than the minimum polygon size mapped. ERDAS generated over one hundred and forty two thousand polygons for the largest subarea which was the Bridgeport Creek Delta/Dechambeau Embayment/Blackpoint and over five thousand polygons for the Lee Vining Creek Tufa, the smallest subarea. Also, because the current year mapping effort is comparing a spectral analysis to hand-drawn polygons, some minor differences among the habitat types is expected.

Figure 3.


Mono Lake Wetland Vegetation Mapping
2005 Polygons overlaying Sammann's Springs/
Sammann's Springs East Subarea on 2009 Image
0
250
500
1,000
1,500
2,000
Meters
N
2005 Polygons
marsh
wet meadow/alkaline
dry meadow
riparian shrub
Great Basin shrub
riparian forest
bare ground
man made
ria
freshwater
brackish lagoon
wet meadow
freshwater pond
hypersaline lagoon
2009 Polygons
AlkalineWetMeadow
DryMeadowForb
FreshwaterPond
GreatBasinScrub
Marsh
Unvegetated

Lee Vining Creek and Rush Creek Comparison

Following the lake fringing wetlands and delta areas classification, another classification of Lee Vining and Rush Creeks was performed. This effort was to generate a direct comparison between LADWP's classification utilizing ERDAS Imagine 9.3 and the vegetation map compiled by McBain and Trush.

Table 5 illustrates the differences between the two mapping methods and the differences in acreages of habitat types. The differences observed in total acres can be attributed to how the mapping area was delineated from the 2009 image in ERDAS. The vegetation class polygons generated by McBain and Trush were overlaid on the 2009 imagery and used as a template to generate the subareas used for the ERDAS classification. Because the subareas were drawn by hand, the acreages were either inflated, including areas that didn't get mapped, or deflated, not entirely encompassing the areas mapped by McBain and Trush. Differences in acres of habitat types, is a direct result of comparing a spectral analysis to a hand drawn vegetation map (Figure 3, 4). The comparison shows that the ERDAS classification is very similar to the vegetation map compiled by McBain and Trush and could be used in the future to calculate acreage change among habitat types on both Lee Vining and Rush Creeks.

Table 5. Comparison of habitat type acreages for LADWP's ERDAS based classification and the vegetation map compiled by McBain and Trush.

Lee Vining Creek ERDAS	2009
Habitat Type	Acres
Dry Meadow Forb	2.6
Great Basin Scrub	178.7
Riparian Forest Woodland	38.1
Riparian Wetland Scrub	39.3
Man Made	11.7
Unvegetated	4.3
Freshwater Stream	3.6
Total Acres	275.7

Lee Vining Creek McBain and Trush	2009
Habitat Type	Acres
Dry Meadow Forb	3.9
Great Basin Scrub	153.1
Riparian Wetland Scrub	33.5
Riparian Forest Woodland	35.3
Man Made	10.0
Unvegetated	8.4
Freshwater Stream	13.9
Total Acres	258.7

Rush Creek ERDAS	2009
Habitat Type	Acres
Dry Meadow Forb	75.1
Great Basin Scrub	752.2
Ripaian Wetland Scrub	175.1
Riparian Forest Woodland	23.8
Man Made	34.7
Unvegetated	47.2
Freshwater Stream	18.0
Total Acres	1026.2

Rush Creek McBain and Trush	2009
Habitat Type	Acres
Dry Meadow Forb	30.4
Great Basin Scrub	804.8
Riparian Wetland Scrub	204.0
Riparian Forest Woodland	26.9
Man Made	46.4
Unvegetated	17.4
Freshwater Stream	27.8
Total Acres	1157.9

Figure 4. Lee Vining Delta. Classification using ERDAS compared to methods employed by McBain and Trush.

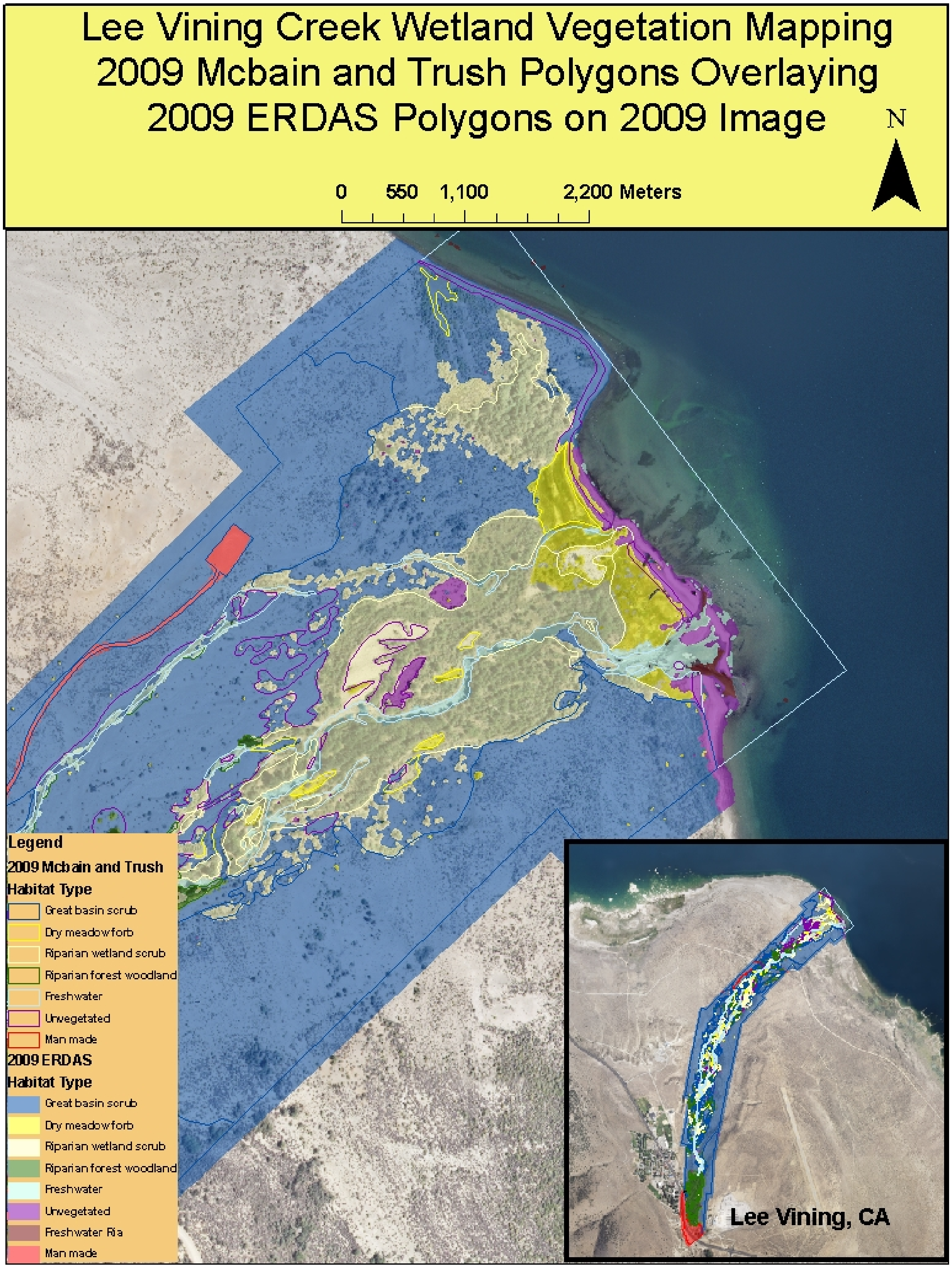
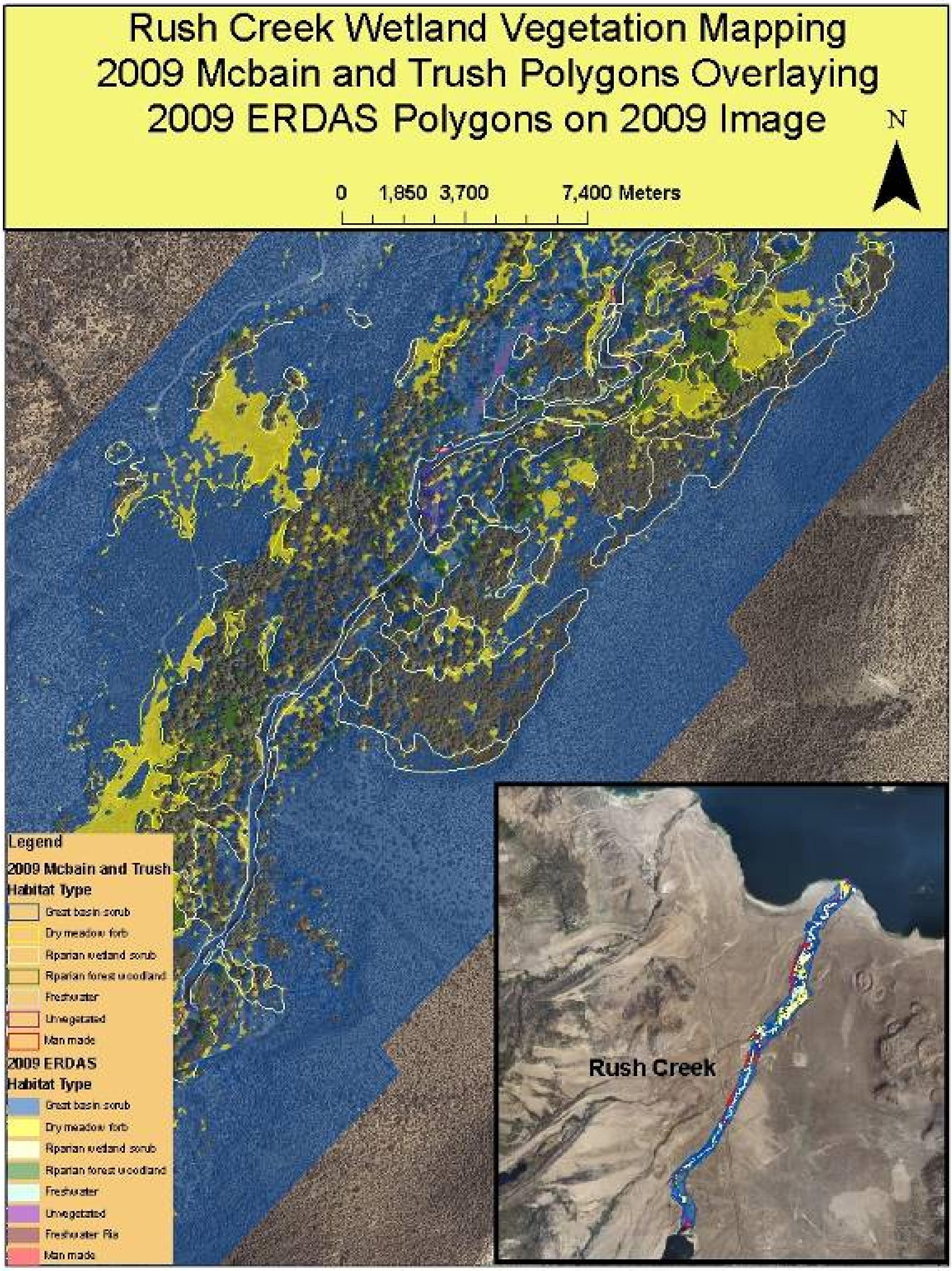


Figure 5. Rush Creek. Classification using ERDAS compared to methods employed by McBain and Trush.



Additional Monitoring

This year was a monitoring year for vegetation sampling in the Basin and will be included here once this draft has been revised. Staff from LADWP continued to place large woody debris in both Rush and Lee Vining Creeks on an opportunistic basis.

Salt Cedar Control

Annual surveys for salt cedar have continued in the lake fringing wetlands and the riparian areas along all of the tributaries to Mono Lake. There was one salt cedar plant detected and treated by LADWP along Rush Creek.

APPENDIX 4

Spring Survey

Mono Lake Spring Survey
November 2009

The Mono Lake Spring Survey was conducted November 02 through 05, 2009 by Los Angeles Department of Water & Power's (LADWP) Brian Norris, Bruk Moges, and Paul Pau. Bob Prendergast surveyed on the first day. The survey was performed to comply with the terms and conditions of LADWP water right Licenses Nos. 10191 and 10192 as set forth in the State Water Resources Control Board Decision 1631 and Order No. 98-05 and per LADWP's Waterfowl Habitat Restoration Plan of 1996. The survey is conducted every 5 years.

The spring locations are shown in Map 1and the spring data are listed in Table 1. Photographs from the spring survey are also included. Many of the spring areas were choked with dense vegetation, making it extremely difficult to access and locate the spring source, as can be seen in the photos. Due to the changes occurring at the Lake and the difficulty in locating many of the springs in the vast area, all of the accessible sites were surveyed using a hand held Global Positioning System (GPS) using the longitude and latitude coordinates from the 2004 survey.

Mono Lake elevation during this year's survey was 6,381.1 feet (USGS Datum), 0.3 feet higher than the 2004 spring survey, and 3.5 feet lower than the1999 survey. Visual observations made during this survey indicate that many of the spring sites visited this year will be inundated with a slight rise in the lake elevation of one to two feet. Most of the springs are expected to be inundated when the lake reaches an average elevation of 6,391 feet. However, others further up the exposed lakebed may begin flowing again.

The next survey is scheduled for the Fall of 2014.

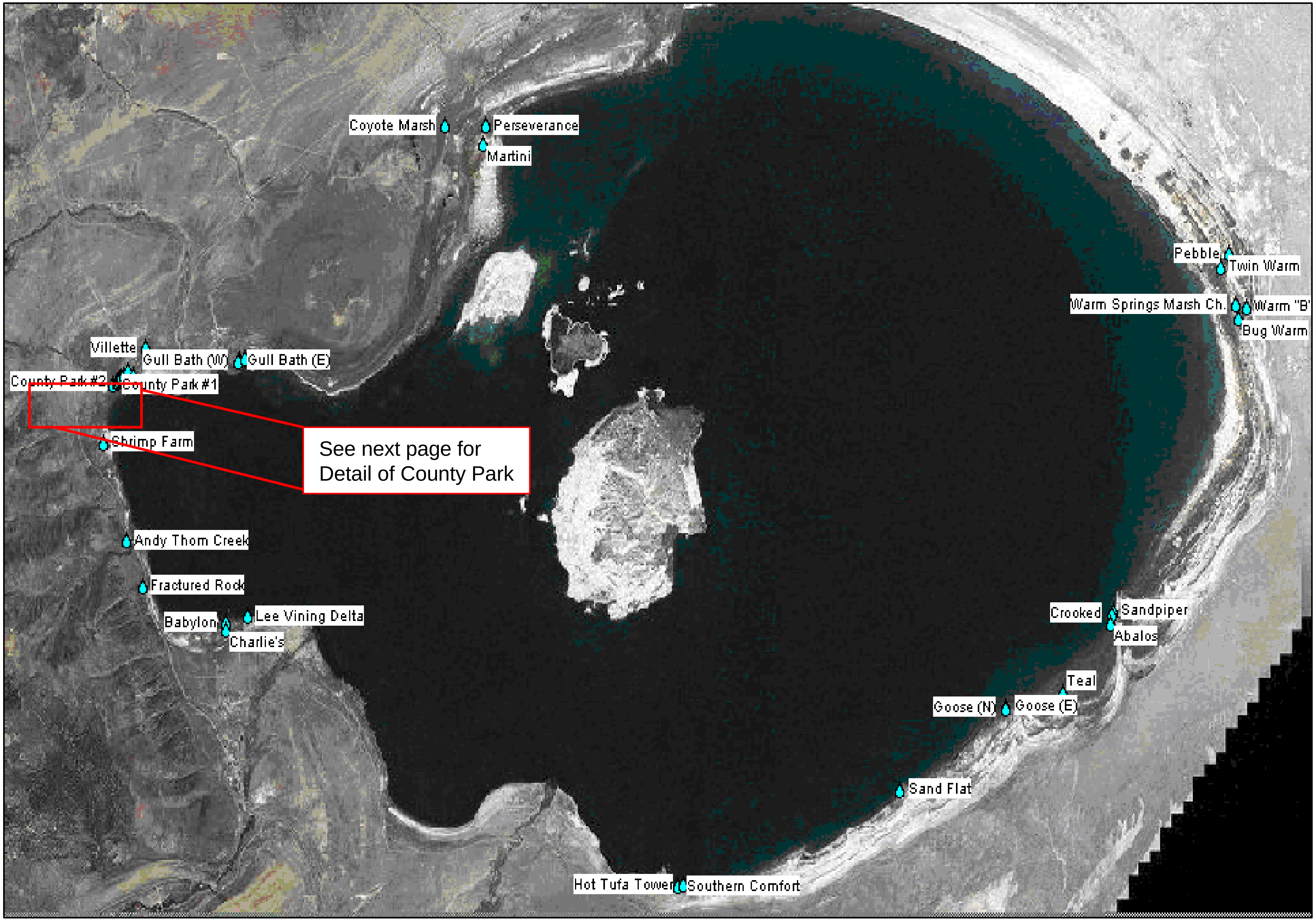
Table 1
Mono Basin Spring Survey 2009

2009 ID	Spring	Flow (cfs)	Measuring Device	Temp. (deg F)	Elec. Cond. (uS/cm)	Sulfur Strands	H_2S Gas	Tufa Tower	Clarity	Photo ID	UTM Coordinates	
											Latitude	Longitude
	South Shore											
M01	Hot Tufa Tower	underwater						Y			N 37° 56.481"	W 119° 01.321"
M02	Southern Comfort	0.15	estimate, no direct flow to lake	90.1	2400	N	N	Y	clear	1328	N 37° 56.465"	W 119° 01.375"
	Southeast Shore											
M03	Sand Flat	trace	vegetated, flow seeping to lake		n/a	N	N	Y		1330	N 37° 57.376"	W 118° 58.555"
M04	Sandpiper	0.57	velocimeter, flow to lake	38.7	540	N	N	N	clear	1349, 1351	N37 59.024”	W118 55.861”
M05	Goose (E)	1.22	velocimeter, flow to lake	54.3	460	N	N	Y	clear	1331	N 37° 58.145"	W 118° 57.214"
M06	Teal	0.2	estimate, flowing to lake	54.1	320	N	N	Y	algae on top	1338	N 37° 58.273"	W 118° 56.491"
M07	Crooked	0.2	estimate, flowing to lake	37.0	390	N	N	N	clear	1343	N 37° 58.996"	W 118° 55.887"
M08	Abalos	0.1	estimate, flowing to lake	56.3	380	N	N	N	clear	1341	N 37° 58.912"	W 118° 55.905"
	East Shore											
M09	Warm “B”	0.58	90^o V-notch,	78.6	3000	N	N	N	clear	1355, 1356	N 38° 01.772"	W 118° 54.224"
M10	Warm Springs Marsh Ch.	vegetated								1362, 1357	N 38° 01.792"	W 118° 54.366"
M11	Twin Warm	0.22	50 ft from spring	92.8	3300	N	N	N	clear	1359	N 38° 02.131"	W 118° 54.568"
M12	Pebble	vegetated		64.4	1700	N	N	N	algae on top	1366	N 38° 02.249"	W 118° 54.457"
M13	Bug Warm	trace, 0.02		66.7	3200	N	Y	N	clear	1358	N 38° 01.668	W 118° 54.328"
	North Shore											
M14	Perseverance	trace flow to lake		58.5	1800	n/a	n/a	N	1373	1373	N 38° 03.232"	W 119° 04.034"
	Solo Hot Tufa Tower	underwater										
M15	Coyote Marsh	trace, vegetated		63.3	600	N	N	N	clear/vegitation	1368	N 38° 03.222"	W 119° 04.550"
M16	Martini	trace		61.9	2200	Y	Y	N	clear	1374	N 38° 03.069"	W 119° 04.072"
	Northwest Shore											

Table 1
Mono Basin Spring Survey 2009

2009 ID	Spring	Flow (cfs)	Measuring Device	Temp. (deg F)	Elec. Cond. (uS/cm)	Sulfur Strands	H_2S Gas	Tufa Tower	Clarity	Photo ID	UTM Coordinates	
											Latitude	Longitude
M17	Gull Bath (E)	1.85	velocimeter	51.1	160	N	N	Y	clear	1435	N 38° 01.075"	W 119° 07.131"
M18	Gull Bath (W)	0.18	velocimeter	50.5	175	N	N	Y	clear	1436	N 38° 01.073"	W 119° 07.160"
M19	Villette	trace	not measurable	48.4	120	N	N	Y	clear	1379	N 38° 01.164"	W 119° 08.346"
M20	County Park #1	0.1	estimate	52.2	140	N	N	Y	clear	1395	N 38° 00.827"	W 119° 08.748"
M21	County Park #2	0.1	estimate	52.0	130	N	N	Y	clear	1394	N 38° 00.846"	W 119° 08.708"
M22	County Park #3	0.1	estimate	50.7	180	N	N	Y	clear	1393	N 38° 00.852"	W 119° 08.707"
M23	County Park #4	0.62	velocimeter	53.2	180	N	N	Y	clear	1392	N 38° 00.875"	W 119° 08.681"
M24	County Park #5	0.08	estimate	55.0	170	N	N	Y	clear	1390	N 38° 00.889"	W 119° 08.663"
M25	County Park #6	0.15	estimate	53.2	140	N	N	Y	clear	1389	N 38° 00.899"	W 119° 08.652"
M26	County Park #7	0.25	velocimeter	53.8	180	N	N	Y	clear	1388	N 38° 00.917"	W 119° 08.618"
M27	County Park #8	0.67	velocimeter	53.2	180	N	N	Y	clear	1386	N 38° 00.953"	W 119° 08.574"
M28	County Park #9	0.92	velocimeter	51.6	145	N	N	N	clear	1385	N 38° 00.914"	W 119° 08.487"
M29	Black Point Seep (Scoria Tufa?)	0.56	velocimeter	45.3	175	N	N	N	clear	1433	N 38° 01.093"	W 119° 07.062"
	West Shore											
M30	Shrimp Farm	0.38	velocimeter	49.1	170	N	N	N	algae, clear	1404	N 38° 00.304"	W 119° 08.859"
M31	Fractured Rock	0.54	velocimeter	63.3	330	N	N	N	clear	1414	N 37° 59.031"	W 119° 08.314"
M32	Andy Thom Creek	0.82	weir estimate	42.6	40	N	N	N	clear	1413	N 37° 59.432"	W 119° 08.535"
	Southwest Shore											
M33	Lee Vining Delta	0.29	weir estimate	51.6	270	N	N	Y	clear	1420	N 37° 58.783"	W 119° 06.962"
M34	Babylon	0.53	velocimeter	51.6	140	N	N	Y	clear	1430	N 37° 58.727"	W 119° 07.245"
M35	Charlie’s	0.08	estimate	51.4	82	N	N	Y	clear/veg	1432	N 37° 58.661"	W 119° 07.241"

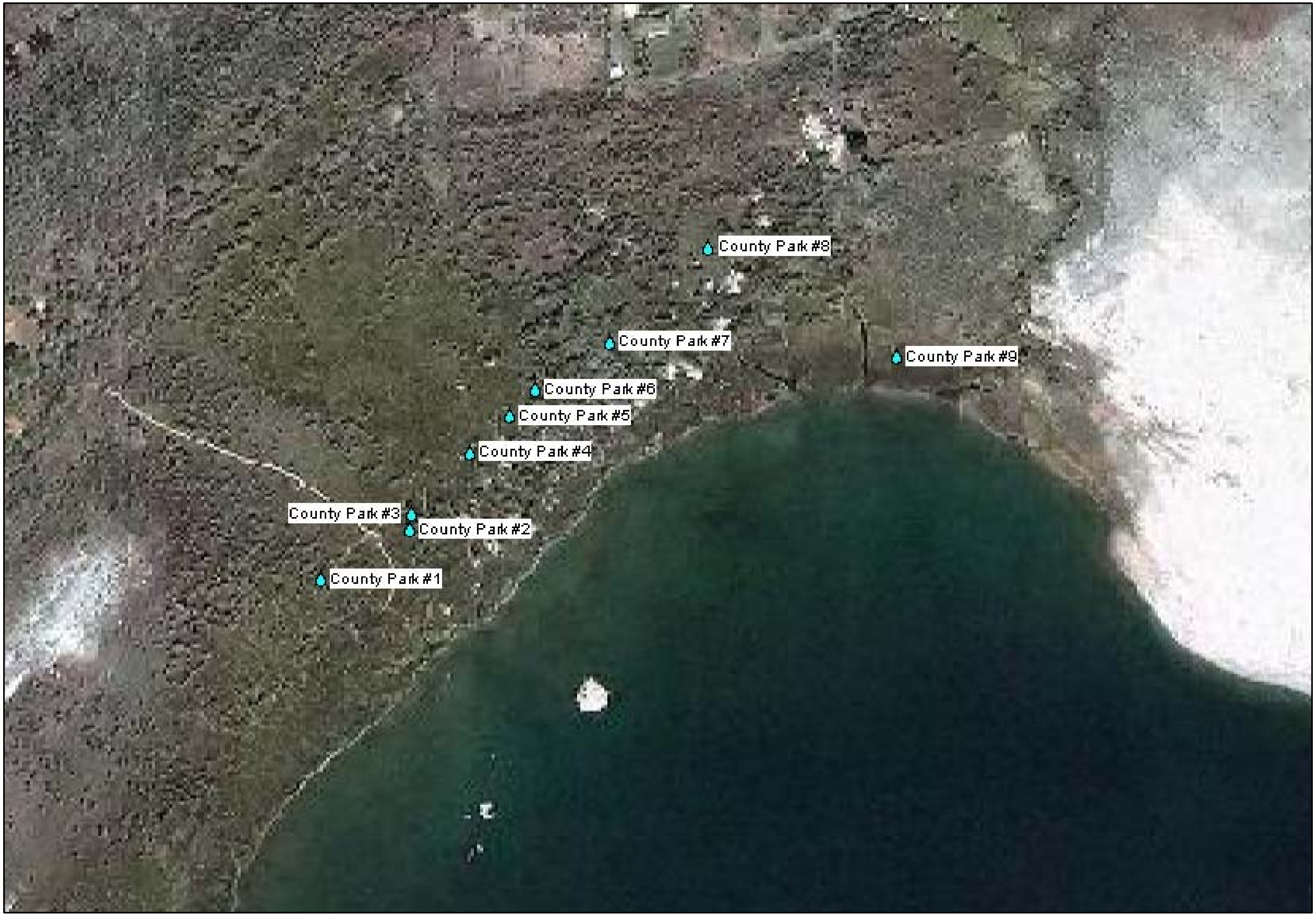
Mono Basin Spring Survey, November 2009
Approximate Spring Locations, Mono Lake



See next page for Detail of County Park

Map 1

Mono Basin Spring Survey, November 2009
Approximate Spring Locations, County Park area of Mono Lake



Map 1 (cont)

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M02 - Southern Comfort

M03 – Sand Flat

M04 - Sandpiper

M05 – Goose (E)

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M06 - Teal

M07 - Crooked

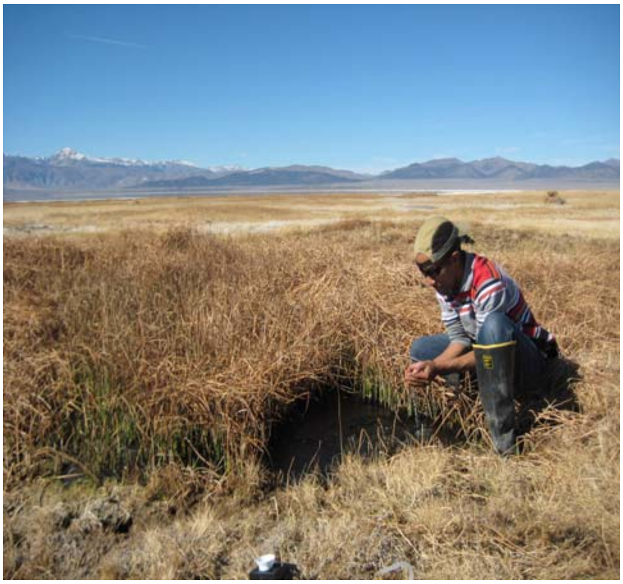
M08 - Abalos

M09 – Warm “B”

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M10 – Warm Springs Marsh



M11 – Twin Warm

M12 - Pebble

M13 – Bug Warm

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M14 - Perseverance

M15 – Coyote Marsh

M16 – Martini

M17 – Gull Bath (E)

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M18 – Gull Bath (W)

M19 - Villette

M20 – County Park #1

M21 – County Park #2

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M22 – County Park #3

M23 – County Park #4

M24 – County Park #5

M25 – County Park #6

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M26 – County Park #7

M27 – County Park #8

M28 – County Park #9

M29 – Black Point Seep

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M30 – Shrimp Farm

M31 – Fractured Rock

M32 – Andy Thom Creek

M33 – Lee Vining Delta

Mono Basin Spring Survey Photos
November 2009

(See **Table 1** for photo data & **Map 1** for photo location)

M34 - Babylon

M35 – Charlie's