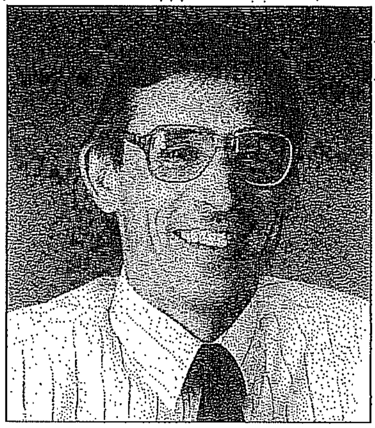
Attachment 1

John M. Melack, Ph.D.



Dr. John M. Melack is a Professor of Biological Sciences at the University of California, Santa Barbara. He received a B.A. in biological sciences from Cornell University in 1969, and a Ph.D. in zoology with a specialization in limnology from Duke University in 1976. While at Duke University he received the prestigious James B. Duke Fellowship. Dr. Melack conducted the research for his doctoral thesis in eastern Africa where he spent two and one half years in Kenya, Uganda, and Burundi. While in Kenya he was Research Associate in the Botany Department of the University of Nairobi. After completing his Ph.D., Dr. Melack was awarded a competitive Post-doctoral Fellowship from the U.S. National Science Foundation which he spent at the University of Michigan, Ann Arbor, Michigan. In 1977, Dr. Melack joined the faculty of the Department of Biological Sciences at the University of California, Santa Barbara, and was promoted to Full Professor in 1987. Since 1979 he has managed the Sierra Nevada Aquatic Research Laboratory, the base for much of the research conducted at Mono Lake.

Dr. Melack is a member of 12 professional societies including the American Society of Limnology and Oceanography, the Ecological Society of America, and the American Geophysical Union. He is an elected National Representative to the Societies Internationalis Limnologiae, and serves on the editorial boards of two journals, Hydrobiologia and Tropical Freshwater Biology. Dr. Melack has served on two National Academy of Sciences committees that prepared reports on Remote Sensing of the Biosphere and The Mono Basin Ecosystem—Effects of Changing Lake Level, and three U.S. National Science Foundation panels that assessed the status and future of research on large lakes and community ecology of lakes and streams. He has represented limnology for five years on NASA's Science Steering Committee for the Earth Observing System, and has served on many review panels for NASA and the U.S. Environmental Protection Agency. Dr. Melack also organized and chaired the Third International Symposium on Inland Saline Waters held in Kenya in 1985.

Dr. Melack has published 86 scientific papers and has 9 more currently in press. Thirty-one of these papers concern saline lakes and 15 deal specifically with Mono Lake. These publications have been peer reviewed and many have appeared in well-respected journals such as Limnology and Oceanography, Freshwater Biology, Oecologia, Science, Nature, Hydrobiologia and Archiv für Hydrobiologie. In addition, he has written 12 book reviews which were published in journals such as Ecology, Science, and American Scientist. Dr. Melack has also prepared 24 technical, workshop, and committee reports, which often are book-length documents. Professor Melack has an active research program in limnology, biogeochemistry, aquatic ecology, and remote sensing, with on-going investigations located in tropical Brazil, the Sierra Nevada, and Mono Lake.

Experience in the Mono Basin

During the course of the 15 years that Professor Melack has been studying Mono Lake, he has been involved in numerous activities related to the assessment of ecological effects of water diversions and to the management of the Mono Basin. He has spoken at public meetings to the California Assembly Committee on Water, Parks, and Wildlife and to UCLA's Public Policy Program. He organized and chaired a special symposium on Mono Lake in 1982. When the U.S. National Academy of Sciences (NAS) formed a committee under Congressional mandate to examine the Mono Lake ecosystem, Dr. Melack was appointed to the committee. Furthermore, he was selected for the Mono Lake study commissioned by the California Legislature in AB 1614 (1984) to examine the ecology of the lake. The NAS investigation of Mono Lake deserves special comment because it is the most unbiased, scholarly examination of the issues to date. The NAS carefully screens potential committee members for their scientific competence and respect; all members serve as volunteers. The final report is the product of rigorous scrutiny by the committee as a whole and by external reviewers. The NAS strives for solid conclusions well supported by scientific evidence. Special attention should be given to the conclusions provided in the NAS report on Mono Lake: The Mono Basin Ecosystem—Effects of Changing Lake Level.

ECOLOGY OF THE OFF-SHORE WATERS OF MONO LAKE, CALIFORNIA

SUMMARY OF CONCLUSIONS

Mono Lake Healthy At Elevations From 6,372 to 6,381 Feet

Although evaluations of ecological health and of ecologically significant changes are often elusive, the rich body of information available for the off-shore habitat of Mono Lake allows an informed judgment. Very rarely can ecological impact assessments use direct measurements spanning a sufficiently long and stressful period, as can be done for Mono Lake. The description of the observed conditions and the analysis of the temporal variations both strongly argue that Mono Lake is healthy and has been healthy during the period from 1979 through 1992. I conclude, therefore, that a management plan that includes lake levels from about 6,372 to about 6,381 feet above sea level is warranted based upon observations of a healthy lake.

DEIR Impact Criteria Inappropriate

A critical step in assessing the ecological impact of changes in lake level is establishing how an ecologically significant impact will be recognized and detected. The Mono Lake DEIR uses a 25 percent change from conditions at a reference lake level as the basis for assigning significance to a change in brine shrimp (Jones & Stokes, 1993). It is my conclusion that the 25 percent criterion is inappropriate for recognition of ecologically significant impacts to the plankton of Mono Lake.

My research team developed the models that were used by Jones & Stokes to support the 25 percent DEIR criterion but my models were never meant to be used in this way. The impact assessment methods used in the DEIR for issues relating to limnology of Mono Lake are unscientific.

Trend Analysis Recommended

Over the past 14 years I have observed that year to year changes in brine shrimp abundance greater than the 25 percent DEIR criterion are a natural feature of Mono Lake. I have also discovered ecological feedback mechanisms that compensate for those factors, including salinity, that influence the abundance of brine shrimp in Mono Lake. Proper assessment of ecological significance of changes in phytoplankton or brine shrimp abundance at Mono Lake requires a consistent trend for at least five years.

INTRODUCTION

I have either performed or directed virtually all of the research on Mono Lake limnology that has been conducted over the past decade. This includes work on the brine shrimp population, its life history and population size, research on Mono Lake's phytoplankton, as well as work on the lake's chemical composition and physical nature.

My interest in saline lakes began with my doctoral research in Africa. A wide variety of saline lakes occur in eastern Africa and offer excellent opportunities for comparative ecology. My doctoral studies emphasized shallow, highly productive lakes which often supported huge numbers of waterbirds. My continuing research at Mono Lake is an out-growth of my doctoral thesis, and is motivated by a general interest in ecosystem dynamics. Initial funding for my studies at Mono Lake, which began in 1978, came from the University of California, National Geographic Society, Santa Clara Audubon Society, and the Packard Foundation. The Mono Lake Committee helped coordinate support from the latter two organizations. As the project expanded, funding was obtained from the California Department of Fish and Game, NASA, and the Los Angeles Department of Water and Power.

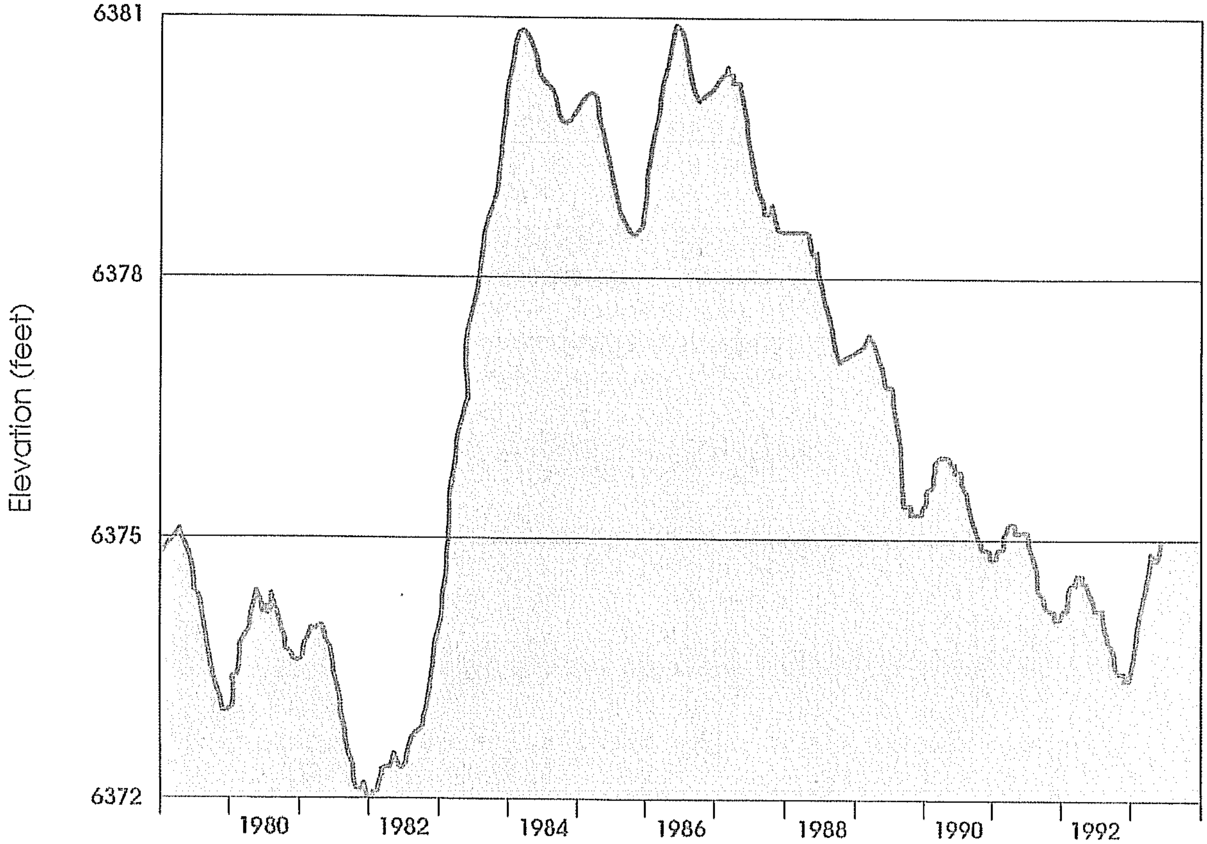
The U.S. National Academy of Sciences (NAS) appointed me to serve on the eleven member NAS committee that prepared the Congressionally-mandated study entitled "*The Mono Basin Ecosystem–Effects of Changing Lake Level.*" It should be noted that the NAS investigation is the most scholarly and unbiased examination of Mono Basin scientific issues performed to date. The NAS carefully screens its potential volunteer committee members for scientific competence and respect; the final report is the product of rigorous scrutiny by the committee and by external reviewers. This is not the case for the CORI Report or the DEIR.

In addition, as part of another study of Mono Lake commissioned by the California Legislature in 1984, I was selected to report on the limnology of the lake.

Saline lakes are common throughout the world and in arid regions often contain more aquatic habitat than freshwater lakes. In the western United States there are several large (>100 km^2 or 39 mi^2) permanent salt lakes; Mono (Patten *et al.*, 1987), Pyramid, Walker, Abert, Devils, Salton, and Great Salt. Because most saline lakes lie in hydrologically closed basins, changes in their size and salinity reflect the balance between inputs of freshwater and losses from surface evaporation. In some cases diversions of freshwater inputs for irrigation or other human uses have resulted in diminished size and increased salinity.

Figure 1

Surface Elevation of Mono Lake



Surface elevation of Mono Lake. Heavy snowfall in 1982-83 led to high inflows of fresh water initiating meromixis. Meromixis is persistent chemical stratification with less saline water overlying more saline water.

At Mono Lake, California, freshwater diversions of inflowing streams for irrigation within the Mono Basin began in the last century. Diversions for export out of the Mono Basin began in 1941 with the extension of the Los Angeles Aqueduct into the Mono Basin. Between 1941 and 1982 the lake surface elevation dropped 14 m (46 ft) and the salinity approximately doubled. From late 1982 through 1983, the lake surface elevation rose 2.6 m (8.5 ft) as exceptionally heavy snowfall accompanying an El Niño - Southern Oscillation and reduced diversions led to high inflows (Figure 1). The inflowing freshwater initiated meromixis, a condition of persistent chemical stratification with less saline water overlying more saline water. Continued diversions and evaporative concentration of surface water led to lake turnover in late 1988. Despite low runoff and drought conditions from 1989 to 1992, lake levels declined less rapidly than before meromixis, as court-ordered flows in Mono Basin streams partially offset evaporative losses from Mono Lake. In 1993, lake levels have risen in response to above average snowfall and runoff.

Predicting ecosystem responses to changes in salinity requires knowledge of the direct effects on physiological characteristics of individual species and of the interactions among species and other aspects of their environment. Salinity bioassay laboratory experiments of the effects of salinity on individual organisims indicate gradual effects of increasing salinity on nearly every life-history parameter (e.g. hatching, mortality, growth, and reproduction) of the only macrozooplankter in Mono Lake, the brine shrimp *Artemia monica* (Dana and Lenz, 1986; Dana *et al.*, 1993). However, interpretation of these results at the population and ecosystem levels is impossible without knowledge of how the brine shrimp interact with their algal food and environment. Comparisons with other hypersaline systems are not possible because there are no well studied lakes which share with Mono Lake the important characteristics of size, water chemistry, and species composition (Melack, 1983). For these reasons, modeling studies and a long-term monitoring program are invaluable tools for predicting responses of the Mono Lake ecosystem to changes in salinity.

This testimony summarizes the results of an on-going study of the limnology and plankton dynamics of Mono Lake conducted from 1979 through 1992. The information and text used here are derived primarily from Jellison *et al.* (1992); further scientific analysis is published in Jellison and Melack (1993a and 1993b) and Jellison *et al.* (1993). As with other areas of environmental concern, the goal of detecting gradual trends due to human activities is made difficult by large year-to-year environmental and ecological variation. During the study, the effects of climatic variation overwhelmed any effects due to changes in salinity predicted from salinity bioassays.

I. GENERAL FEATURES OF MONO LAKE

Mono Lake covers 160 square kilometers (62 square miles) and has a mean depth of 17 meters (56 feet) at an elevation of 1943 meters (6,375 feet). Sodium, chloride and carbonate are the major ions; sulfate, borate, silica, and phosphate concentrations are also high. The pH is about 10, and the salinity ranged from 77 to 98 grams per liter during the study.

A. Simple Food Chain

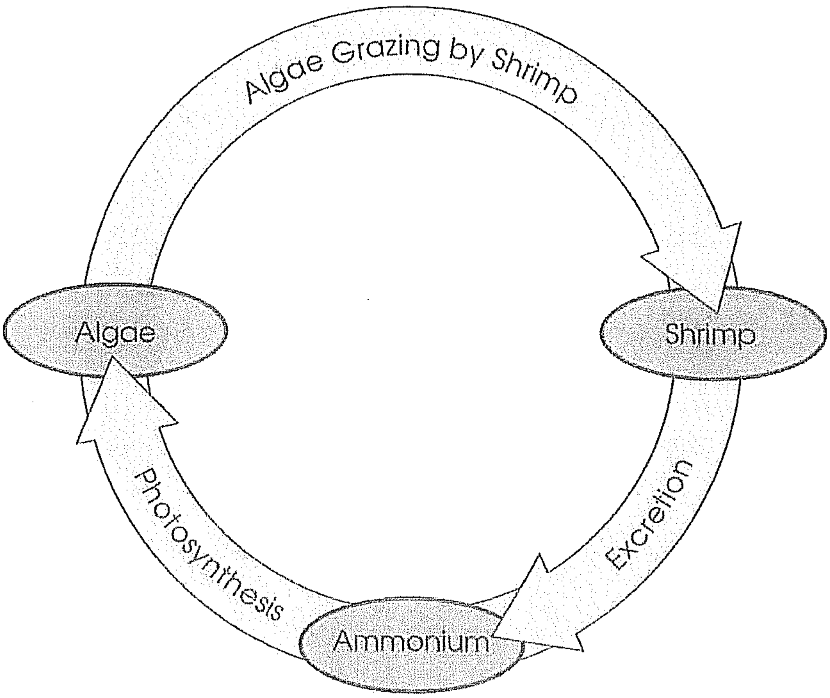
The planktonic food chain of Mono Lake has few species, as is typical of hypersaline waters (Figure 2.) At the bottom of the food chain are the planktonic algae. Green algae, blue-green algae and diatoms predominate. They are fed upon by the brine shrimp, *Artemia monica*, which filters the water with bristled appendages.

B. Plankton Growth is Nitrogen Limited

The planktonic food chain of Mono Lake is said to be nitrogen limited because the limiting nutrient for the planktonic algae is ammonium

Figure 2

Ammonium is the Limiting Nutrient in the Mono Lake Food Chain



Note: Ammonium is the limiting nutrient in the Mono Lake food chain. Lake sediments supply ammonium to surface waters during the fall and winter when the lake is completely mixed. Brine shrimp excretion is the major source of surface water ammonium when the lake is stratified during spring and summer.

(NH_4). There are two main sources of NH_4 for the planktonic algae: the decomposition of organic material in the sediments of the lake bottom, and brine shrimp excretion (Figure 2). When the lake mixes deeply, typically in the fall and winter, the surface waters are fertilized by NH_4 from the bottom sediments. In the spring and summer, when top-to-bottom temperature differences inhibit deep mixing, the main source of NH_4 for the planktonic algae is brine shrimp excretion.

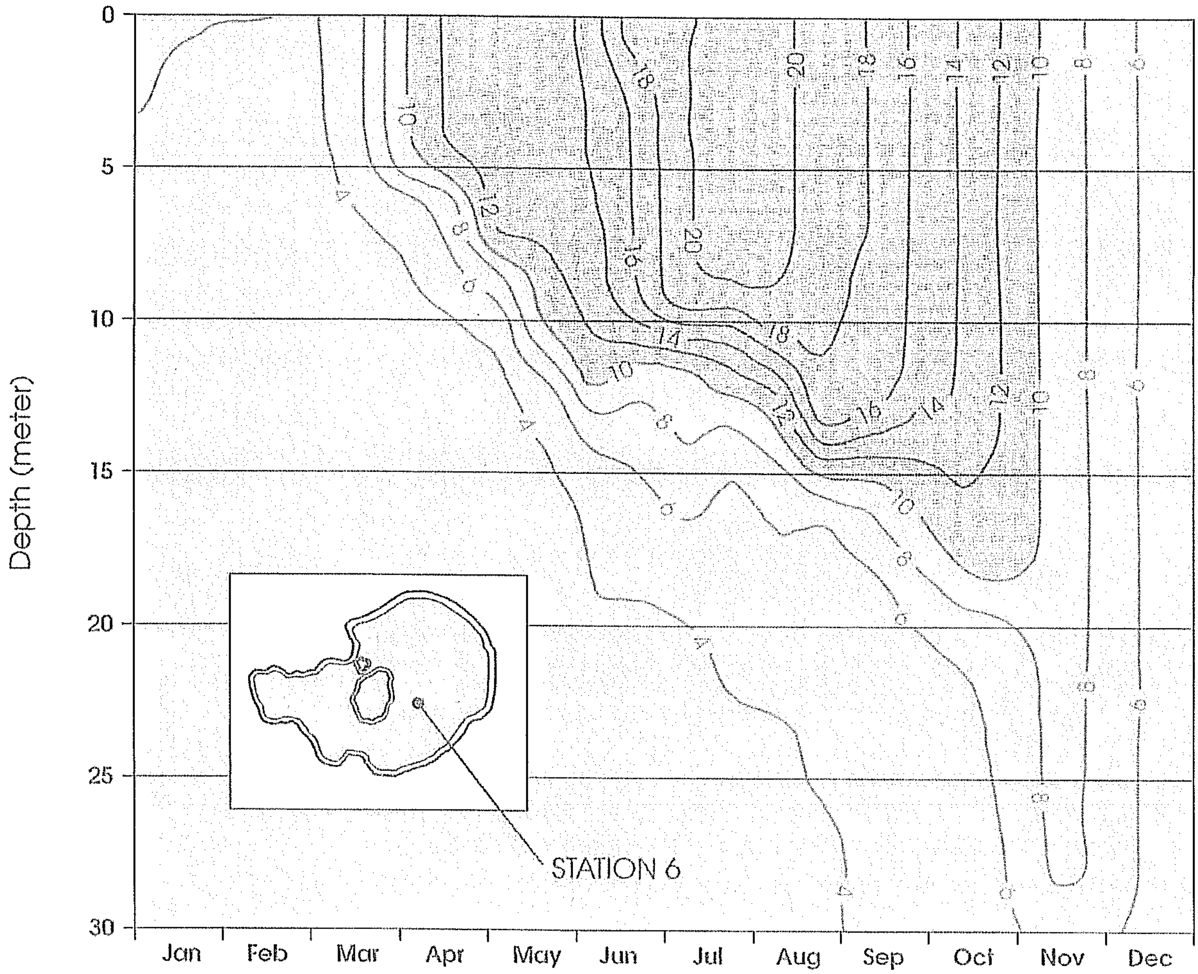
C. Autumnal Mixing Replenishes Surface Nitrogen

Mono Lake undergoes an annual cycle of thermal stratification, with a warm mixed layer floating on top of a cooler, and therefore denser, layer in the spring and summer. The seasonal boundary that separates the warmer and cooler water layers is called the thermocline.

The annual thermal regime observed in 1990 (Fig. 3) is typical of that observed in other years. Annual minima were observed in February and ranged from 1 to 4°C (34 to 39°F). Thermal stratification began in late March in the upper portion of the water column and gradually increased. The thermocline progressively deepened through the summer while temperatures in the upper portion of the water increased

Figure 3

1990 Temperature (°C) at Station 6



Note: The shaded portion of this temperature plot shows the layer of warm (>10°C) surface water that began to develop in March 1990 as a result of solar heating. The layer reached a maximum depth of about 17 m in October. It was obliterated by lake turnover in November.

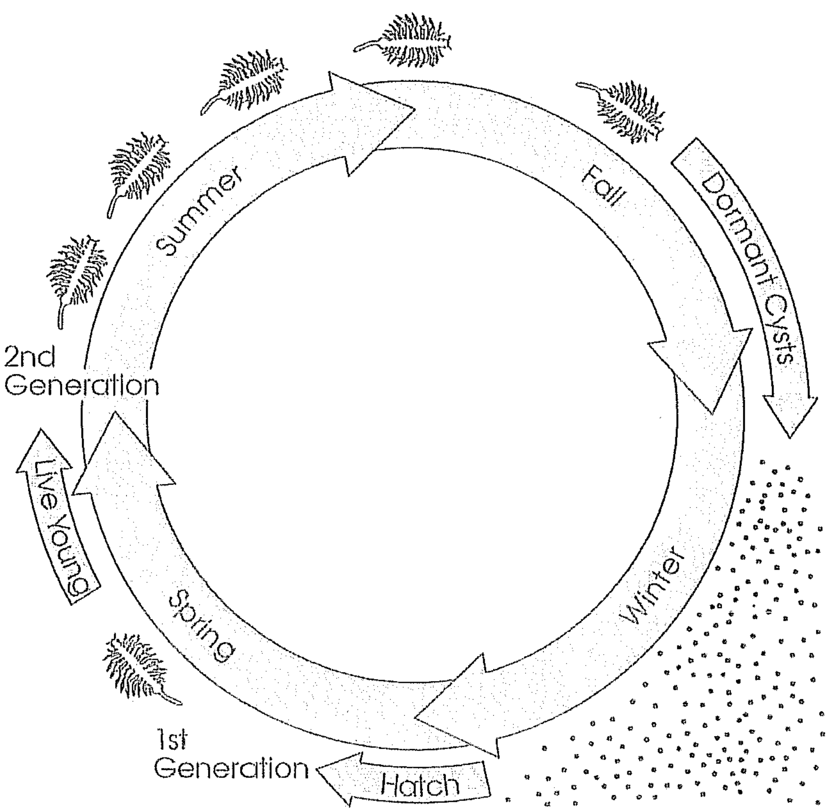
to peak values of 20 to 21°C (68 to 70°F) during August. The mixed layer deepened rapidly in autumn as surface waters cooled, and thermal stratification ended in late October or early November.

D. Shrimp and Algae are Tightly Linked

The plankton of Mono Lake have marked seasonal cycles of abundance. Phytoplankton are abundant throughout the lake during winter and after the onset of the seasonal thermocline in early spring. *Artemia monica* hatch from over-wintering cysts from January to May (Figure 4). By mid-May, the first adult *A. monica* appear. Feeding by the brine shrimp results in a rapid decrease in algal abundance in the upper water column. At the same time though, shrimp excretion is the major

Figure 4

Mono Lake Brine Shrimp Life Cycle



source of ammonium for the algae being grazed. The first generation of adult brine shrimp produce live young which grow into a second generation. The two generations overlap during the summer and reproduce mostly by producing cysts which sink to the bottom. During summer, phytoplankton are sparse and *Artemia monica* abundant above the deeper water which is devoid of dissolved oxygen and unsuitable for the brine shrimp. In autumn, the phytoplankton increase in the surface waters as thermal stratification weakens and as the *A. monica* population declines.

E. Fourteen Year Database Spans Elevations From 6,372 to 6,381 Feet

While these general patterns were observed in all years of study from 1979 through 1992, there were also marked differences in the timing and magnitude of plankton populations due to differences in climate and the vertical mixing regime of the lake. The period can be divided into four time periods for which there are direct measurements of conditions in the lake and which are defined by the annual mixing regime of the lake: monomictic (complete vertical mixing once each year), 1964 to 1982 (Figure 5); meromictic (only partial mixing during the year), 1983 to 1987 (Figure 6); transition to holomixis (complete vertical mixing), 1988 to 1989; and again monomictic, 1990 to the present.

II. DIRECT OBSERVATIONS OF A CHANGING LAKE

A. Monomixis (1964 to 1982); Seasonal Temperature Stratification

Monomixis refers to the seasonal temperature stratification and associated mixing dynamics seen at Mono Lake today (Figure 5). A seasonal thermocline inhibits vertical mixing in the spring and summer and isolates the planktonic algae in the upper mixed layer from the NH_4 produced in the sediments by bacterial decomposition. The accumulated NH_4 is mixed into the surface waters when the thermocline breaks down in the fall.

1. A Baseline for Assessing Future Change

From 1964 to 1982 Mono Lake had a monomictic thermal regime (Figure 5), declining lake levels and increasing salinity. The limnology of Mono Lake was first documented in the mid-1960's (Mason, 1967). Subsequent studies were initiated in the mid-1970's (Winkler 1977; Melack, 1983) in which the seasonal dynamics of the plankton were described. Lenz (1984) documented a progressive increase in the ratio of peak summer to spring abundances of adult brine shrimp (Fig. 7, first three years). The smaller spring numbers resulted in greater food availability for the first generation and much higher production of live young by the first generation, and was followed by a large second generation. Thus, it appeared that changes in the size of the spring hatch resulted in large changes in the ratio of the sizes of the two generations.

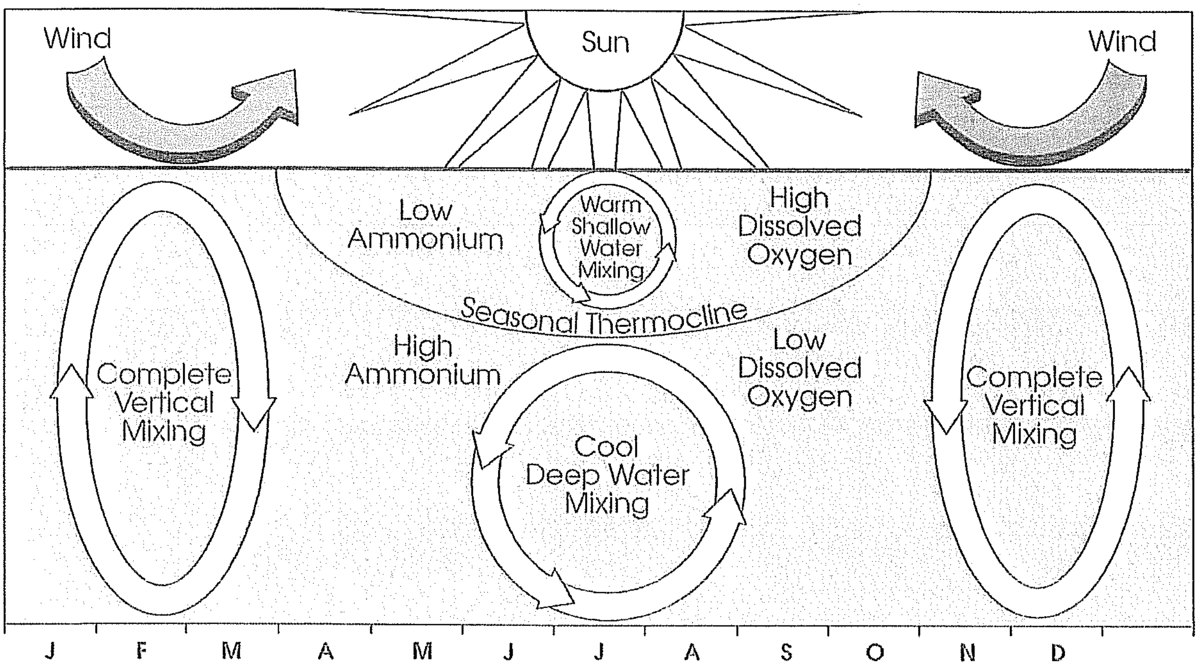
B. Meromixis (1983 to 1987); Persistent Salinity Stratificaiton

Meromixis refers to the persistent salinity stratification that occurs when large freshwater inputs into a saline lake cause a lens of relatively dilute water to rest on top of a layer of undiluted water (Figure 6). The boundary between the two layers is called a chemocline and it inhibits vertical mixing in much the same way as a thermocline. The biological consequences of meromixis can be very pronounced because vertical mixing can be inhibited for many years as it was at Mono Lake between 1983 and 1987.

1. El Niño Brings Five Years of Continuous Salinity Stratification

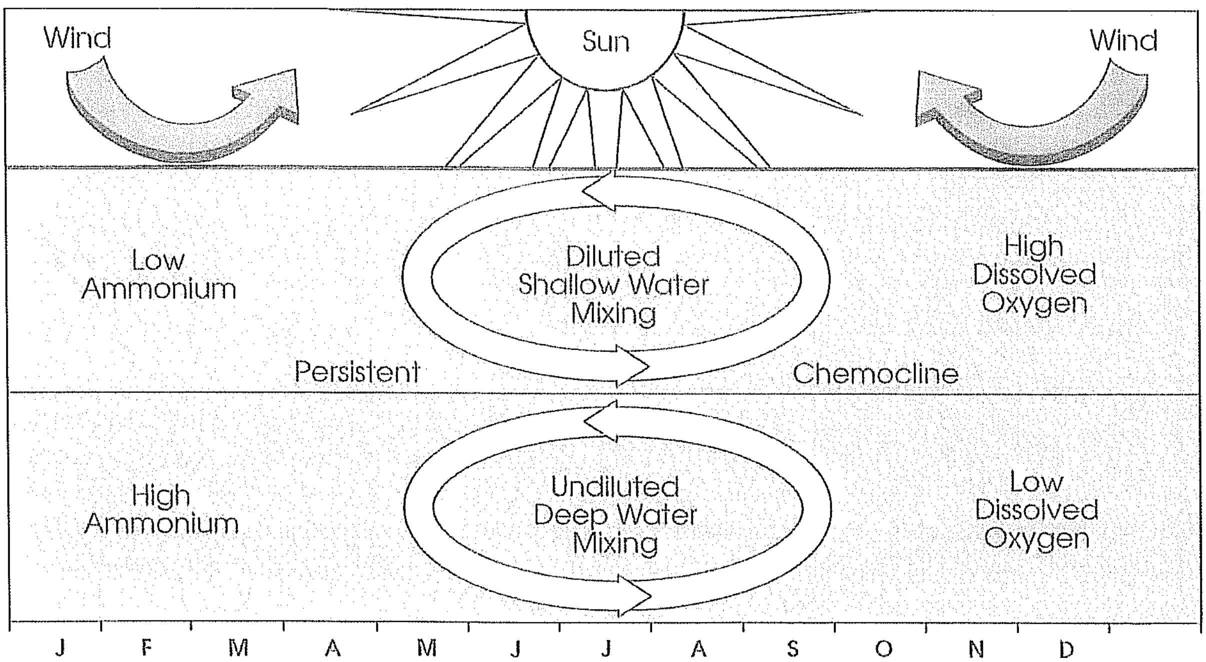
In 1983, the large influx of freshwater into Mono Lake resulted in the onset of meromixis. The decrease in surface salinities resulted in a chemical gradient of about 15 grams total dissolved solids per liter between the the upper mixed layer and the layer below the persistent chemocline (Figure 6). Evaporative concentration of the upper layer and reduced inflows due to continued diversions reduced this difference to about 6 grams total dissolved solids per liter by late 1985. However, high runoff in 1986 established a secondary chemocline above the original one. Evaporative concentration, reduced inflows, and deep mixing continued to reduce the vertical chemical stratification from 1986 through 1988, and meromixis was eventually terminated in November 1988.

Figure 5 Monomixis



Note: Monomixis refers to the seasonal stratification of Mono Lake between a warm surface layer and a cool bottom layer. Seasonal temperature stratification leads to a build up of ammonium in the cool bottom layer during the spring and summer. When stratification breaks down in the fall, the release of this built up ammonium into the surface water fuels an algal bloom.

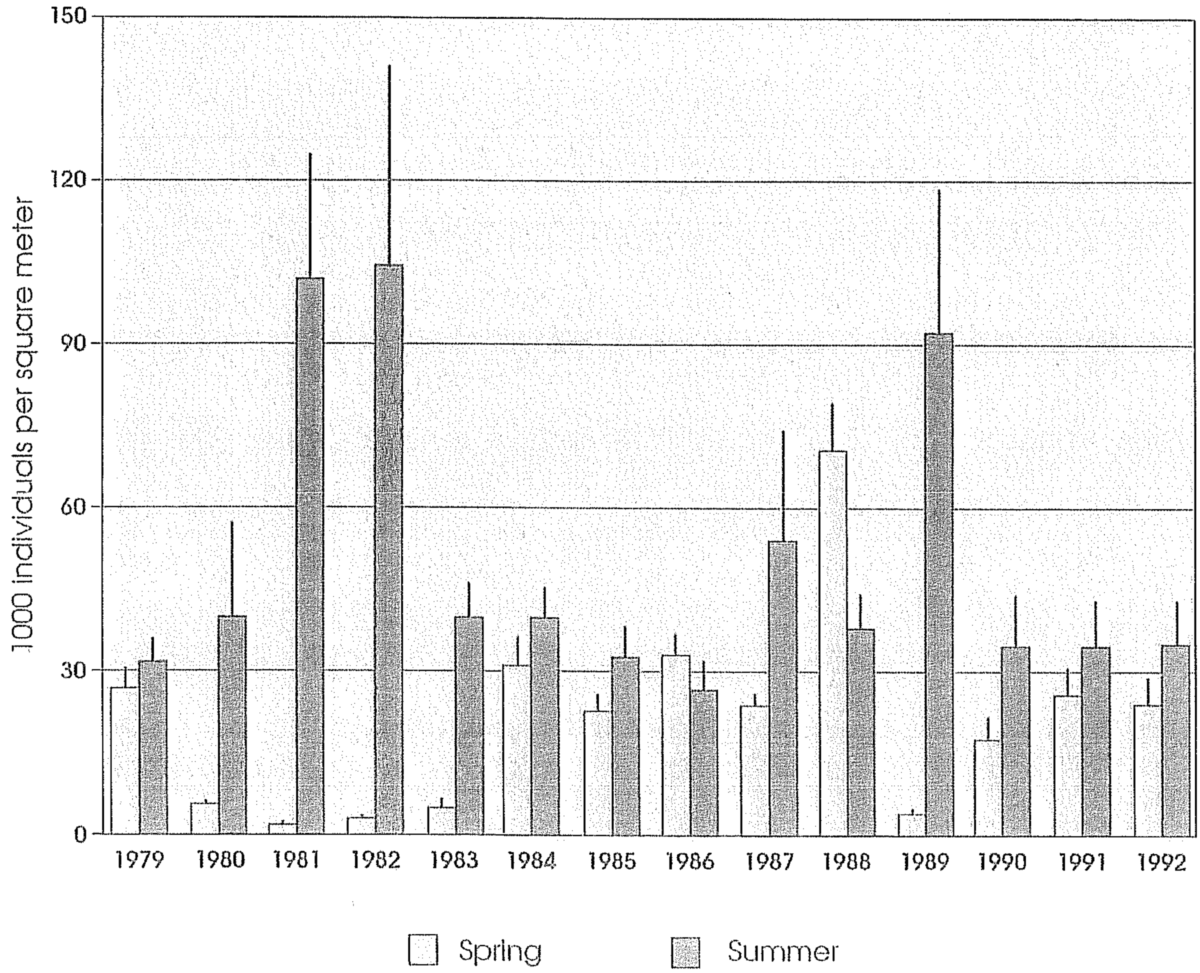
Figure 6 Meromixis



Note: Meromixis refers to the persistent salinity stratification of Mono Lake that can be caused by high freshwater inflows. Because salinity stratification can continue for many years, ammonium can build up to very high levels in the undiluted bottom layer while falling to low levels in the upper diluted layer.

Figure 7

Spring and Summer *Artemia* Peak Adult Abundances, 1979 to 1992



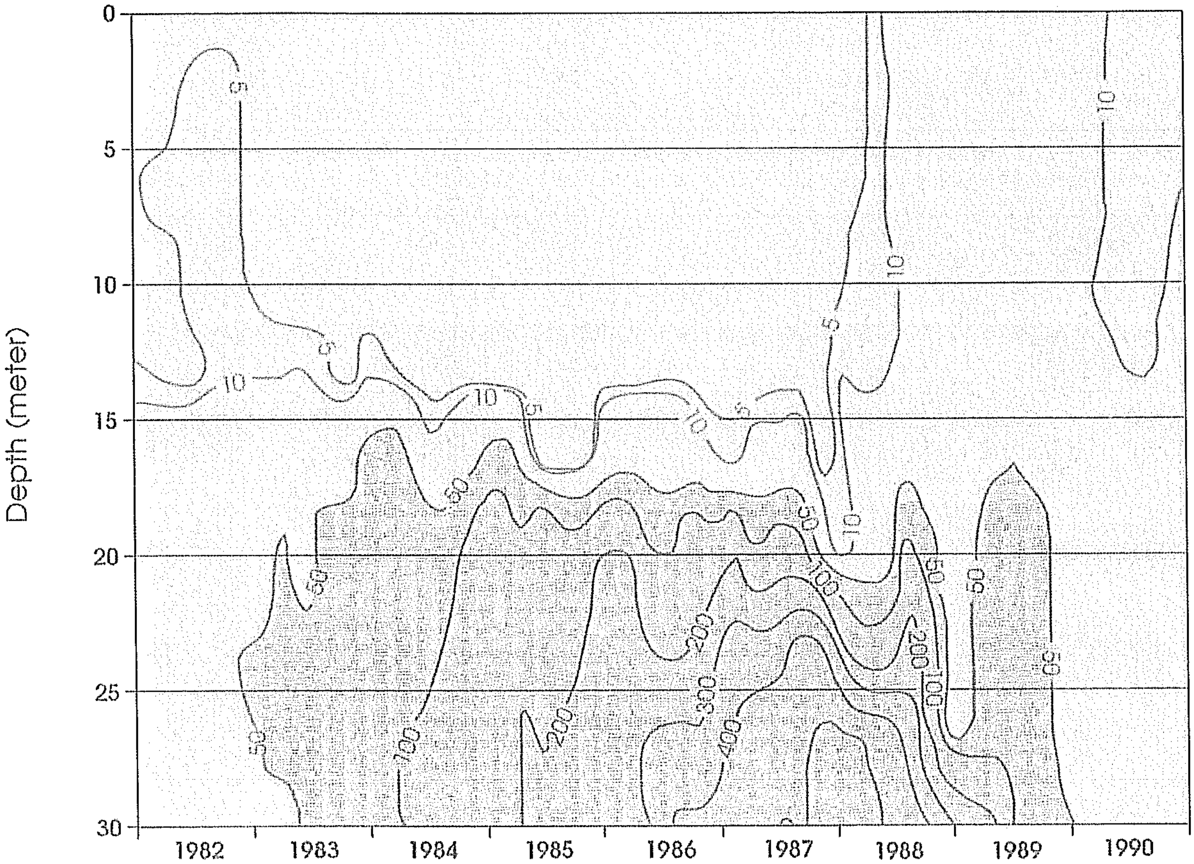
Spring (gray) and summer (solid) *Artemia* peak adult abundances, 1979 to 1992. Error bars show one standard error of the estimate; 1979 to 1981 data from Lenz (1984).

2. Reduced Ammonium Supply Causes Drop in Algae

Following the onset of meromixis in 1983, ammonium and phytoplankton were markedly affected. The ammonium concentration in the upper layer was reduced to near zero and remained low until late summer 1988 (Fig. 8). Accompanying this decrease in upper layer ammonium concentrations was a dramatic decrease in the algal bloom associated with periods when the brine shrimp are less abundant (November through April) (Fig. 9). At the same time, decomposition of organic material and release from the anoxic (oxygen-free) sediments resulted in a gradual buildup of ammonium in the bottom layer over the six years of meromixis (Figure 8).

Figure 8

Lake Wide Ammonium (micro Molar)



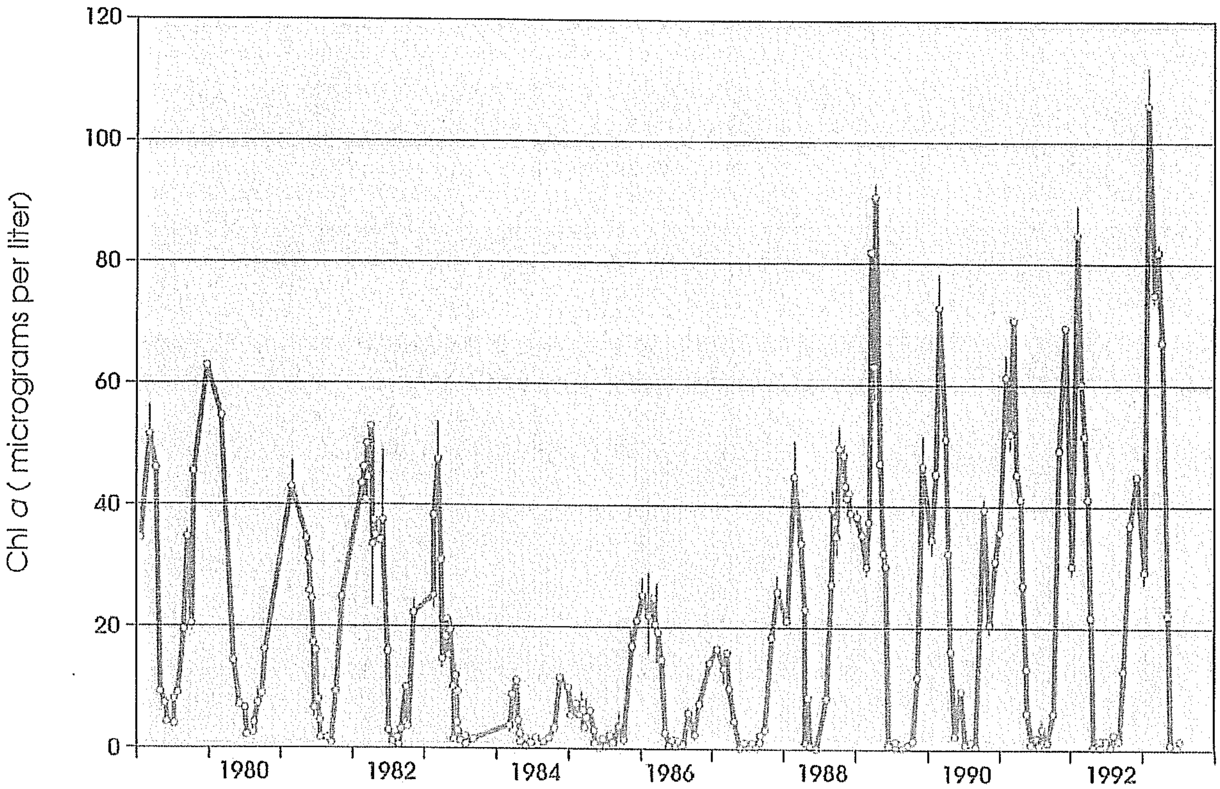
Note: The shaded portion of this ammonium plot shows the build up of ammonium in the undiluted bottom water layer during meromixis and residual high concentrations remaining during the transition to holomixis.

3. Shrimp Do Well

Brine shrimp dynamics were also affected by the onset of meromixis (Figure 7). The size of the first generation of adult *Artemia monica* in 1984 was 31,000 per square meter of water column (334,000 per square foot), nearly ten times as large as observed in 1981 and 1982, while peak summer abundances of adults in 1984 were much lower than in 1981 and 1982. Following this change, the two generations of *Artemia* were fairly consistent during the meromictic period from 1984 to 1987. The size of the spring generation of adult *Artemia monica* only varied from 23,000 to 31,000 per square meter while the second generation of adult *Artemia monica* varied from 33,000 to 54,000 per square meter. During 1984 to 1987, recruitment into the first generation adult class was a nearly constant but small percentage

Figure 9

Mixed-layer Chlorophyll *a* Concentrations (micrograms per liter)



Mixed-layer chlorophyll *a* concentrations (micrograms per liter). Error bars show one standard error of the estimate. Chlorophyll *a* is a measure of algal abundance.

(about 1 to 3 percent) of the cysts calculated to be available (Dana *et al.*, 1990). Also, fecundity (number of eggs produced per female) showed a significant correlation with ambient algal concentrations. Sixty one percent of the variance in fecundity is explained by the abundance of algae.

C. Transition to Holomixis (1988 to 1989)

Holomixis refers to a state of complete vertical mixing, or turnover. After five years of salinity stratification, turnover was a significant event.

1. Prelude to Turnover

Although turnover did not occur until November 1988, successive deepening of the mixed layer occurred during the period from 1986 to 1988. By spring 1988, the mixed layer included the upper 22 m of the lake and included 60 percent of the lake's bottom and 83 percent of the volume. In addition to restoring an annual mixing regime to much of the lake, the deepening of the mixed layer had increased the nutrient supply to the upper layer by entraining water with very high ammonium concentrations. Upper layer ammonium concentrations were fairly high during the spring, and March algal populations were much higher than in 1987.

The peak abundance of spring adult *Artemia* in 1988 was twice as high as any previous year from 1979 to 1987 (Figure 7, page 10). This increase could have been due to enhanced hatching and/or survival of larvae. The pool of cysts available for hatching was potentially larger in 1988 because cyst production in 1987 was larger than in the four previous years and because significant lowering of the chemocline in the autumn and winter of 1987 had 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. Larval survival may also have been enhanced because chlorophyll *a* levels in the spring of 1988 were higher than the previous four years (Figure 9). This hypothesis is corroborated by results of an experiment in which larval survival of *Artemia monica* was greater in high food treatments relative to low food treatments.

2. Turnover

Mono Lake returned to the previous condition of annual autumnal mixing from top to bottom with the complete breakdown of meromixis in November 1988. Ammonium, which had accumulated to high levels in the bottom layer during meromixis, was dispersed throughout the water column, raising surface concentrations to high values. Oxygen was diluted by mixing with the anoxic water and was consumed by the biological and chemical oxygen demand previously created in the bottom layer. 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 to 3 milligrams per liter) but were still below those observed in previous years (4 to 6 milligrams per liter). The timing of hatching of *Artemia* cysts was delayed by the low oxygen concentrations and occurred slightly later in the spring. Recovery of dissolved oxygen concentrations to levels observed in other years occurred in March.

3. Increased Ammonium Supply Enhances Algal Growth

Elevated ammonium concentrations following the breakdown of meromixis led to high chlorophyll *a* levels in spring 1989 (Figure 9). Concentrations in March and April in the upper portion of the water were the highest observed during the study. Subsequent decline to low midsummer concentrations due to brine shrimp grazing did not occur until late June. In previous meromictic years, this decline occurred up to six weeks earlier.

4. Shrimp Experience High Spring Mortality

First generation numbers of *Artemia monica* in 1989 were initially high in March (about 30,000 per square meter) and within the range seen from 1984 to 1988, but decreased by late spring to 4,200 per square meter. This mortality was higher than observed during meromixis and may have been due to elevated concentrations of potentially toxic compounds resulting from the breakdown of meromixis.

5. Shrimp Numbers Rebound in the Summer

Ample food, i.e. algae, as indicated by high spring chlorophyll *a* in 1989, resulted in high individual *Artemia monica* fecundity. During meromixis, brood sizes associated with low food levels in May and June were much lower. The large brood sizes and large production of live young resulted in a high peak abundance of summer adults (93,000 per square meter). This pattern of low numbers of first generation adults followed by much higher summer abundances was also observed in 1981 and 1982. In contrast, the pattern observed during meromictic years was a large first generation followed by a summer population of approximately the same size. While individual reproductive parameters were mostly similar during the summer periods of low algal biomass, the exceptionally large second generation in 1989 led to lower than usual algal biomass and depressed individual reproduction rates. Summer brood size, female length, and cyst production were all the lowest observed in the period from 1983 to 1989. Reproductive characteristics were not monitored in 1982 when a similarly large second generation occurred. While meromixis ended in November 1988, the effects of the large pulse of deep-water ammonium injected into the mixed layer on algal and *Artemia monica* dynamics were present throughout 1989.

D. Monomixis (1990 to Present); Return to Baseline Conditions

Mono Lake was monomictic during 1990, 1991, and 1992 and lake levels, 1,942.6 to 1,943.4 m (6,373.5 and 6,376 ft), were similar to those present from 1977 to 1981. The seasonal patterns in chlorophyll *a* and *Artemia* were similar to pre-meromictic conditions observed in 1979. Ammonium was not measured in 1979, so no comparison is possible. The seasonal pattern of concentrations of ammonium from 1990 to 1992 were similar to that observed during pre-meromictic conditions in 1982. The similarities between 1979 (1982 for ammonium), 1990, 1991, and 1992 suggest that the effects of the large ammonium pulse accompanying the breakdown of meromixis in 1988 were gone.

The peak abundances of *Artemia* were remarkably similar from 1990 through 1992, with a fairly large first generation of adult *Artemia* followed by a summer peak of the same magnitude. This pattern is similar to that observed in 1979 and during meromixis, 1984 to 1988. Adult summer population peaks from 1990 to 1992 were all 35,000 per square meter despite a difference in first generation peak adult abundance (18,000, 26,000, and 24,000 per square meter for 1990, 1991, and 1992 respectively). The summer population peak in 1979 was almost identical, 32,000 per square meter.

E. Conclusions

1. Salinity Stratification Highlights Nitrogen Limitation

My research at Mono Lake has spanned years with and without meromixis. The onset of meromixis prevented the annual winter period of vertical mixing with consequent reductions in ambient ammonium levels in the mixed layer. This led to marked reductions in algal biomass and annual photosynthetic activity. Jellison and Melack (1993a) report a marked reduction in photosynthetic activity integrated over the entire water column during meromixis.

2. Compensatory Interactions of Algae and Brine Shrimp

During the study, large variations in the spring generation of *Artemia* enabled compensatory effects between algal and *Artemia* populations to be observed. In 1981, 1982, and 1989 small first generations were followed by very large summer populations. Increased reproduction by the first generation *Artemia* during years when a small spring hatch occurs is the most prominent compensatory interaction observed in the plankton dynamics. Examination of reproductive characteristics (Dana *et al.*, 1990) revealed food limitation of individual *Artemia* fecundity during much of the time. Laboratory experiments indicate that low ambient food levels observed in spring during meromixis depress survivorship.

My data indicate the importance of nitrogen recycling to photosynthetic activity and the compensatory interactions between algae and *Artemia*. Within a moderate salinity range, zooplankton production may not be limited as much by absolute physiological rates at different salinities as by availability of food. In addition to ongoing monitoring, current research is focusing on the development of a plankton model that incorporates interactions between nitrogen, algal, and *Artemia* components of the pelagic ecosystem. Initial results suggest that population responses (e.g., total cyst production, peak abundances, secondary production) to changes in salinity will be less than those predicted by direct extrapolation of salinity bioassay experiments and that both primary and secondary production are predominately determined by nitrogen recycling within the lake. However, further work is necessary to confirm these findings, and important questions remain as to the long-term effects on the nitrogen budget of changes in salinity or the frequency of periods of meromixis which will likely accompany major changes in lake level.

III. ANALYSIS OF VARIABILITY OF ALGAE AND BRINE SHRIMP

Mono Lake is subjected to natural and human-caused conditions which can affect the organisms living in the lake and the functioning of the ecosystem. The period from 1979 through 1992 has an excellent record of the ecological status of the off-shore waters of the lake, as summarized above. In addition, during this period the lake was influenced by a major climatic perturbation and experienced the lowest lake level in the historical record. Therefore, a rich source of information is available with which to evaluate the ecological health of Mono Lake.

A. Trend Analysis is Best Way to Assess Historical Lake Level Impacts

Ecological health can be assessed on the basis of number of organisms, variations in those numbers, and productivity of the plants and animals living in the lake. Good health can be indicated by population sizes and productivities being similar to those in other lakes that experience similar natural environmental conditions but no anthropogenic perturbations. This approach is difficult to apply to Mono Lake because no appropriately similar lakes exist. Good health can also be assessed on the basis of the tendency of the abundances and productivities to have a long-term increasing or decreasing trend or only variation around an approximately constant average value. The data available from the off-shore waters of Mono Lake are suitable for this approach.

Ecologists have had a long standing interest in the analysis of the temporal variability of populations and ecosystems. For example, I examined the variability of phytoplankton abundance and photosynthesis in lakes of the world (Melack, 1979) and have cited examples of such analyses for other organisms. Numerous statistical methods are now available with which to judge the nature of temporal variations (e.g. Colwell, 1974; Platt and Denman, 1975; Carpenter, 1990; Jassby and Powell, 1990; Lewis, 1990). Two recent approaches proposed by Jassby and Powell (1990) and Lewis (1990) will be applied here.

B. Moving Average Approach Shows No Biological Trends at Elevations From 6,372 to 6,381 Feet

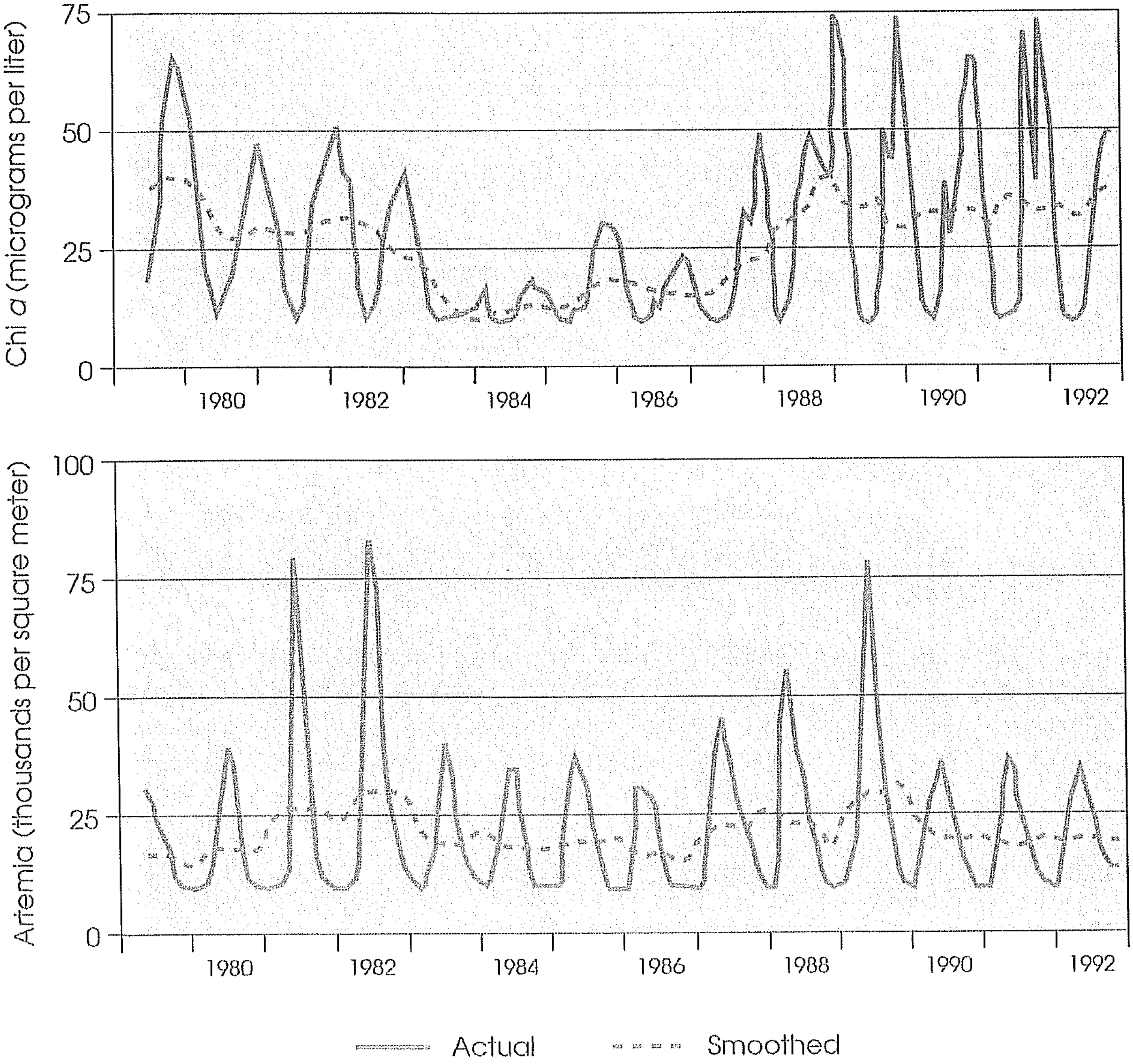
Time-series from 1979 through 1992 for the abundance of phytoplankton (measured as the concentration of the photosynthetic pigment, chlorophyll *a*) and numbers of adult brine shrimp are illustrated in Figure 10. Actual measurements (solid line) are compared to smoothed values (dashed line) computed as a 12 month moving average.

1. No Evidence of Harm to Algae

The smoothed line for chlorophyll *a* shows clearly the reduction in algal abundance during the meromictic period and the similarity of the values prior to and after the meromictic period. While the summer minima are fairly similar among the years, the peak values are much

Figure 10

Time-series of Phytoplankton Chlorophyll *a* Concentrations and *Artemia* Abundance, 1979 through 1992



Time-series of phytoplankton chlorophyll *a* (Chl *a*) concentrations (micrograms per liter) and *Artemia* abundance (thousands per square meter), 1979 through 1992.

more variable. There is no increasing or decreasing trend in the abundance in the phytoplankton over the whole period. However, a decreasing trend is evident from 1982 to 1984 during an interval with rapidly rising lake levels and the onset of meromixis. An increasing trend is apparent from 1985 to 1988 as lake levels fell and vertical mixing deepened. These 2 to 3 year periods with increasing or decreasing values are misleading in the evaluation of the long-term health of Mono Lake, and strongly illustrate the danger in making management decisions based on insufficient evidence.

2. No Evidence of Harm to Shrimp

Overall, the *Artemia* abundance is remarkably consistent from one year to the next (Figure 10, page 17). The smoothed data have no increasing or decreasing trend. Large summer populations occur in 1981 and 1982, when a small spring hatch resulted in high summer numbers, and in 1989, when the spring abundances were reduced because of the anoxia and possibly the presence of toxic substances in the spring that followed the end of meromixis. As with the phytoplankton, slight upward and downward trends are evident for 2 to 3 year periods, but no long-term decrease or increase is apparent.

Proper assessment of an ecologically significant trend in the status of the phytoplankton or brine shrimp of Mono Lake requires a consistent pattern for at least five years.

C. Percentile Approach Shows No Biological Trends At Elevations From 6,372 to 6,381 Feet

When examining time-series data such as those for the phytoplankton and brine shrimp, aggregate statistics that consider maxima, minima, and variation are valuable. Lewis (1990) proposed several simple measures of these characteristics. He suggested using the 95th percentile of algal biomass or abundance for a given year to designate the maximum biomass for that year and using the 5th percentile as the minimum biomass. This approach frees the estimate from bias associated with sample size and reduces the influence of erroneous values at the extremes. The difference between 95 and 5 percentile values is a measure of variation, and when expressed as a percent of the mean is an indication of the relative variability for lakes of different biomasses.

1. No Evidence of Harm to Algae

The variation of the Mono Lake phytoplankton expressed as a percent of the mean was 179 percent for the period from 1979 through 1992. Phytoplankton variation for three lake level intervals are as follows:

- 139 percent (6,372 to 6,375 feet),
- 206 percent (6,375 to 6,378 feet),
- 212 percent (6,378 to 6,381 feet).

Less variation occurred at the lower lake levels and more variation occurred at higher lake levels. If the values for Mono Lake are compared to those from the 16 freshwater lakes that Lewis (1990) examined, Mono Lake's variation was less than the mean of 271 percent for the 16 lakes. Hence, even during a period with a major perturbation caused by meromixis and with the lowest lake level on record, the phytoplankton of Mono Lake were less variable than those in large lakes such as Tahoe, Washington, and Huron.

2. No Evidence of Harm to Productivity

Annual primary productivity (i.e. growth of phytoplankton) and annual secondary productivity (i.e. growth of brine shrimp) provide integrated measures of the ecosystem function. Table A lists primary and secondary productivity for Mono Lake for individual years and for the same lake level intervals used above. When individual years are expressed as a per cent of the overall mean, the values vary from 197 percent to 48 percent of the mean primary productivity and from 169 percent to 69 percent of the mean secondary productivity. The highest average primary and secondary productivities occurred during the lake level interval during which the lake was in transition to and from meromixis. The lowest values occurred during meromixis at the highest lake levels.

IV. APPLICATION OF RESULTS FROM SIMULATION MODELS OF VERTICAL MIXING AND BRINE SHRIMP DYNAMICS

In strong contrast to the DEIR, my analysis is derived primarily from actual measurements of conditions in the off-shore water of Mono Lake. However, considerable effort was made by my research team at the University of California, Santa Barbara, to develop simulation models appropriate for forcasting conditions in Mono Lake at higher and lower lake levels than have been observed. Two models were formulated: DYRESM, a one dimensional vertical mixing model, was adapted to Mono Lake to predict the likelihood of meromixis under various inflow regimes. An original plankton model was developed to assess possible responses of the brine shrimp to different lake levels. To help evaluate the models, their sensitivity to a range of potential conditions was determined and use and refinement of the models has continued.

Both models have their limitiations and assumptions which were carefully explained in the auxiliary material provided to the State Board. However, Jones & Stokes Associates' incorporation of results from the models into the DEIR does not adequately reflect their limitations or explain their assumptions.

Table A

Annual Primary (Algal) and Secondary (*Artemia*) Production in Mono Lake

	Primary Production		Secondary Production	
	($gC\ m^{-2}\ yr^{-1}$)	% of Mean	($gC\ m^{-2}\ yr^{-1}$)	% of Mean
1982	1107	197	–	–
1983	523	93	156	119
1984	269	48	102	78
1985	399	71	103	79
1986	462	82	90	69
1987	371	66	120	92
1988	1064	189	140	107
1989	499	89	221	169
1990	641	114	130	99
1991	418	74	125	95
1992	435	77	120	92
Mean for entire period: 1982-1992	563	–	131	–
6,372-6,375-Ft 1982, 1991, 1992	653	116	123	94
6,375-6,378-Ft 1983, 1988-1990	682	121	162	124
6,378-6,381-Ft 1984-1987	375	67	104	79

A. DYRESM: Sophisticated Mixing Model Applied to Mono Lake

A dynamic reservoir simulation model (DYRESM) was developed by Imberger and Patterson (1981) and has been applied to reservoirs, freshwater lakes and saline ponds as it matured during a decade of use and improvement. I spent a sabbatical with Imberger and Patterson in 1987 and learned the physical limnology underpining their model. J. Romero, one of my Ph.D. students, has been applying DYRESM to Mono Lake since 1990, and J. Patterson spent two months in Santa Barbara in late 1991 to 1992 working on further refinements of the model to Mono Lake.

1. Unusual Mixing Mechanisms Suspected

Modification, testing, and validation of DYRESM has continued to the present. Validation simulations for 1990 and 1982 to 1990 were performed to determine the accuracy of DYRESM and the modeling assumptions made. Meteorological data for the period from November 1989 to November 1990 were used for all the simulations. The limitations of this 12-month meteorological database reduced the accuracy of longer term simulations. DYRESM successfully reproduced much of the observed variation in the vertical structure of temperature and conductivity for 1990 and during the onset, persistence and breakdown of meromixis. However, the model calculated insufficient vertical mixing across the pycnocline, the region with the largest density difference. For example, the breakdown of meromixis was not simulated until the end of 1989, one year later than was observed. Hence, mixing mechanisms not included in DYRESM, such as methane bubbles or mixing near the edges of the lake, may be important. Further problems may stem from uncertainties in the groundwater hydrology of Mono Lake. Better meterological measurements, such as those made in 1992, have improved recent simulations. Although DYRESM, one of best models of vertical mixing available, is based on well established physical processes and has been applied to Mono Lake carefully, the veracity of the 50-year simulations used in the DEIR must be judged as semi-quantitative because of the probability of missing mixing mechanisms and data insufficiencies.

B. Plankton Model

1. Compensatory Feedback Mechanisms Expected to Mitigate Salinity Effects

The plankton model used for the DEIR was derived from a previously developed model of seasonal changes in the *Artemia* population (i.e. a cohort model), supplemented by nitrogen cycling and algal growth. The cohort model integrates the observed effects of temperature, salinity and algal abundance on various life history characteristics of the brine shrimp. The salinity effects were derived from a review and re-analysis of all salinity bioassay experiments previously conducted on *Artemia monica* (Dana *et al.*, 1993). Simulations with the cohort model indicated the influence of increased salinity on population characteristics such as abundance and cyst production are less than those that would be calculated by direct extrapolation of results from the salinity bioassays because of the compensatory feedback between the algae and *Artemia.*

2. Nitrogen Limitation Important

The plankton model described many of the general characteristics of the plankton dynamics observed in Mono Lake including the seasonal partitioning of nitrogen among ammonium, algal and *Artemia* pools. It made reasonable estimates of annual primary, secondary, larval and cyst production. However, the abundances of some brine shrimp life stages were not well simulated. The model suggests that the availability of nitrogen dominates the plankton dynamics.

3. No Scientific Justification for DEIR Impact Criteria

So far, the Mono Lake plankton model has improved our understanding in two ways. It has revealed some previously unknown feedback mechanisms and highlighted those aspects of the ecosystem in need of further study. The predictive value of the model for conditions in Mono Lake possibly occurring at lake levels not observed is less secure. The sensitivity analysis done on the model provides some sense of its limitations. However, if species change in dominance or biogeochemical processes not included become important, the uncertainty of the model's predictions increases. Prudent judgement should guard against extracting narrow quantitative criteria for significant ecological changes associated with lake level alternatives from the plankton model of Mono Lake.

V. RELEVANCE OF FINDINGS TO ASSESSMENT OF ECOLOGICAL EFFECTS OF CHANGING LAKE LEVELS ON MONO LAKE

Though scientific evaluation of ecological health and of ecologically significant changes are often elusive, the rich body of information available for the off-shore habitat of Mono Lake allows an informed judgment. Very rarely can ecological impact assessments use direct measurements spanning a sufficiently long and stressful period, as can be done for Mono Lake. The description of the observed conditions and the analysis of the temporal variations both strongly argue that Mono Lake is healthy and has been healthy during the period from 1979 through 1992 (Figure 11). Furthermore, at the higher levels in this range the lake was meromictic and had an interval with much lower primary productivity but maintained a robust brine shrimp population. Therefore, a management plan that includes lake levels from about 6,372 to about 6,381 feet above sea level is supported by observations of a healthy lake.

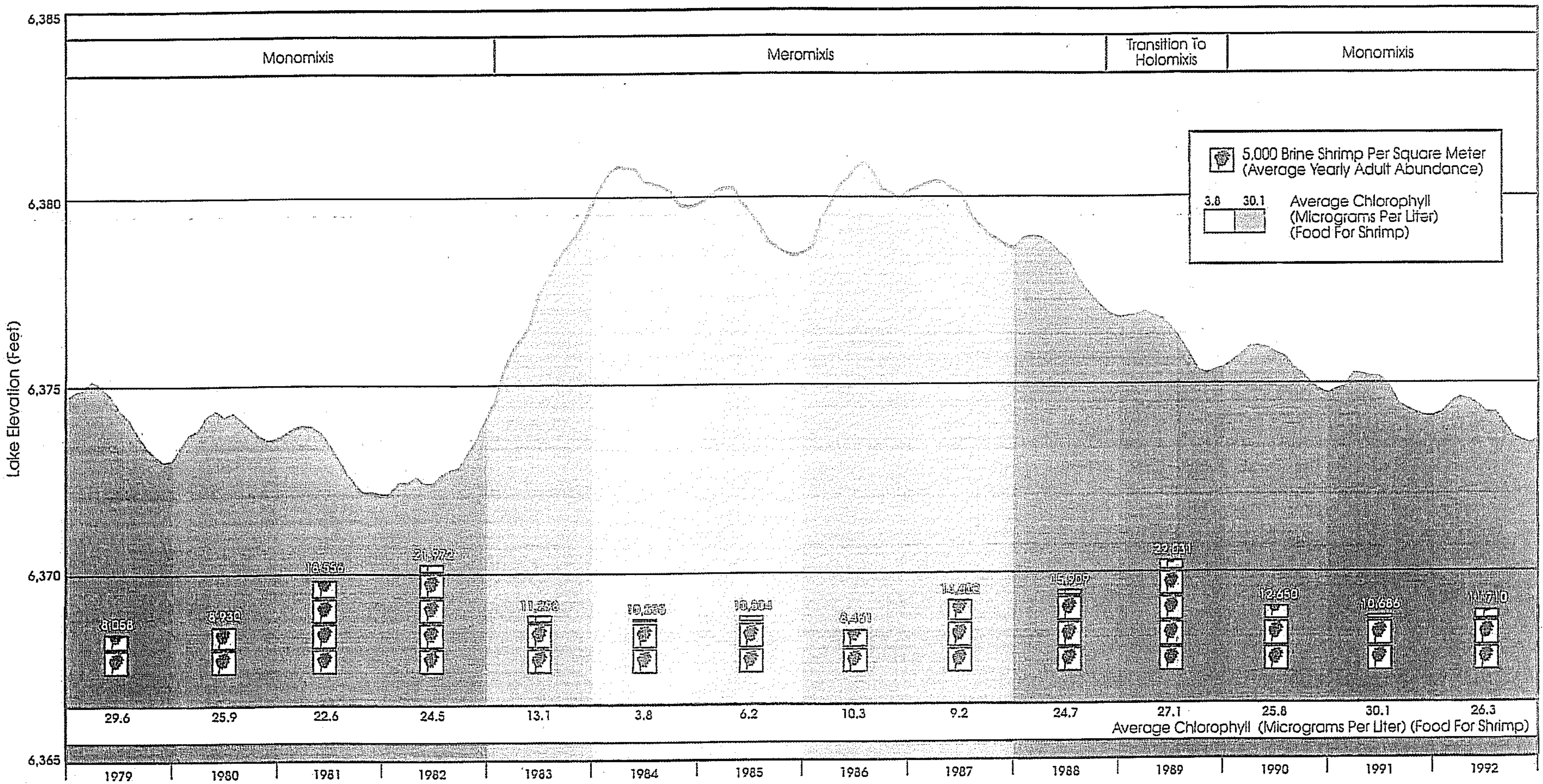
A. Future Salinity Stratification Unlikely

Ironically, the greatest perturbation to the lake during the last 14 years was a natural one which raised the lake level. The likelihood of natural or human-induced increases in lake level causing other episodes of meromixis can be evaluated from historical records and simulation models. Jellison and Melack (1993b) examined the historical record for Mono Lake and concluded that meromixis appears to be a rare event. Application of a vertical mixing model driven by a standard year of meteorology and by an historical 50 year record of stream inflows also indicated that meromixis would be infrequent for the range of lake levels observed since 1979.

B. DEIR Impact Criteria Inappropriate

A critical step in assessing the ecological impact of changes in lake level is establishing how an ecologically significant impact will be recognized and detected. The DEIR uses a 25 percent change from conditions at a reference lake level as the basis for assigning significance to a change (Jones & Stokes, 1993). If such criteria were applied to the records of phytoplankton status during the last 14 years, the

Mono Lake Elevation and Chlorophyll and Brine Shrimp Abundances



chlorophyll concentrations and primary productivity during the period when the lake was at 6,378 to 6,381 feet above sea level would be judged significantly less than values for these measures of the status of the phytoplankton for lake levels of 6,372 to 6,375 feet above sea level. In fact, mean annual and seasonal maximum chlorophyll concentrations during the higher lake level range were only about one third of those during the lower lake level range. However, the lake functioned well and produced almost as much brine shrimp. Clearly, the 25 percent criterion are inappropriate for recognition of ecologically significant impacts to the plankton of Mono Lake.

C. Detectable Impact Criteria Needed

A criterion for change must be operationally detectable if it is to be useful for management of Mono Lake. The time-series data available for the phytoplankton and brine shrimp illustrate very well the need for many years of data to recognize actual trends or the lack of trends. Moreover, with the limnological information also available, the factors causing any changes that do occur can be established.

D. Longterm Monitoring Needed

The primary lesson to be learned from the information available about the plankton of Mono Lake is that successful management of the lake requires carefully planned monitoring of the health of the ecosystem. If lake levels above or below those observed from 1979 to 1992 are recommended, then the need for continued monitoring is even more acute. Furthermore, an operational plan which includes definition of the basis for detection of a significant impact and recommends appropriate action is essential.

E. Historical Database Better Basis for Management Plan than DEIR Models

The historical database I have amassed provides a proper foundation for a scientific management plan based upon the ongoing analysis of ecosystem trends with standard statistical methods. My database and the statistical methods I used are a more reliable basis for management decisions than the preliminary ecosystem models presented in the DEIR.

CITATIONS

Printed References

Carpenter, S.R. 1990. Large-scale perturbations: opportunities for innovation. Ecology 71: 2038-2043.

Colwell, R.K. 1974. Predictability, constancy, and contingency of periodic phenomena. Ecology 55: 1148-1153.

Dana, G.L. and P.H. Lenz. 1986. Effects of increasing salinity of an *Artemia* population from Mono Lake, California. Oecologia 68: 428-436.

Dana, G.L., R. Jellison, and J.M. Melack. 1990. *Artemia monica* cyst production and recruitment in Mono Lake, California, USA. Hydrobiologia 197: 233-243.

Dana, G.L., R. Jellison, J.M. Melack, and G.L. Starrett. 1993. Relationships between *Artemia monica* life history characteristics and salinity. Hydrobiologia 263: 129-143.

Imberger, J. and J.C. Patterson. 1981. A dynamic reservoir simulation model-DYRESM. pp. 310-361. In H.B. Fischer (ed.) Transport models for inland and coastal waters. Academic Press, New York.

Jassby, A.D. and T.M. Powell. 1990. Detecting changes in ecological time series. Ecology 71: 2044-2052.

Jellison, R.S., G.L. Dana, and J.M. Melack. 1992. Ecosystem responses to changes in freshwater inflow to Mono Lake, California. pp. 107-118. IN: C.A. Hall, V. Doyle-Jones, and B. Widawski (eds.). The History of Water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. White Mountain Research Station Symposium 4. University of California, Los Angeles.

Jellison, R. and J.M. Melack. 1993a. Algal photosynthetic activity and its response to meromixis in hypersaline Mono Lake. Limnol. Oceanogr. 38:818-837.

Jellison, R. and J.M. Melack. 1993b. Meromixis in Mono Lake, California. I. Vertical mixing and density stratification during the onset, persistence, and breakdown of meromixis. Limnol. Oceanogr. 38:1008-1019.

Jellison, R., L.G. Miller, J.M. Melack, and G.L. Dana. 1993. Meromixis in Mono Lake, California II. Nitrogen fluxes. Limnol. Oceanogr. 38:1020-1039.

Jones & Stokes Associates. 1993. Environmental impact report for the review of Mono Basin water rights of the City of Los Angeles. Draft. May. (JSA 90-171.) Sacramento, CA. Prepared for the State Water Resources Control Board, Division of Water Rights, Sacramento CA.

Lenz, P.H. 1984. Life-history analysis of an *Artemia* population in a changing environment. J. Plankton Res. 6:967-983.

Lewis, W. M., Jr. 1990. Comparisons of phytoplankton biomass in temperate and tropical lakes. Limnol. Oceanogr. 35:1838-1845.

Mason, D.T. 1967. Limnology of Mono Lake, California. University of California Publ. Zool. 83:1-110.

Melack, J. M. 1979. Temporal variability of phytoplankton in tropical lakes. Oecologia 44:1-7.

Melack, J. M. 1983. Large, deep salt lakes: a comparative limnological analysis. Hydrobiologia 105:223-230.

Patten, D.T., F.P. Conte, W.E. Cooper, J. Dracup, S. Dreiss, K. Harper, G.L. Hunt, P. Kilham, H.E. Klieforth, J.M. Melack, and S. A. Temple. 1987. The Mono Basin ecosystem, effects of changing lake level. National Academy Press, Washington, D.C. 272 p.

Platt, T. and K. L. Denman. 1975. Spectral analysis in ecology. Ann. Rev. Ecol. Syst. 6:189-210.

Winkler, D. W. (ed.) 1977. An ecological study of Mono Lake, California. Institute of Ecology Publication No. 12. Davis, California: Institute of Ecology.

Attachment 2

THE MONO BASIN ECOSYSTEM

Effects of Changing Lake Level

Mono Basin Ecosystem Study Committee
Board on Environmental Studies and Toxicology
Commission on Physical Sciences, Mathematics,
and Resources
National Research Council

National Academy Press
Washington, D.C. 1987

TABLE 6.3 Predicted Effects of Lake Elevation and Salinity on Aquatic Plants

Lake Elevation (ft)	Salinity (g/l)	Effects on Aquatic Plants
6430-6380 (current level)	<50-89	Phytoplankton and phytobenthic algae flourish.
6370	102	Phytobenthic algal production reduced for some species.
6360	121	Reduction in phytoplankton productivity.
6350	148	Decrease in phytoplankton and phytobenthic productivity. Shift in phytoplankton species composition expected.
6340-6330	185-237	Large decreases in all types of algal productivity. Further changes in species composition.

TABLE 6.4 Predicted Effects of Lake Elevation and Salinity on Aquatic Animals

Lake Elevation (ft)	Salinity (g/l)	Effects on Aquatic Animals
6430-6380 (current level)	<50-89	Brine shrimp and brine fly populations flourish.
6370	102	Brine shrimp populations unimpaired. Brine fly populations unimpaired by physiological effects of salinity. Loss of about 40% of submerged hard substrate relative to 6380 ft.
6360	121	Brine shrimp experience slight impairment of hatch. Brine fly larvae show modest decrease in growth.
6350	148	Brine shrimp: no hatch of cysts; decreased naupliar growth and juvenile metamorphosis; and reduced female fecundity. Brine fly: no growth of eggs; reduced female fecundity and reproductive potential.
6340	185	Brine shrimp: nonviability of dormant cysts; inhibition of preemergence mechanism of diapaused embryo; high mortalities in naupliar lifestage; and large reductions in adult populations. Brine fly: high mortalities in larval brine fly; reduced adult populations.
6330	237	Brine shrimp: loss of populations except for small populations located near freshwater spring inflows. Brine fly: loss of populations except for small populations located at shorelines where fresh water is present.

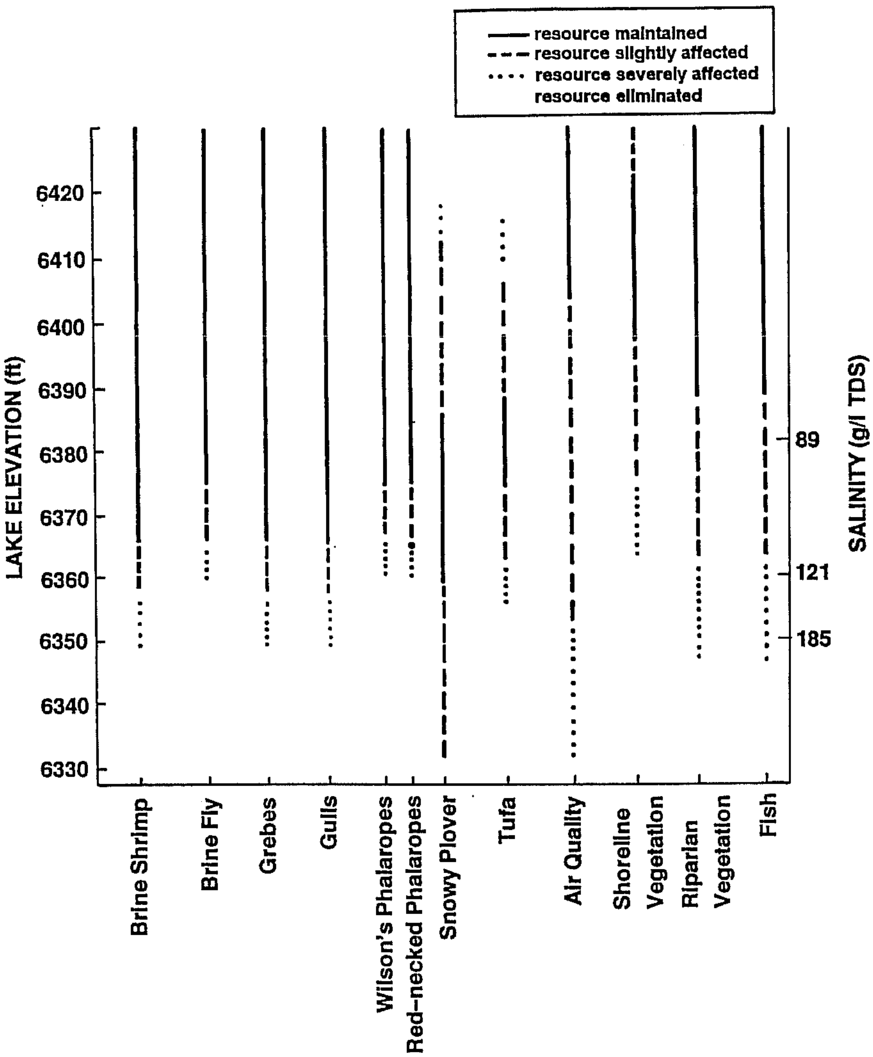


FIGURE 6.3 Ranges of lake levels affecting resources of the Mono Basin, with three salinities added for reference.

Attachment 3

BNW

THE FUTURE OF MONO LAKE

REPORT OF THE COMMUNITY AND ORGANIZATION RESEARCH INSTITUTE
"BLUE RIBBON PANEL"

FOR THE LEGISLATURE OF THE STATE OF CALIFORNIA

DANIEL B. BOTKIN
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WATER RESOURCES CENTER
UNIVERSITY OF CALIFORNIA
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THE FUTURE OF MONO LAKE

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FOREWARD

Questions surrounding the management of Mono Lake and its watershed are among the major water policy issues facing Californians today. The Mono Lake basin provides breeding and refuge habitat for approximately one million birds and is a significant scenic resource. It is also the source of a portion of the water supply for the City of Los Angeles. In the last decade or two, considerable attention has been drawn to the fact that the City's need for large scale diversions from the Mono Basin to meet its water supply committments may not be consonant with the long-term preservation of the avian habitat and the basin's scenic attributes. To help in resolving this dilemma, the California State Legislature authorized and supported a study of the determinants and effects of alternative levels of Mono Lake. The study, conducted under the auspices of the Community and Organization Research Institute at the University of California, Santa Barbara, was directed and prepared by a distinguished panel of scholars chaired by Professor Daniel Botkin of U.C. Santa Barbara.

The University of California Water Resources Center is pleased to publish the results of this study in the hope that it will contribute to understanding many of the issues surrounding the management of Mono Lake. In so doing, the Center is responding to a major element in its own charge to disseminate new knowledge and information on water resources. Although most of the Water Resources Center's publications are subjected to peer review, an exception was made in this case because of legislative deadlines and the need to release the information in a timely manner. The contents of the report are solely the responsibility of the five authors on the blue ribbon panel and publication of it by the Water Resources Center in no way constitutes or implies the Center's endorsement of the substance or findings of the panel.

Readers should also be aware of a concurrent study conducted by a panel of the National Research Council and recently published by the National Academy Press under the title, *The Mono Basin Ecosystem*. This latter study, undertaken for the U.S. Forest Service, focuses on a broad range of land and water management issues faced by the Forest Service in the Mono Basin watershed. By contrast, the study reported here was limited by legislative mandate to an examination of the factors which influence the level of Mono Lake. While the conclusions of the two studies differ in some important respects, both panels underscore the need for additional research on virtually all facets of the hydrology, geology and ecology of the Mono Basin. In publishing *The Future of Mono Lake*, the Water Resources Center hopes not only to inform but also to direct the attention of water researchers and managers alike to the need for additional scientific investigations of this unique natural resource.

Henry J. Vaux, Jr.
Director

PREFACE

State of California Assembly Bill AB 1614 (Waters, 1984) "Mono Lake Water Levels Study," provided $250,000 for scientific studies concerning "the effects of water diversions on the Mono Lake ecosystem," and required that "the study shall evaluate the effects of declining lake levels, increasing salinity, and other limnological changes of Mono Lake upon all of the following:"

(a) "The total productivity, seasonality, and physiology of brine shrimp, flies, and algae living in and around Mono Lake."

(b) "The numbers, productivity, physiology, and residency patterns of breeding and migratory bird populations."

(c) "The extent and magnitude of dust storms from the relicted bed of Mono Lake and their implications for human health, wildlife, and surrounding vegetation."

(d) "The hydrology of the lake, evaporation, and freshwater spring flow and associated habitats."

This report is a summary and an overview of the scientific investigations undertaken pursuant to AB 1614. It fulfills the requirements of Assembly Bill AB 1614, to the extent possible, with funds provided by this bill.

Following passage of this bill, the California Department of Fish and Game contracted with the Community and Organization Research Institute (CORI) of the University of California, Santa Barbara, to conduct the studies, with Professor Daniel B. Botkin as project director. Subsequently, a Blue Ribbon Panel was formed to oversee the studies, choose contractors for specific studies, and write the overview which is published herein.

The Blue Ribbon Panel consisted of the following persons:

Dr. Daniel B. Botkin, Professor of Biology and Environmental Studies, University of California, Santa Barbara; Principal Investigator. (Area of expertise: Ecosystem Ecology).

Dr. Wallace S. Broecker, Lamont-Doherty Geological Observatory, Columbia University, (Geochemistry).

Dr. Lorne G. Everett, Manager, Natural Resources Program, Kaman Tempo, Santa Barbara, (Hydrology).

Dr. Joseph Shapiro, Limnological Research Center, University of Minnesota, (Limnology).

Dr. John A. Wiens, Professor of Ecology, Department of Biology, Colorado State University, (Avian Ecology).

(Note: Dr. W. T. Edmondson, Department of Zoology, University of Washington, Seattle, was initially a member of the panel. The combination of retirement and the pressure of other activities made it impossible for Dr. Edmondson to continue and he was replaced by Dr. Shapiro. The panel wishes to thank Dr. Edmondson for his contributions while at the same time making clear that he bears no responsibility for the conclusions contained in this report.)

At the outset of the study, the panel elected to fund five research subcontracts involving investigators active in the study of Mono Lake. The primary purpose of this work was to identify and synthesize existing data to aid the panel in assessing the adequacy of knowledge on different topics and in analyzing the issues concerning Mono Lake. In addition, new research was supported where that was considered essential. The new research focused on the geology and geomorphology of the lake, on the limnology of the lake, on the development of computer models of the lake ecosystem, and on modeling the air quality at Mono Lake[1]. The five research subcontractors and their studies were:

Dr. Thomas A. Cahill, Director, Crocker Nuclear Laboratory and Professor of Physics, and member, Air Quality Group, Crocker Nuclear Laboratory, University of California, Davis (Study: Air Quality at Mono Lake);

Dr. Joseph R. Jehl, Jr., Associate Director, Hubbs Marine Research Institute, San Diego, CA and Associate Professor and Adjunct Professor, Departments of Biology and Zoology, San Diego State University, San Diego (Caspian Terns, Phalaropes, and Grebes of Mono Lake);

Dr. John M. Melack, Associate Professor, Department of Biological Sciences, University of California, Santa Barbara (Limnological Conditions at Mono Lake);

Dr. Scott Stine, Postdoctoral Fellow, Lamont-Doherty Geological Observatory, Columbia University (Geomorphic and Geohydrographic Aspects of the Mono Lake Controversy);

Dr. David W. Winkler, Lecturer in Ecology, Section of Ecology and Systematics, Cornell University, Ithaca, N.Y. (California Gull and Snowy Plover Populations of Mono Lake).

Copies of the final reports from these subcontractors (listed in Appendix D of this report) can be purchased from the Community and Organization Research Institute, University of California, Santa Barbara.

In addition to the studies by subcontractors, the panel sought information from various concerned groups and agencies, including the Los Angeles Department of Water and Power, the U.S. Forest Service, Inyo National Forest, within whose jurisdiction Mono Lake and its watershed lie, and the Mono Lake Committee, a conservation organization.

Concurrent with the CORI study reported herein, the National Academy of Sciences undertook a separate study of the Mono Basin Ecosystem under contract to the U.S. Forest Service. The purpose of this latter study was to assist the Forest Service in developing a management plan for Mono Lake and its watershed. The CORI panel made every attempt to cooperate with the National Academy of Sciences staff to avoid unnecessary duplication of effort and to promote the best use of the resources available for both studies. The NAS panel was invited to a workshop held by the CORI study panel in November, 1986. Although information from the CORI study became known to the NAS panel, NAS policies prevent the sharing of their information with the CORI panel prior to its publication.[2]

The two studies were conceived and executed with different objectives in mind. The NAS study focused on the Forest Service's need to manage the entire Mono Basin Scenic Recreation Area and included consideration of cattle grazing, the maintenance of upland vegetation, and the management of terrestrial wildlife. In contrast, the CORI study focused solely on the effects of declining lake levels as required by California Assembly Bill 1614.

ACKNOWLEDGMENTS

The Panel acknowledges the assistance of the following: The staff of CORI including Dr. Jack Votey, Director, Ms. Irene McDaniel and Ms. Jeanie Cornet for maintenance of the budget and other administrative matters; staff of the University of California, Santa Barbara, Environmental Studies Program for secretarial and administrative work including Ms. Christine Walden, Ms. Leslie Campbell, and Ms. Marylee Prince; staff of the U.S. Forest Service, Inyo National Forest, especially Mr. John Ruopp for his repeated assistance in field trips to the lake, and in making information available to us from the forest service's records, and Ms. Christina Hargis and other staff who participated with us on field trips. Both the Mono Lake Committee and the Los Angeles Department of Water and Power provided assistance on field trips, made information available to the panel, and provided comments and analyses of specific topics as requested by the panel; Ms. Kathryn Simpson for the report illustrations and for her excellent work and advice to the panel on the design and layout of the report.

Finally, the panel thanks Dr. Dwayne Maxwell of the California Department of Fish and Game for his unfailing devotion to the project and his assistance to the panel in his role as coordinator for that Department.

EXECUTIVE SUMMARY

This report, undertaken pursuant to State of California Assembly Bill 1614, "Mono Lake Water Levels Study," summarizes and synthesizes scientific knowledge and investigations related to the effects of water diversions and associated declines in lake levels on the ecosystem of Mono Lake. The report summarizes information on the hydrology and geology of the lake, including its scenic geological features; the lake's ecosystem, especially its brine shrimp, brine flies, and algae; the birds that utilize the lake; the potential for air pollution from the dust raised by winds from the exposed bed of the lake; and the lake as a natural area and scenic resource.

Mono Lake lies within a closed watershed immediately east of the Sierra Nevada in central California. The fact that neither the lake nor the watershed in which it lies has an outlet means that the lake itself is quite saline and that, historically, its level has fluctuated widely in response to natural variations in the rates of precipitation, evaporation, and transpiration. Since 1940, the lake levels have also been affected by diversions from tributary streams by the Los Angeles Department of Water and Power to provide water supply for the City of Los Angeles. These diversions, which have averaged 90,000 acre-feet per year, caused the level of the lake to fall by approximately 45 feet between 1941 and 1982. During the same period, the volume of the lake decreased by about 50% and salinity increased from approximately 50 grams/liter (g/l) to 90 g/l.

Continuation of these diversions at the historical rate, which constitutes approximately 17% of the present water supply for the City of Los Angeles, when coupled with normal climatic variation is likely to have adverse consequences on both the scenic qualities of the lake and its capacity to support substantial populations of migratory birds which use the lake for breeding and migratory refuge. These consequences include: a decline in the production of brine shrimp and brine flies which are the primary food for water birds that use the lake; loss of breeding habitat for some birds; erosion of shoreline features including the tufa towers for which the lake is well-known; occasional episodes of air pollution which exceed California's legal standards; and ultimately, the demise of the lake ecosystem.

Although scientific knowledge of the lake and its ecosystem is far from adequate, available information is sufficient to permit estimates to be made about the likely consequences of continued diversion at the maximum rates which the diversion facilities now permit (90,000 acre-feet/year) and about the approximate times when these consequences would first be realized. The first impact could be realized as soon as 1989 when a land bridge between the shoreline and a major breeding area, Negit Island, would be exposed. By about 1994, an important geological change may occur in the lakebed slope when the "topographic nick point" will be exposed, leading to accelerated rates of erosion and the destruction of some riparian habitat. A third major consequence could be realized by 1999 when the decline of the lake and associated reductions in its volume raise salinity levels to the point where the productivity of the brine shrimp will begin to decline. Finally, the existing lake ecosystem could cease to function by 2012 when lake salinities reach levels at which brine shrimp and brine flies could no longer survive, thus depriving most breeding and migratory bird species of their food source at the lake. If both modern climatic conditions and historical rates of diversion continue indefinitely, the lake would ultimately reach a steady-state level some 31 to 48 feet below the current level of 6378 feet. This is considerably below the level that could support the current lake ecosystem.

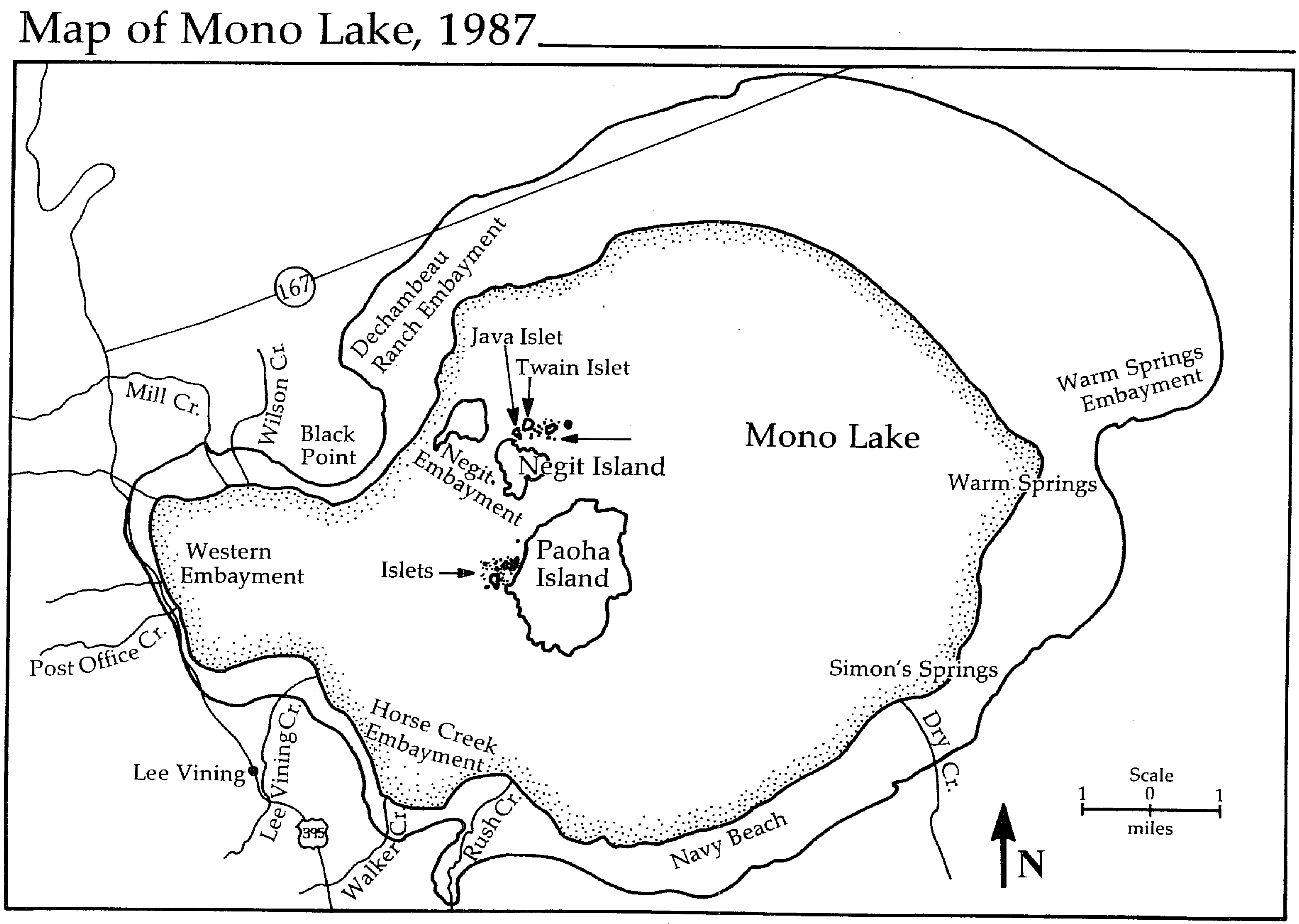

Figure 1. *Map of Mono Lake.*

If the inflows to Mono Lake are to be managed to avoid these consequences, it is necessary to identify not only those lake levels at which critical changes occur but also the buffer levels that would have to be maintained to prevent the lake from falling below these critical levels as a consequence of normal climatic variation. There are three key buffer levels, each of which implies some reductions in the tributary diversions by the Los Angeles Department of Water and Power.

At Level I, 6382 feet, key features of the lake ecosystem and most scenic attributes will be protected, although there will be some erosion of the tufa towers. To attain this level, diversions would have to be reduced to approximately 38,000 acre-feet per year, approximately 42% of the historical average. Reduction of diversions of this magnitude imply an associated reduction of 10% in the water supply presently available to the City of Los Angeles.

At Level II, 6372 feet, a substantial portion of the gull breeding habitat would be lost, a significant number of the tufa towers would be endangered, the breeding biology of the snowy plover would be endangered, and a portion of existing wetlands would be threatened with drainage. The production of brine shrimp and brine flies could be maintained at this level, however. This level could be maintained by reducing annual diversions to 55,000 acre-feet, 61% of the historical rate. This reduction would imply a 6.7% decrease in the water supply presently available to Los Angeles.

At Level III, 6362 feet, the lake could become unreliable as a staging and breeding area for birds. Few gulls could be expected to nest at the lake because of the reduction of good quality nesting habitat. It is likely that the food supply for two important bird species, grebes and phalaropes, would be significantly reduced. This level would provide a 10 foot buffer above the critical level of 6352 feet at which the lake ecosystem would be fundamentally altered. At this level, the production of brine flies and brine shrimp would be reduced to the point where bird populations could no longer be supported. To achieve this level, diversions would have to be reduced to 68,000 acre-feet or 76% of the historical rate. This would imply a reduction of 4.2% in the water supply presently available to Los Angeles.

The estimates made in this report are subject to a substantial degree of scientific uncertainty. More definitive conclusions regarding the management of Mono Lake can only be made when additional scientific evidence is available. Areas where knowledge is incomplete or uncertain and where additional research would be helpful are enumerated and described.

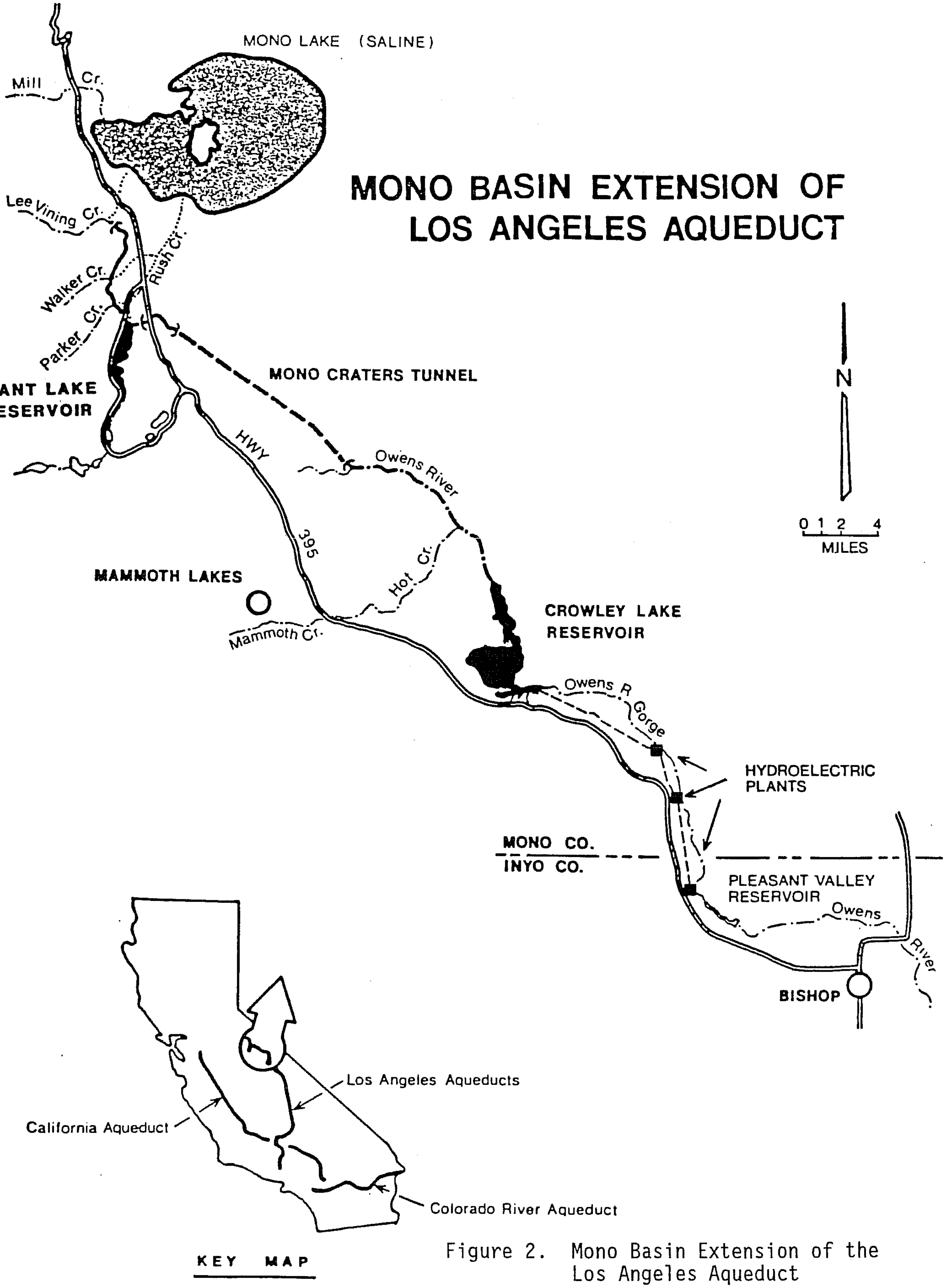

Figure 2. Mono Basin Extension of the Los Angeles Aqueduct

THE FUTURE OF MONO LAKE

Report of the CORI "Blue Ribbon Panel"

For the Legislature of the State of California

Daniel B. Botkin (Committee Chairman), Wallace S. Broecker, Lorne G. Everett, Joseph Shapiro, and John A. Wiens (Members)

SECTION I. BACKGROUND OF THE MONO LAKE CONTROVERSY

Mono Lake, located east of the Sierra Nevada in the Great Basin near the town of Lee Vining, is one of California's few large natural lakes (Figures 1 and 2). It is a closed, saline water body with unique chemical and biological characteristics. Even among salt lakes the chemistry of Mono Lake is unusual, and for that reason the lake supports an unusual group of species and has unusual geological features associated with it.

Mono Lake is well known for its scenic qualities. It is a large lake in a dry valley with an abundance of water birds. Conspicuous tufa towers line its shores and protrude from its surface, set against a backdrop of mountains and high desert. The lake is highly productive biologically, and supplies both food (in the form of brine shrimp and brine flies) and nesting habitat (on near-shore lands and on islands) for the abundant bird life.

Because Mono Lake has no outlet it is in a perpetual state of adjustment to changes in inflow and evaporation. During times of high inflow the lake expands, increasing both its surface elevation and its volume; when inflow decreases the lake shrinks in level and volume. These fluctuations have important environmental consequences. As the lake contracts the salts that have accumulated in the waters over thousands of years are concentrated, increasing salinity. Shore-lands are uncovered (at times permitting wind and water erosion of the exposed surface), and islands swell in size, sometimes becoming peninsular to the shore-lands. With a rise in lake level, the lake salts are diluted (salinity decreases), the shore-lands are reinundated, and the islands shrink in size, at times becoming wholly submerged. (Although lake level, volume, and salinity are interrelated, most discussions of Mono Lake refer simply to the lake level, which is readily perceived and directly measured, rather than the total volume.)

The fluctuations of Mono Lake that have occurred since the middle of the 19th century are known from historic accounts and lake level records (Figure 3). Prior to 1940, when the City of Los Angeles began to divert the tributary streams that feed Mono Lake, the lake surface ranged between elevations of approximately 6404 feet and 6428 feet (the "historic high stand," attained in 1919) (Table 1).

Since 1940 the Los Angeles Department of Water and Power has been diverting water from streams tributary to Mono Lake. During this time these diversions have averaged roughly 90,000 acre-feet (1 acre-foot=325,850 gallons) of water per year, constituting approximately 17% of the city of Los Angeles's water supply.[3] As a result, the surface of Mono Lake has fallen 45 feet--from an elevation of 6417 feet in 1940 to an "historic low stand" of 6372 feet in late 1981 and early 1982. The lake volume has decreased by half (from about 4.5 million acre-feet to about 2.2 million acre-feet) and the lake salinity has doubled (from approximately 50 g/l to approximately 100 g/l). The abnormally wet weather of the past 5 years forced a minor rise in lake level, to an elevation of about 6381 feet in August 1986, followed by a decline to 6378 feet in November, 1987

(Table 1). Within the last decade, however, the lake has dropped as much as two feet per year during dry years; the lake has dropped four feet from 1985 to 1987. Recent salinities have been about 88 to 92 g/l.

Mono Lake receives both surface and subsurface flows from the Mono Basin, but only the surface flows are diverted. Currently some surface flow [19cfs (cubic feet per second) in lower Rush Creek[4] and 4-5 cfs in lower Lee Vining Creek[5]] is mandated to allow the maintenance of trout in streams flowing to the lake; this decreases the present diversion and increases the water entering the lake. The diversion facilities of the LADWP make possible the diversion of surface water from all but two streams that feed the lake, but reservoirs are presently too small to store all of this diversion in wet years. Thus, in wet years any flow above the maximum diversion and storage capacity now goes into the lake. This has occurred in several recent years, accounting for the recent rise in the lake level and leading to a stratification of the lake into an upper, fresher layer and a lower, more saline layer.

Work partially sponsored by the CORI study group has also reconstructed the

HISTORY OF LAKE LEVELS

TIME	LAKE LEVEL (feet)	SALINITY (g/l)[a]
Recent Level (August, 1986)	6381	88 g/l
Current Level (November, 1987)	6378	92 g/l
Historic High (1919)	6428	42 g/l
Historic Low (1982)	6372	102 g/l
Known High (Last 4,000 yrs)	6499	(20 g/l)[b]
Known Low (Last 4,000 yrs)	6368	(85-88 g/l)[b]

[a] g/l = grams/liter
[b] Assuming total dissolved salts same as today

[Table 1: *The table shows a few historically important lake levels and their associated salinities. The August, 1986 level was used in the National Academy of Sciences report and is given here for comparison. The current level at the time of this writing is the low point for the year.*]

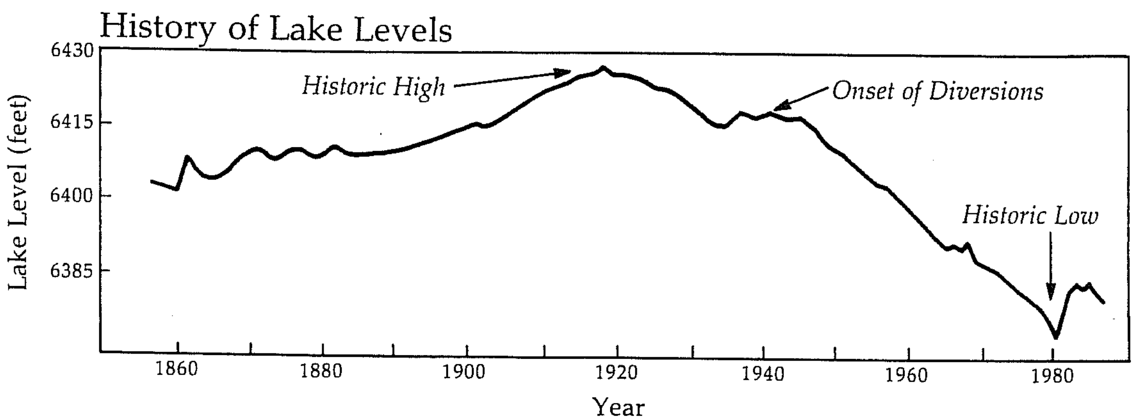

Figure 3. *The level of Mono Lake in historic times, since records have been taken, are shown in feet above sea level. The point marked "onset of diversions" (1940) marks the beginning of the diversion of water by the Los Angeles Department of Water and Power.*

last 4,000-year history of the lake's levels.[6] This study indicates that the lake reached a high elevation of 6499 feet and a low elevation of 6368 feet prior to historic times. Evidence indicates that the lake level has not been below 6368 feet during the last 4000 years.[7]

Mono Lake became the focus of an environmental controversy in the middle and late 1970's, when the lake surface declined to 6376 feet with the result that Negit Island--a major breeding area for the California gull--became connected to the mainland. Coyotes made their way across the newly exposed land bridge and onto the former island, disrupting the breeding of the gulls. The birds successfully bred on small islets in the succeeding years, but in 1981 the two largest of these islets also became linked to the mainland, permitting invasion by coyotes.

The Mono Lake controversy involves not only gulls, but other types of animals as well. There is an inverse relationship between lake level and salinity. Researchers point out that the brine shrimp and brine flies that presently thrive in the lake, and which constitute the major source of food for the birds that migrate there annually, would be threatened by the increase in salinity that accompanies a decline in lake volume. A major drop in the shrimp and fly populations, in turn, could have detrimental effects on the birds that depend on them for food.

Mono Lake Food Web

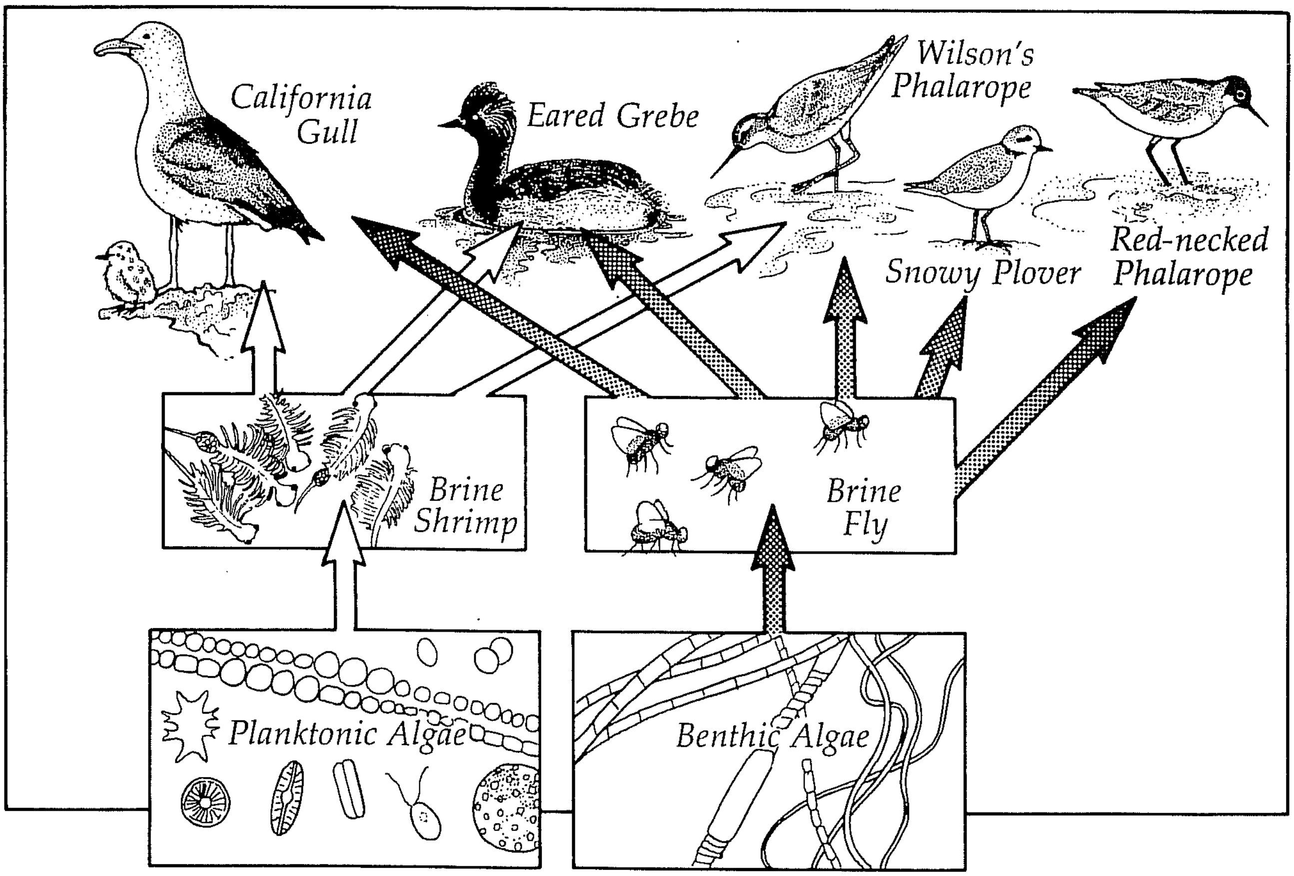

Figure 4. *Mono Lake Food Web. This diagram shows who feeds on whom in the Mono Lake ecosystem. Compared to most ecosystems, Mono Lake has few species and the food web is relatively simple. The algae, called the primary producers, provide food for the lake's two major herbivores: the brine shrimp and brine fly. These in turn are prey for the birds.*

Feeding Habits

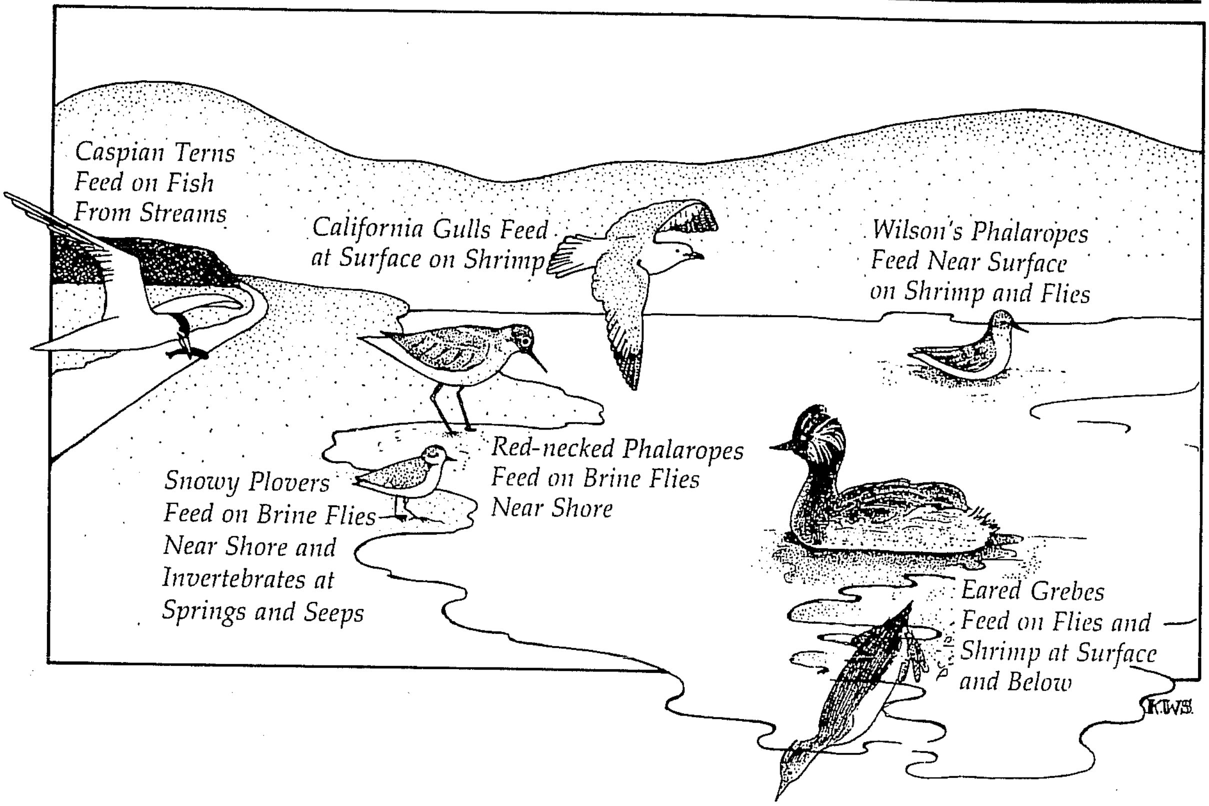

Figure 5. *Feeding Habits of Birds Using the Lake. What the birds feed on and where they find their food are illustrated here.*

Finally, the Mono Lake controversy involves air pollution. The recession of the lake has exposed thousands of acres of former lake bottom. This new, barren shoreline, which is composed of fine sediments, is subject to erosion by winds. High winds that sweep across the exposed shoreline pick up particulate matter that can be carried in large concentrations over considerable distances.

If no diversion of waters had been made, it is estimated that the lake surface in late December 1981 to early January 1982 (when the lake reached its historic low of 6372 feet) would have stood at 6430 feet, which is 58 feet higher than it was at that time.[8] This implies that the drop in the lake level is totally the result of water diversion and not the result of climatic change or other natural factors. Given the maximum diversion possible with 1986 LADWP facilities, a continuation of diversions would lead to a projected steady-state level of the lake or "dynamic equilibrium" fluctuating between elevations of 6347 to 6330 feet, 31 to 48 feet below the present level. At the projected low stand, lake volume would be approximately 0.89×10^6 acre-feet and salinity approximately 250 g/l. The dynamic equilibrium levels are the levels that would be maintained taking into account variations in rainfall and evaporation that would occur with variations in climate such as have occurred between 1937 and 1982. (If the climate were absolutely constant, with exactly the same rainfall, temperature, and cloud cover patterns recurring every year, then there would be a single equilibrium level, which would then be called a "static equilibrium" level.) If more severe droughts, such as occurred in prehistory since the last ice age, were to recur, then the steady-state level might drop even more, to as low as 6300 feet.[9]

Several factors, such as changing economic conditions, rate structures, and new State or Federal water projects, could alter the rate of diversion. Construction of new reservoir facilities could allow for storage of all the surface flow from those streams now being diverted, increasing the actual volume exported from the Mono Basin.

These projections lead to the following concerns:

1) Will continued water diversions lead to the loss or serious impairment of habitat for the birds that now use the lake for breeding?

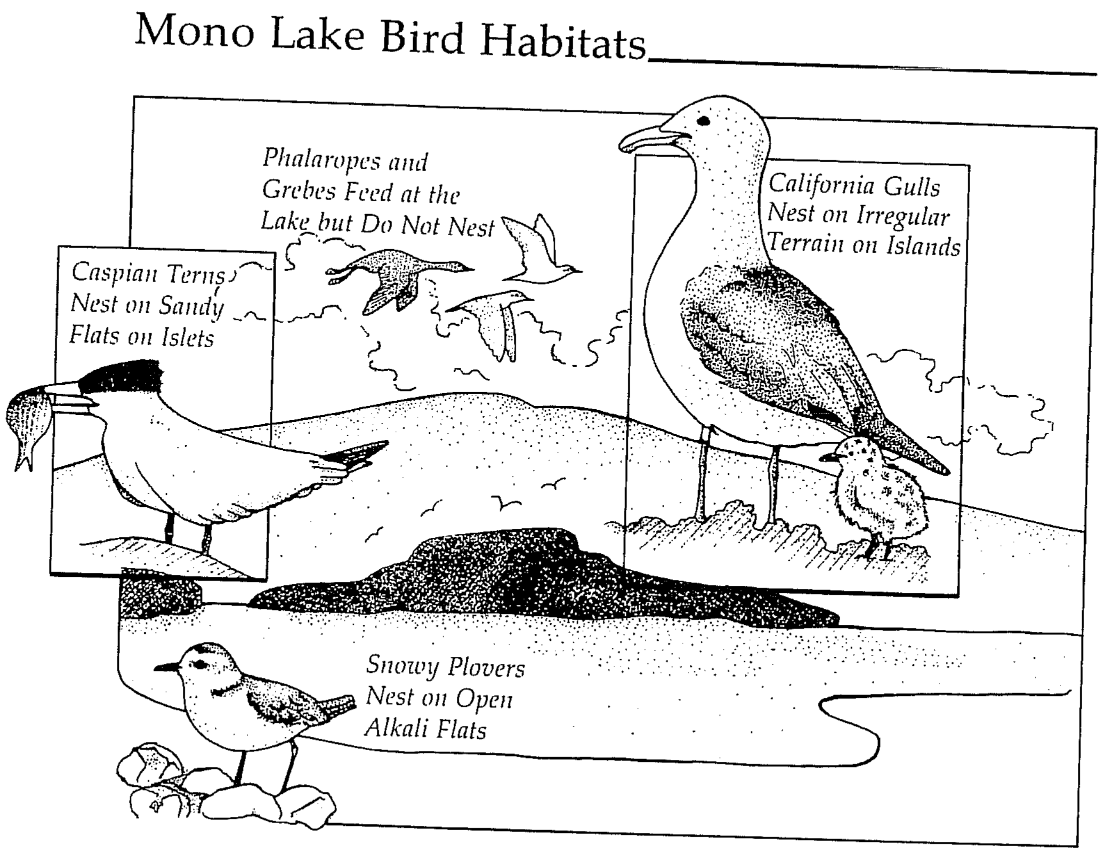

Figure 6. *Mono Lake Bird Habitats. Where the major bird species nest at Mono Lake is illustrated in this figure.*

2) Will changes in salinity accompanying continued diversions adversely affect the biota of the lake, and thereby reduce the food supplies of the one million migratory birds that use the lake as a stopover site?

3) At what lake levels can these effects be expected to occur?

4) Will such effects have serious consequences for the overall populations of any of the bird species, or significantly reduce their numbers in California?

5) Will changes in lake level have undesirable effects on any of the lake's scenic attractions, including its geological formations (notably the tufa deposits), its wetlands, and its wildlife?

6) Will future fluctuations of the lake lead to air pollution levels that exceed legal standards?

SECTION II. GENERAL FEATURES OF THE LAKE AND ITS BIOTA

Current Status

Mono Lake is a large, deep body of highly saline and alkaline water, presently covering approximately 44,000 acres. The lake's salts are the product of thousands of years of evaporative concentration. Presently the lake salinity is approximately 92 g/l--roughly two and one-half times that of the ocean.

Brine shrimp and brine flies thrive in this highly saline water, feeding on algae that grow suspended in the lake waters ("planktonic algae") or attached to the lake bottom ("benthic algae"). The flies and shrimp have somewhat different food and habitat requirements (Figure 4). The brine flies require submerged hard-rock or tufa surfaces for reproduction and shallow waters for feeding. The brine shrimp, on the other hand, inhabit the open waters of the lake.

The brine shrimp and brine flies cannot live in waters that are too fresh or too salty. Therefore, a key to the continued existence of the shrimp and flies is the persistence of the level (and therefore volume) of Mono Lake within a certain range. The brine shrimp and brine flies provide most of the food for the large numbers of migratory water birds that use Mono Lake (Figure 4 and Table 2).

The lake is visited annually by some one million birds, the most abundant of which are eared grebes, California gulls, Wilson's and red-necked (or northern) phalaropes, Caspian terns, and snowy plovers (Figures 4, 5, and 6; and Table 2).[10] (See Appendix B for more detail concerning the birds of Mono Lake.)

The California gulls use the lake's islands for breeding. Adult birds feed on a variety of prey, especially brine shrimp, which they obtain near the surface of the lake. The young are fed on brine shrimp and brine flies obtained at the lake surface and along the shore (Figures 4 and 5; Table 2).[11] The California gull population at Mono Lake numbers about 50,000 annually, constituting the second largest colony of the species in the world.

Approximately 750,000 eared grebes per year (approximately 30% of the North American population) use Mono Lake as a migratory stopover for molting and fattening. The birds feed on both brine shrimp and brine flies. Since the grebes can dive, they have access to food at the surface as well as at depth. About 80,000 Wilson's phalaropes per year (constituting perhaps 10% of the world's population of adult birds) use the lake as a migratory stopover for molting and fattening. Unable to dive for their food, this species is restricted to foraging for brine shrimp and brine flies at the surface of the lake.

TABLE 2. MONO LAKE BIRD HABITATS

CASPIAN TERNS:	Nest on sandy flats on islets; small breeding colony.
CALIFORNIA GULLS:	Nest on irregular terrain on islands and islets; compete with Caspian terns for breeding areas in some cases. About 40,000 to 50,000 breeding adults use the lake as a nesting area. Access to freshwater sources is necessary.
SNOWY PLOVERS:	Nest in open alkali flats and pumice dune habitats over the eastern half of the lake and on the northwestern shore. Freshwater sources are required near to the breeding areas. Approximately 11% of the state's population (about 384 breeding adults) nest at the lake.
EARED GREBES:	Do not nest at Mono Lake; use the lake as a migratory stopover for molting and fattening. Approximately 750,000 use Mono Lake, which is about 30% of the North American population.
WILSON'S PHALAROPES:	Do not nest at Mono Lake; use the lake as a migratory stopover for molting and fattening. This species breeds in prairie marshes of the West. It apparently requires sources of fresh water. Mono Lake provides one of the largest concentration points for this species in the world, an estimated 80,0000 individuals using the lake each year.
RED-NECKED (NORTHERN) PHALAROPES:	Do not nest at Mono Lake; use the lake as a short-term migratory stopover. They do not molt or stage there, but stay only a few days. This species breeds in low arctic regions. The North American population is estimated to be more than two million, with 50,000 to 65,000 (perhaps 2-3% of the world's population) using Mono Lake.

Some 60,000 red-necked phalaropes (comprising 2-3% of the New World population) use the lake for a short-term migratory stopover each year. They feed primarily on brine flies at or near the surface in close proximity to shore.

Caspian terns breed in small numbers on the lake's islands and feed on freshwater fish from nearby lakes and streams.

Snowy plovers, which use certain portions of the shore-lands for breeding, require access to freshwater sources for successful reproduction. These birds feed primarily on brine shrimp and on small invertebrates. Numbering about 380 per year, the snowy plovers at Mono Lake comprise about 11% of the California population of the species.

Consequences of Fluctuations in Lake Level

Both the biology and the geology of Mono Lake are affected by fluctuations in lake level. Rises and falls in surface elevation are accompanied by changes in the configuration of the lake shore, in the area of different types of habitats, and in the volume (and therefore the salinity) of the lake.[12] There are several important consequences of fluctuations in lake level:

1) Changes in size and status of the available nesting habitats for birds, especially on islands and islets in the lake. For example, as a result of the lake expansion during the past several years, much of the gull nesting area on the Paoha islets was lost to erosion.[13]

2) Changes in the area of submerged hard-substrate environment on which brine flies depend.

3) Changes in the location, shape, and area of fresh water habitats (including freshwater marshes and streams) important to some of the birds and to other wildlife, and considered by many people as important scenic resources.

4) Changes in the exposed tufa formations, which give Mono Lake a part of its unique aesthetic qualities and which are considered by many people as important scenic resources. For example, as a result of the lake expansion during the past several years, many tufa towers were undercut by waves.[14]

5) Changes in the area of "playas," which are exposed, lake-sediment flats whose particles can be blown by strong winds and may create air pollution hazards.

6) Changes in lake salinity which, when either too low or too high, may be detrimental to the brine shrimp and brine flies and thus to the animals that depend on these organisms for food.

7) A short period of high rainfall and high inflow of fresh water into the lake can create a layer of fresh water floating on top of the saline waters of the lake. When this occurred in recent years, the stratification of the lake persisted and altered the cycling of chemical elements in the lake. Such a stratification can affect the production of algae living in the lake.

TABLE 3. GEOLOGICAL CONSEQUENCES OF SPECIFIC LAKE LEVELS

Elevation	Summary of Events
6381	*August 1986 lake level; Salinity 88 g/l.
6380	*Begin to exceed air pollution standards; below this there is increasing degradation in air quality. *Total suspended particulates (including arsenic and sulfate levels) from blowing dust from Mono Lake exceed State of California Air Quality Standards 11% of the year at all levels including and below current level. *For 11% of the time, particulates in the air would reach twice current legal maximum values in a small area with a low human population adjacent to the lake; this area, however, does not include any major thoroughfare; vegetation impacted is the sagebrush desert ecological community.
6378	*November 1987 level; lowest point reached during this year.[15]
6375	*Current lake ecosystem maintainable and bird populations sustainable, but a decline in the status of the lake ecosystem begins to occur before this. *Negit Island becomes a peninsula; loss of gull nesting habitat (at 6376 feet coyotes can wade through the water between the mainland and Negit). *Salinity 97 g/l; beginning of decline in status of lake ecosystem.
6372	*Historic low lake level. *Erosion of islands increases below this level. *Twain and Java islets become peninsulas; major loss of gull nesting area.
6370	*For 11% of the time, particulates in the air would exceed five times current legal maximum values in a small area adjacent to the lake, and would be twice current legal maximum values over a larger area that crosses Route 167. Fine particles may be transported as far as the White Mountains, 50 miles distant.
6368	*Salinity reaches 110 g/l. *The level of the topographic nick point. Erosion of uplands (with resulting stream incision, tufa erosion, and wetland drainage) increases below this point. *Erosion decreases breeding habitat for snowy plovers. *Minimum wetland area occurs just below this nick point.
6363	*Salinity reaches 120 g/l. *Hatching of brine shrimp declines from 50% of eggs in a brood at this level to 15% at 6358 feet. *Food for grebes and phalaropes declines significantly below this level.

Table 3 Continued on Page 10

TABLE 3. GEOLOGICAL CONSEQUENCES OF SPECIFIC LAKE LEVELS (CONTINUED)

Elevation	Summary of Events
6359	*Salinity reaches 130 g/l. *Critical point for lake ecosystem, especially for food species for water birds. *Brine shrimp hatching would be at most 1/4 to 1/3 of present values. *Algal food supply for brine fly declines rapidly below this level. *Food for grebes and phalaropes declines significantly. *Nesting habitat for birds greatly reduced.
6356 to 6357	*Eight Negit islets become peninsulas, further reducing gull nesting habitat. *Two Paoha islets become peninsulas of Paoha Island, also reducing gull nesting area.
6352	*Salinity reaches 150 g/l. *Demise of lake ecosystem. Development of the early life history stage of the brine flies is seriously interfered with; hatching of brine shrimp cysts probably ceases. Thus, at this point the present aquatic ecosystem will have been destroyed except perhaps for small refuge populations of shrimp and flies where fresh water is flowing into the lake.

SECTION III. THE CONSEQUENCES OF FLUCTUATIONS IN LAKE LEVEL

III.A. Consequences Associated with Specific Lake Levels

Several changes in the shape and form of the lake, the chemistry of its water, and characteristics of the lake ecosystem can be associated with specific lake levels. These relationships are described in the following sections. The major events which are expected to occur at each lake level are summarized in Table 3. A few of the most important lake levels are shown in Figure 7.

Choice of Water Balance Models

Estimates of the effects of water diversion on the lake level and volume are made by the use of water balance models that take into account the flow of water into the lake and evaporation from the lake. Several water balance models have been developed for Mono Lake, the two most important of which are known as the "Vorster model"[16] and the Los Angeles Department of Water and Power model ("DWP model"). All projections of lake levels in this report are based on the Vorster model. The Blue Ribbon Panel evaluated both the DWP and Vorster water balance models and

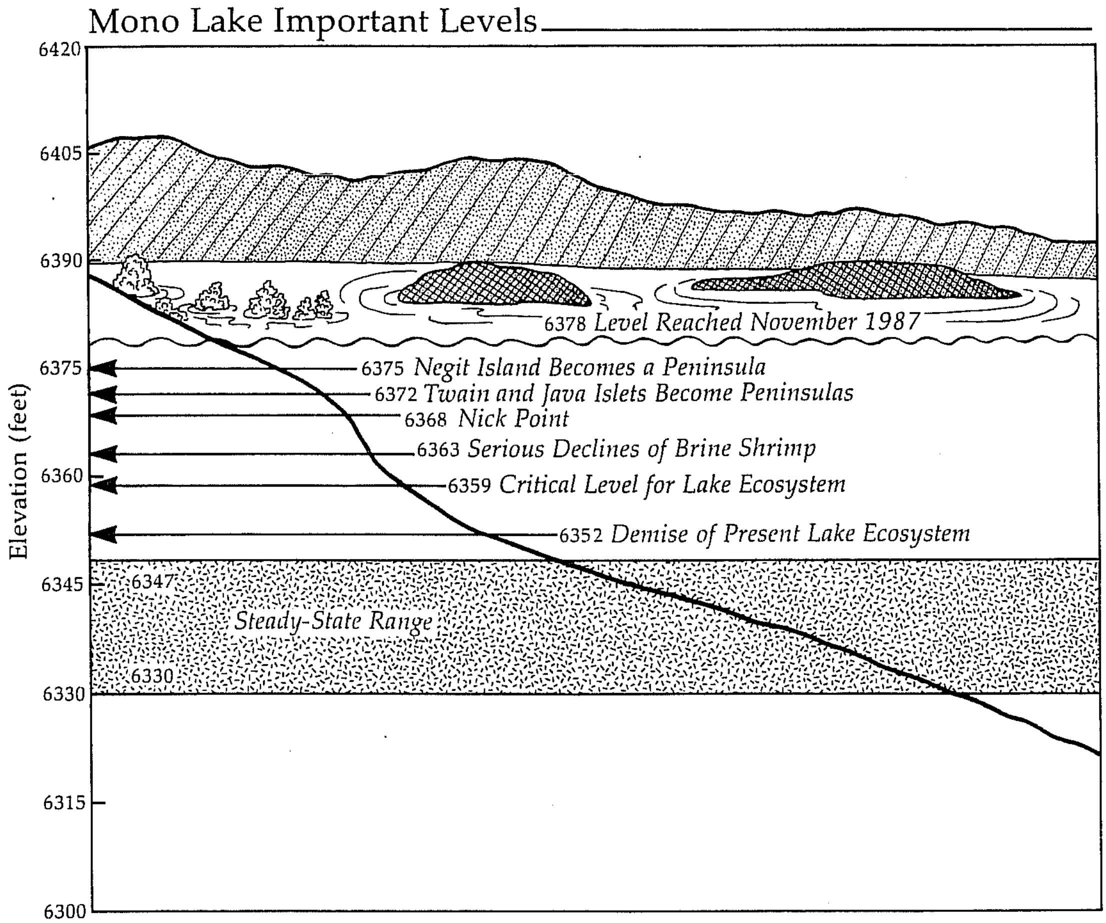

Figure 7. *Mono Lake Important Levels. Levels at which important events have happened or will happen to the Mono Lake ecosystem are shown. The "steady-state range" is the range of levels between which the lake will vary if water diversion continues indefinitely into the future at the maximum rate that current facilities allow and if the climate in the future varies as it has in the recent past. (See text for explanation.)*

elected not to use the DWP Model both because that model contained certain mathematical and regression errors and because there were significant shortcomings associated with the procedures used to determine evaporation rates. A careful evaluation of the Vorster model, on the other hand, showed it to be technically acceptable. To avoid confusion, it should be noted that the Vorster model used here is the one developed by Vorster. It is not the modified version of Vorster's model used by the National Academy of Science's panel to predict equilibrium lake levels.[17]

Decline in the Status of the Lake Ecosystem

As stated earlier, there is an inverse relationship between lake level and salinity; the lower the lake level the greater the salinity (Figure 8). Experimental evidence indicates that a decline in the status of the lake ecosystem begins to occur at an elevation of 6375 feet, where salinity reaches a value of 97 g/l. At this lake level the growth of brine shrimp and brine flies, and the abundance of certain algae, begins to decline. Negit Island becomes connected to the mainland at this level, opening up nesting habitats of California gulls to predation and disruption by coyotes. (At 6376 feet coyotes can wade between Negit and the mainland, removing Negit as an isolated breeding site.) Such a connection to the mainland occurred in 1978, and the island remained connected to the mainland for the next 5 years. Prior to this event, the island was used by many gulls as breeding habitat, but throughout the period of connection it remained unused by the gulls. Since the recent rise in the lake level, the island has been reoccupied by a small number of nesting gulls. Under current climatic and diversion conditions, the lake will reach an elevation of 6375 feet around 1989.

Land Bridging of Twain and Java Islets

At 6373 feet, Twain and Java islets become accessible to coyotes, and at 6372 feet these islets become true peninsulas. These islets, along with Negit Island, have been the primary breeding habitats for the California gull at Mono Lake. The available nesting habitat around the lake was decreased in this way when the lake reached its historic low of 6372 feet in late December, 1981 to early January, 1982.

Below this level a sequence of islands and islets would become peninsulas, with additional adverse effects on the nesting birds. At the present time, Twain and Java are once again islets and support breeding gulls. Under current climatic and diversion conditions, Twain and Java will again become connected to the mainland around the year 1992.

Exposure of Submerged Hard Surfaces

The shore-lands of Mono Lake are littered with boulders, pumice blocks, and tufa, which together form a "hard substrate habitat." The submerged areas of hard substrate near the shore are important to the brine flies, serving as the habitat for the fly larvae.[18] When the hard substrate becomes exposed to the air as the lake level recedes, it is no longer available to the fly larvae. This littoral area will decrease rapidly with decreasing lake level, from approximately 6,800 acres at 6380 feet, to 3,010 acres at 6372 feet, and to 1,271 acres at 6360 feet.[19] The decrease in littoral area will decrease fly larvae substrate and may also lead to a decrease in their algae food supply. This decrease in hard substrate habitat could lead to a significant decrease in the population of brine flies.[20] Since little is known about the ecology of brine flies and because it is not possible to make accurate estimates of the relationships between hard substrate environment and the abundance of brine flies, it would be imprudent to allow the lake level to recede to a point at which more than half of the hard substrate currently under water would be exposed. Under current climatic and diversion conditions, about 30% of the existing submerged hard substrate environment will be exposed by approximately 1990, and approximately 60% by 1994.[21]

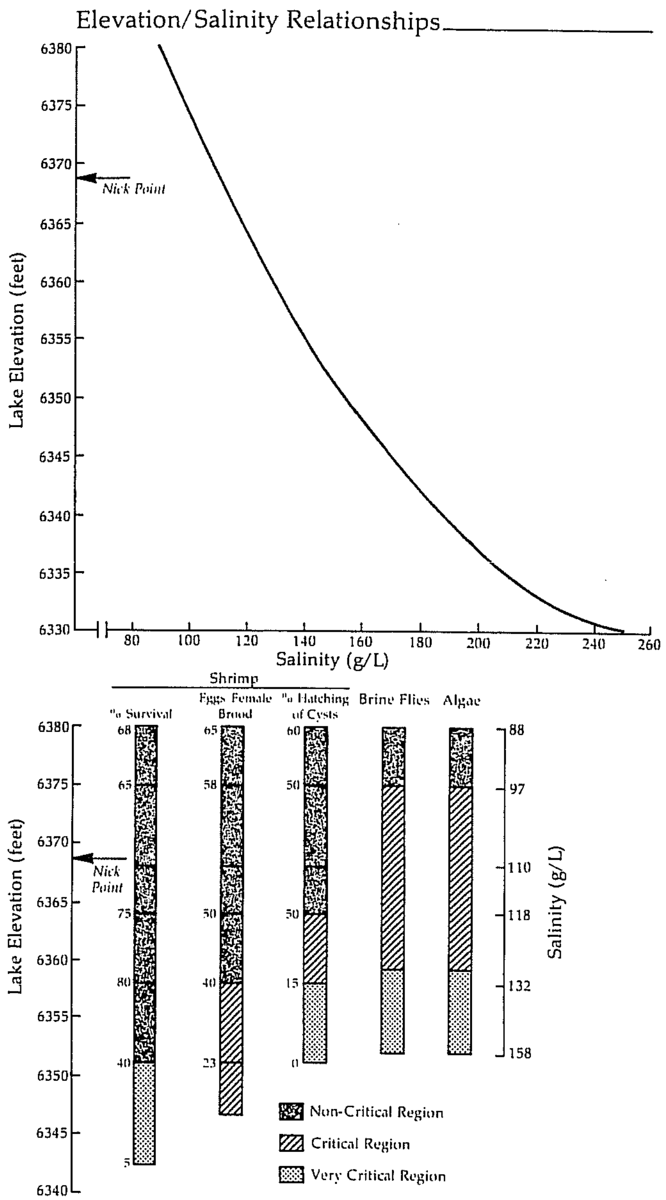

Figure 8. Elevation/Salinity Relationships. The top part of this figure shows the relationship between lake level and the salinity of the lake water. The bottom part of the figure illustrates important effects on the brine shrimp, brine flies, and algae living in the lake.

The Nick Point

The elevation 6368 feet is known as the "nick point" (Figure 7). This is a point at which a change takes place in the gradient of the land, a change produced by erosion and deposition. The gradient is steeper below the nick point than above. The nick point appears to have been produced when the lake reached its lowest level since the end of the last ice age (Tables 1 and 3).

When the nick point is exposed by lake levels below 6368 feet, substantial deep channeling ("incision") takes place where streams cross the nick point. The stream flows erode the stream sides, removing material and deepening the channel. When this happens, wetland vegetation near the stream can be lost. This can lead to substantial changes in the area of wetlands around the lake. However, the exact change in the shape, size, and vigor of vegetation in the remaining wetlands cannot be accurately estimated with current information. Under current climatic and water diversion conditions, Mono Lake will reach the nick point around the year 1994.

Decline in Brine Shrimp Hatching

At 6363 feet, when salinity reaches 120 g/l, the lake faces a danger point (Figures 7 and 8). Hatching of the brine shrimp declines from 50% of the eggs per brood at this elevation to 15% at 6358 feet, where the salinity reaches 130 g/l.[22] Furthermore, the algal food supply for the brine shrimp may decline somewhat in this range. As a result, food for the grebes and phalaropes declines significantly below this level. Under current climatic and water diversion conditions, Mono Lake will reach 6363 feet by approximately the year 1999.

Loss of Large Amounts of Island Area

At 6356 to 6357 feet, eight of the Negit islets, totaling more than 33 acres, become connected to the mainland by land bridges, leaving only 8 acres of hard rock area on the remaining islets available to nesting gulls. This compares with the approximately 93 acres of gull hard rock nesting area available at present lake levels, of which 60 acres on Negit Island becomes connected to the mainland at 6375 feet.

At 6356 to 6357 feet, two of the major Paoha islets totaling 16 acres also become connected to Paoha Island, leaving just 4 acres of soft rock area available to gulls. (At present lake levels, there are approximately 11 acres of soft rock habitat available on the Paoha islets.)[23] Under current climatic and water diversion conditions, Mono Lake will reach the 6356-6357 foot elevation by approximately year 2007.

Demise of the Lake Ecosystem

By elevation 6352 feet, when salinity reaches 150 g/l, development of the early life history stage of the brine flies is seriously curtailed and the hatching of brine shrimp cysts probably ceases. Thus, at this point the present aquatic ecosystem will have been destroyed except perhaps for small refugee populations of shrimp and flies where fresh water is flowing into the lake. Under current climatic and water-diversion conditions, Mono Lake will reach 6352 feet by year 2012.

Air Quality

As the lake level drops, more and more areas of lake bottom deposits are exposed. When they are dry, these deposits can be moved by the wind. The sediments in the playas form fine particulates in the air that contain certain toxic heavy metals, including arsenic. As a result, there has been a concern that declines in the lake level would lead to significant air pollution and to conditions that violate California air quality standards. This issue was addressed through the application of computer models of air flow and air quality.[24]

Having reviewed the results of the study of air quality, it is the conclusion of the panel that air pollution does not pose a significant danger to the Mono Lake ecosystem or to the vegetation and wildlife in the Mono Basin. The legislature should recognize, however, that the air near to and downwind from the playa areas has occasionally been in violation of air quality standards of the State of California. Further declines in lake level will lead to further air quality degradation and to conditions in which the air quality would exceed legal standards 11% of the time (Table 4). The areas at variance with these standards are, however, sparsely populated and include lightly traveled State Route 167.

Air-quality models predict that at a lake level of 6370 feet, under wind conditions that occur an estimated 11% of the time, an area of between 79 and 116 square miles extending northeast from Mono Lake and crossing State Route 167 would exceed legal levels for suspended solids; the suspended dust also contains a concentration of arsenic two orders of magnitude higher than recommended by the California Air Resources Board for acceptable levels for cancer risk.[c] The area subject to

TABLE 4. PREDICTED AREA EXCEEDING AIR QUALITY STANDARDS 11% OF THE DAYS

LAKE ELEVATION (feet)	AREA EXCEEDING STATE TOTAL SUSPENDED PARTICULATE LIMIT (square miles)
6380	58 - 81
6370	79 - 116
6360	92 - 145
6350	107 - 172
6340	111 - 188
6330	123 - 217

[This table is from calculations by Drs. Thomas Cahill and Thomas Gill in their supplement to Appendix B of their report to the CORI panel.]

[c] These standards are enforced in California whether a human being is inside the area or not.

this air pollution increases as the lake level drops. If the lake were to recede to the bottom of the predicted steady-state level of 6330 feet, an area of between 124 and 223 square miles (depending on wind direction) would be subject to air quality that exceeds state standards 11% of the time (Table 4). At the present time, there is no evidence that vegetation or wildlife in the area northeast of Mono Lake, subject to dust storms, shows any negative effects from the dust in comparison to wildlife and vegetation elsewhere. However, no quantitative study of the vegetation and wildlife has been conducted to examine such effects.

III.B. General Consequences of Changing Lake Levels

The statements in the previous sections provide details regarding the ecological consequences that are associated with specific lake levels. Certain features of the ecology and environment of Mono Lake are less directly related to specific lake levels or are known with somewhat less certainty, but they are no less important. In this section, the information which is available on these features of the Mono Lake ecosystem is summarized. Research findings about which there is a difference of opinion among investigators, including one such difference between this panel and the National Academy of Science Panel, are evaluated.[25] To place these findings in the context of the entire lake ecosystem, it is helpful to consider the key cause-effect linkages among the most important components of the system (Figure 9).

Effects of Changing Lake Levels on the Birds Using Mono Lake

The effects of changes in the water diversion and of changes in lake levels on the birds are through their food sources (which are affected by changes in lake salinity), through effects on breeding habitats, and through the needs of some species for sources of fresh water (the snowy plover, California gull, and Wilson's phalarope).

A severe reduction in the abundance of the brine shrimp and brine flies will adversely affect California gulls, grebes and phalaropes. In addition, gull reproduction will be reduced substantially through losses of suitable nesting habitat, which would accompany the land bridging of Negit Island and Java and Twain islets to the mainland and, at lower lake levels, the loss of other potential breeding sites. Whether or not these losses of food supplies or breeding habitats would have serious consequences for the regional or world-wide populations of these species depends in part on the capacity of the birds displaced from Mono Lake to relocate to other suitable lakes in the western United States. In the absence of firm evidence to the contrary, it is unwarranted to assume that they will relocate successfully. Although the loss of Mono Lake populations of these bird species would adversely affect regional populations, it appears unlikely that this would lead to their world-wide extinction.

Regardless of the impact of the loss of the Mono Lake bird populations to the regional and world-wide status of the species, such a loss would have an obvious negative impact on the scenic and aesthetic aspects of the lake, aspects that clearly have been valued by many people.

Caspian terns exist at Mono Lake as a small population that is likely to disappear regardless of lake levels; this would not have discernible effects on the regional population of the species.

The snowy plover is included on State and Federal endangered species lists, and therefore comes under protection of the Federal Endangered Species Act of 1973. The effects of changes in lake level on this species are mixed. The plovers nest in open playa and pumice dunes that will increase in area as the lake level drops and decrease if the level were to rise substantially. The

Key Cause and Effect Relationships of the Mono Lake Ecosystem

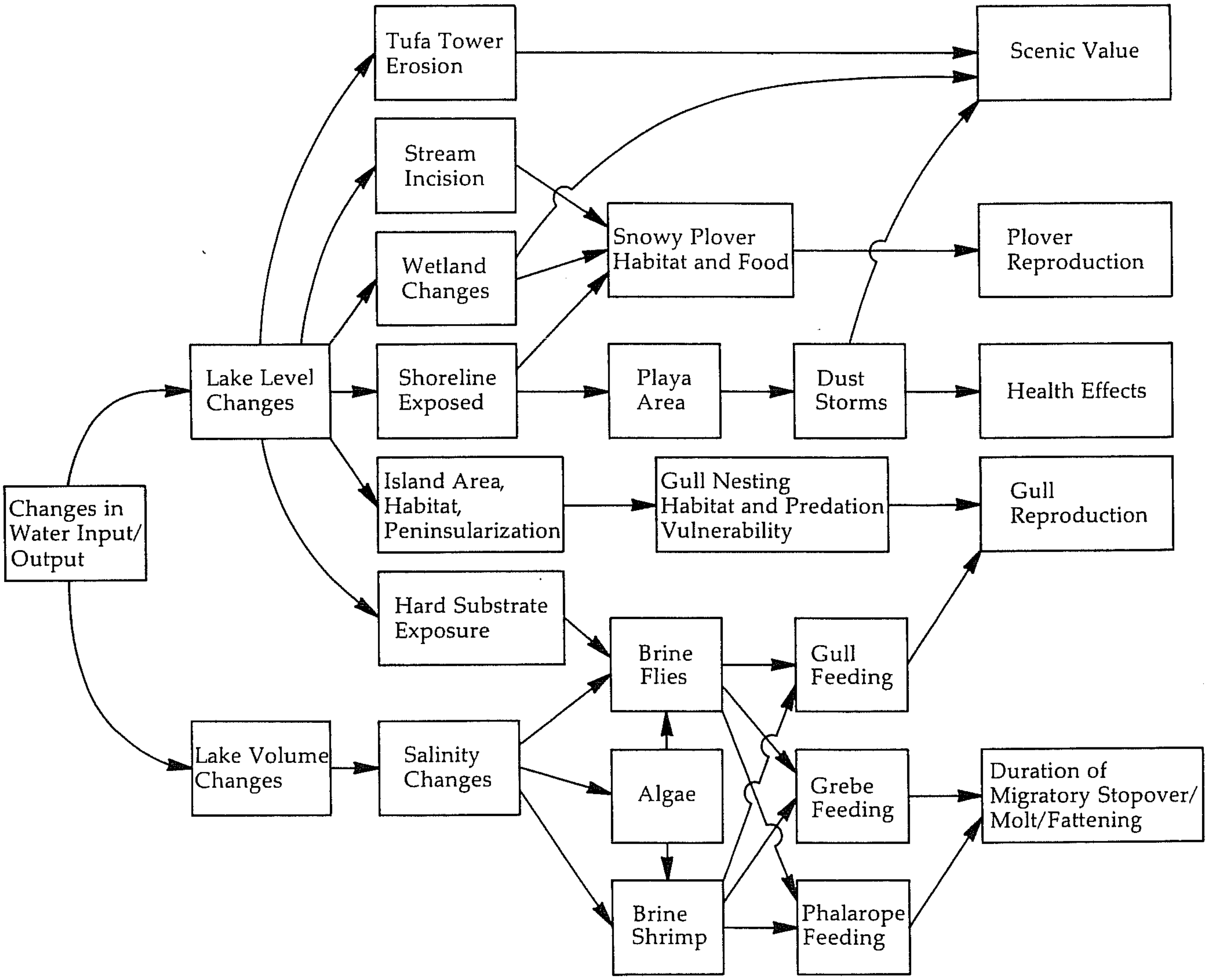

Figure 9. *Ecosystem Cause and Effect Relationships. In this diagram, each arrow indicates a cause and effect relationship between two boxes, with the arrow leading from the cause to the effect. For example, starting at the left, changes in water input/output cause changes in lake levels and lake volume. This diagram summarizes the major implications of changes in the level of Mono Lake.*

plovers feed on invertebrates at springs or seeps near the lake as well as on the brine flies at the lake shore; other invertebrates might provide food sources for this species if the brine flies were no longer available. Although the breeding population at Mono Lake represents approximately 11% of the nesting snowy plovers in California, the loss of the Mono Lake breeding colony would not by itself be likely to lead to extinction of this species.

A more extensive analysis of the birds of Mono Lake, and a synthesis and interpretation of the differing views about the effects of changes in lake levels on these birds, is given in Appendix B.

Wetlands

There are two kinds of wetlands at Mono Lake: stream-side wetlands and freshwater marshes. The marshes occur primarily where freshwater springs rise to the surface. The location of these springs might change as the lake rises and falls forcing the water table up and down. A large change in lake level might lead to the loss of some existing marshes. As the lake has dropped, new marshes have developed. Although new marshes might develop as the location of freshwater springs change, considerable time might be required to establish such new marshes. There could be long periods with few marshes for people to visit and for wildlife to use as habitat.

The stream-side vegetation includes woody vegetation, especially stream-side trees; these vegetated areas are known as "riparian woodlands." In the past, these areas contained trees such as willow, cottonwood, Jeffrey pine, lodgepole pine, and white fir. These areas were especially valued as a part of the scenic resource, were an important habitat for birds and mammals not necessarily dependent on the saline waters of Mono Lake (such as mink, bobcat, and mule deer) and have in the past been popular fishing areas.

Historical records suggest that the riparian woodlands have undergone considerable change since the beginnings of the water diversion. For example, Rush Creek, formerly the largest stream entering the lake, was lined with cottonwoods and Jeffrey pines, and was once voted one of the ten top trout-fishing streams in America by the magazine *Field and Stream*. A report to the Inyo National Forest states that as much as 8 miles of riparian woodlands along Rush Creek have disappeared since diversions began.[26] The lower part of Lee Vining Creek was also a well known trout fishing area.

Riparian woodlands depend on the existence of surface and near-surface flows. The surface flow can be seasonal or otherwise intermittent, but the percentage of the time when flows and volume meet requirements to maintain streamside vegetation communities is not known for the species of woody plants found naturally along the streams in the Mono Basin. The National Academy of Sciences report[27] estimates that the current minimum flows required at the time of their report to meet the requirements for trout habitat in Rush Creek (19 cfs) and in Lee Vining Creek (10 cfs) are sufficient to support riparian vegetation. The lack of surface flow from 1941 to 1986, however, caused damage to this vegetation that to this day has not been repaired, and it is unlikely that these flows alone will lead to a rapid regeneration of the riparian woodlands. To reestablish stream-side vegetation, perennial surface flow may be required, and the volume of flow required for this regeneration is undetermined at this time.

In addition, recolonization of riparian woodlands can be aided by a stable or rising lake level. A dropping lake level leads to the erosion of stream channels, which cuts away the stream-side habitat and can in turn lead to the loss of existing trees and prevent or retard the establishment of seedings.

The panel finds no evidence to support the NAS claim that 10 cfs that have been released under a court mandate to Lee Vining Creek and 19 cfs released to Rush Creek would reestablish riparian conditions that existed prior to 1941. These releases represent about 1/5 to 1/10 of the pre-1941 average streamflow. Some pre-1941 flows were also not natural because some water was diverted for agricultural irrigation. Measurements in the summer of 1987 indicate that only 1/2 of the 19 cfs released into Lower Rush Creek reached the county road crossing, located about a mile above Mono Lake. Measurements at the mouth of Lee Vining Creek this past summer indicate that as little as 2.5 cfs reaches Mono Lake when 10 cfs are released by LADWP into Lower Lee Vining Creek 4 miles upstream.[28] Thus, only a small volume of the water released is available to riparian vegetation. In addition, the current artificially induced flow regimes do not permit seasonal flooding above the banks, which would enhance the recovery of riparian vegetation.

Tufa Towers

Tufa towers are unique calcium carbonate formations that are structurally fragile. Formed under water, they may topple when they are exposed and when waves undercut the sediment at their bases. Many of these formations were seriously damaged by the lake-level increase between 1982 and 1986, when the collapse of towers was caused by waves undercutting the tower bases. Lake levels that exceed 6381 feet or drop below 6372 feet will be likely to lead to a further loss of the tufa towers.

SECTION IV: AN ECOLOGICAL PERSPECTIVE ON THE MANAGEMENT OF MONO LAKE: KEY LAKE LEVELS

The panel recognizes that Mono Lake is a natural area with unique scenery and natural history that has been valued for a long time, and that the lake as an ecosystem and as part of the scenery is worthy of conservation. Mono Lake has been valued at several spatial scales: at a regional scale for its scenic qualities as a large lake in the high desert on the east side of the Sierra Nevada with its abundant bird life; at a local level for its rare and unusual features, especially the tufa towers and the wetlands; and as a natural area where visitors view the abundant bird life. The loss of the lake as a living ecosystem would be a loss to the people of the State of California, the west, and the nation. The loss of the brine shrimp and brine flies would lead to the end of the use of the lake by the major bird species (except perhaps the snowy plover), which would have an obvious adverse impact on Mono Lake as a scenic and natural area. At the center of the Mono Lake issues is the question: What are the key lake levels needed for the management of Mono Lake as a biological and scenic resource? The studies funded by Assembly Bill AB 1614, in conjunction with information previously available, lead to several major conclusions.[d] Before these can be stated, however, it is necessary to develop the concept of "buffer" lake levels.

The Concept of a Buffer

Sound management of Mono Lake rests not only on the identification of lake levels at which critical changes occur, but also on an understanding of the idea of a lake "buffer level." A buffer level is the level at which the lake must be maintained during climatically normal years to keep it from falling to a critical elevation during times of drought. Droughts occur often in the Mono Basin and can be so severe that substantial drops could occur in the lake elevation even if there were no water diversions. If it is decided that the environmental changes that occur at a particular lake level are to be

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[d] The findings given here are subject to all the usual scientific caveats, including: that the conclusions drawn are based on available evidence; additional evidence could lead to changes in some conclusions.

avoided, then it would not be sound management to keep the lake at or only slightly above that level. Instead, the critical elevation should be buffered by enough water to compensate for the inevitable drought-induced fluctuations in lake level.

Therefore, the management of the lake must be thought of in terms of a **protected lake level** and a **buffer lake level**. The protected level is the level below which the lake could not drop without suffering critical biological and scenic damage. The buffer level is the level above the protected level that allows for fluctuations in lake level produced by normal climatic variations.

In the following analysis, the buffer level is the key level for management. The buffer levels chosen are those that protect against conditions corresponding to the most prolonged drought of the present century (the period between 1928 and 1934). If the lake were managed so that it remained at a buffer level stated in this report during normal rainfall years, it would drop to, but not below, the protected level even if the climate underwent a drought equal to the worst drought period of the 20th century. It should be understood that it is possible that droughts in the future could exceed the worst drought experienced in the 20th century. Concern for such an unknown, more serious drought, could lead to the choice of an even larger buffer.

In this report, buffer levels are chosen under the assumption that LADWP will not augment its capacity to divert and that diversions will continue at the historically prevailing average of 90,000 acre-feet per year. At the current time, the rate of diversions are constrained by a court-ordered release of 23 to 24 cfs to support trout populations in two streams tributary to Mono Lake. If these releases were to continue indefinitely in the future, then the required buffer levels would be somewhat lower than indicated in the following analysis.[29]

Key Lake Levels

It is the conclusion of the panel that, for the management of Mono lake, there are three key buffer lake levels: 6382, 6372, and 6362 feet above sea level, each with different ecological significance for the lake.[e] [30]

Level I: 6382 feet

A buffer lake level of 6382 feet[31] provides a 14 foot buffer against a key lake level of 6368 feet. A buffer level of 6382 feet thus protects all key aspects of the lake and its designated national recreational area, including:

* the major species of birds using the lake as a feeding, staging, or breeding area;
* the tufa towers;
* the existing wetlands;
* the lake ecosystem and its brine shrimp and brine flies.

This lake level acts as a buffer against variations in climate including episodes equivalent to the worst droughts of the 20th century. If the lake were at 6382 feet and subjected to such a drought, it would temporarily drop 14 feet to 6368 feet (Figure 9).[32] If the lake were maintained at 6382 feet during normal rainfall years, the island and islet areas that are important gull breeding habitats would remain islands for all years except for a period of a few years during severe droughts, when Negit Island and the islets Twain and Java would be peninsulas. A buffer level of 6382 feet also protects the lake from dropping below the nick point, at 6368 feet, a point at which the topographic relief changes markedly. If the lake drops below the nick point erosion of tufa towers, marshlands, and stream beds will be irreversible. Except during the driest periods, the buffer

[e] An important factor in the choice of these levels is the calculation of the salinities that would be reached. In this report, the calculation of salinity for any lake level is based on the gravimetric method. In this method, a sample of water is weighed, the water evaporated, and the remaining salts weighed. The salinity is then calculated from these two weights.

level of 6382 feet also provides a sufficient area of hard-substrate environment, which is important for the brine flies.

The choice of a buffer level of 6382 feet accepts the occasional exposure of dry land between the present shore and Negit, Twain, and Java, transforming them from islands to peninsulas; with this buffer level, however, this situation would be unlikely to persist. It is the conclusion of the panel that short-term connection of these areas to the shore would not result in long-term detriment to the birds using Mono Lake.

It should also be recognized, however, that tufa destruction and Paoha-islet degradation will occur if the lake is maintained at an elevation of 6382 feet. When the lake rises to levels above 6381 feet, there will be some erosion of small towers at south tufa, as well as the flanks of the Paoha islets. The panel considers this loss a legitimate tradeoff for preserving Negit, Twain, and Java as nesting grounds, keeping the salinity below the level at which the brine shrimp hatch decreases, and protecting the topographic nick point from exposure.

Level II: 6372 feet

A lake level of 6372 feet provides a 13-foot buffer against a key lake level of 6359 feet.[33] A buffer level of 6372 feet sacrifices substantial portions of gull habitat, endangers significant numbers of tufa towers, threatens much existing wetland with drainage, and adversely affects the breeding biology of plovers. The effects of maintaining the lake at this level on phalaropes and eared grebes are uncertain at this time, but it is possible that there would be a significant reduction in the food resources of these species.

Below the protected level of 6359 feet, salinities rapidly increase, producing significant decreases in the production of brine shrimp and brine flies.

Level III: 6362 feet

A lake level of 6362 feet provides a 10 foot buffer above 6352 feet.[34] This level is extremely dangerous for the lake ecosystem; major reductions in the production of brine shrimp and brine flies would occur as the lake varied with climate between 6362 and 6352 feet. At 6352 feet there would be a cessation in production of brine shrimp and brine flies sufficient to support the large numbers of birds and a demise of the lake ecosystem as it now exists. The lake would become unreliable as a staging and breeding area for birds. Few gulls would be expected to nest at the lake because of the great reduction in available nesting habitat of sufficient quality even if food were available. It is highly likely that the food supply of the grebes and phalaropes would be severely reduced.

TABLE 5. TIME REMAINING BEFORE KEY LAKE LEVELS ARE REACHED

The dates at which the lake reaches five critical levels are as follows:

LEVEL	IMPACT	DATE
6375	Negit becomes peninsula	1989
6372	Key Lake Buffer Level 2	1991
6368	Exposure of topographic nick point	1994
6363	Serious declines occur in brine shrimp production as this level is passed.	1999
6362	Key Lake Buffer Level 3	2000
6352	Brine shrimp and flies unable to reproduce	2012
6335	Projected "steady-state" after	2090

(All dates are approximate.)

Key Lake Levels for Management

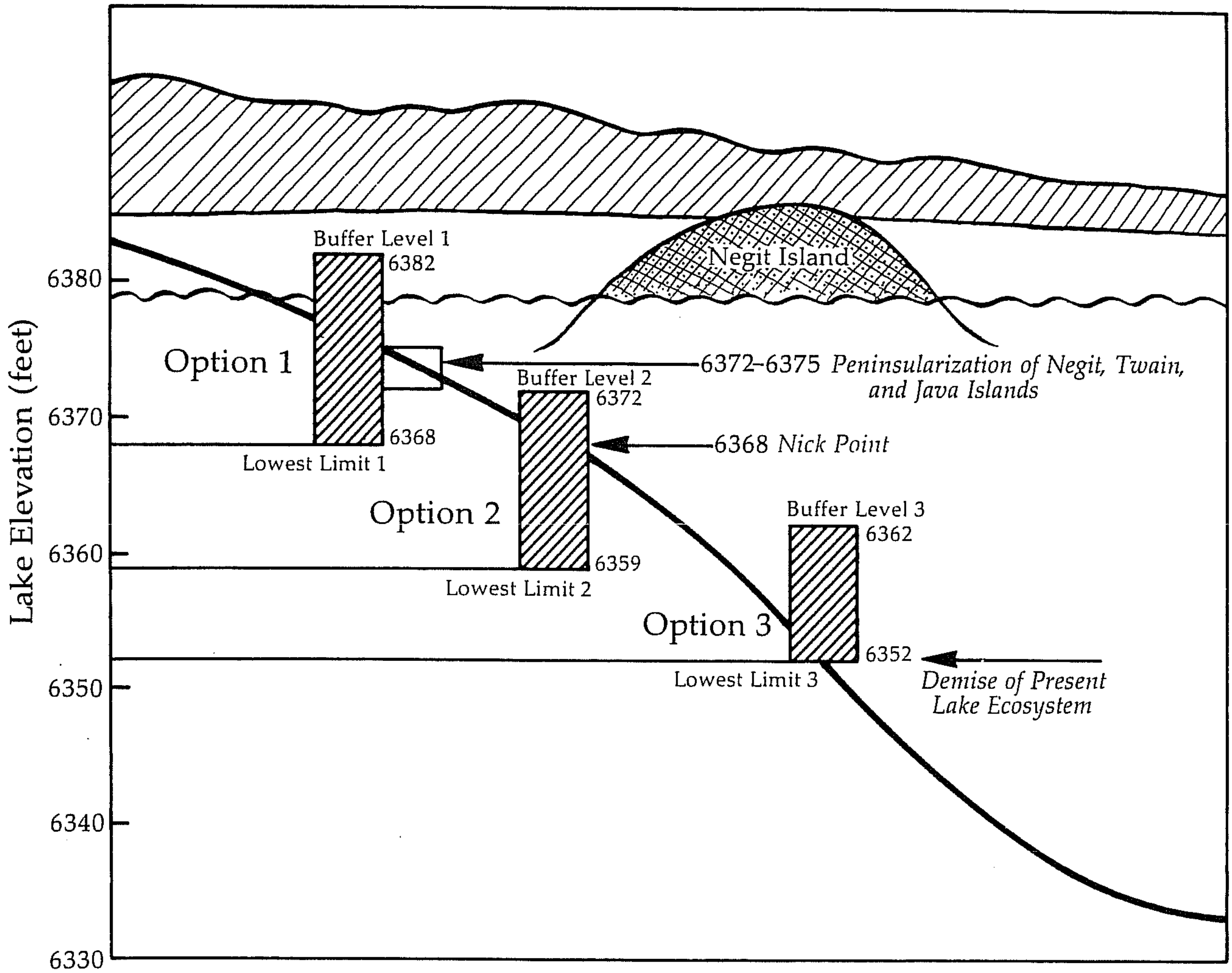

Figure 10. *Three Key Lake Levels For Management are shown along with the associated buffer level of each. A management policy whose goal is to keep the lake above one of the "lowest limits" shown on the figure would have to maintain the lake at the buffer level during normal weather years. The buffer level shown assumes that the export of water to the City of Los Angeles continues in the future at the maximum rate that current facilities allow and that evaporation is accurately estimated by the Vorster model. [Currently a court injunction requires some water releases to maintain trout habitats in two streams that feed Mono Lake. If these releases continue, a slightly lower buffer level would be required (see text for explanation).]*

Time Remaining Before Serious Consequences Occur

Serious consequences to the lake ecosystem will occur in the near future if LADWP continues to export Mono Basin water in amounts similar to those that have been exported for the past three decades (Table 5).

Negit Island will be exposed in 1989; the nick point sometime about 1994. The lake level will continue to drop until it stabilizes in about 100 years at a level of about 6335 feet, 17 feet below the elevation at which the lake's ecosystem would collapse. [This projected trend for lake level is made under the assumption that the average climate in the future will be the same as has occurred during the last 50 years, and that the average diversion rate will remain the same as that during the last 20 years (Figure 11 and Table 5).]

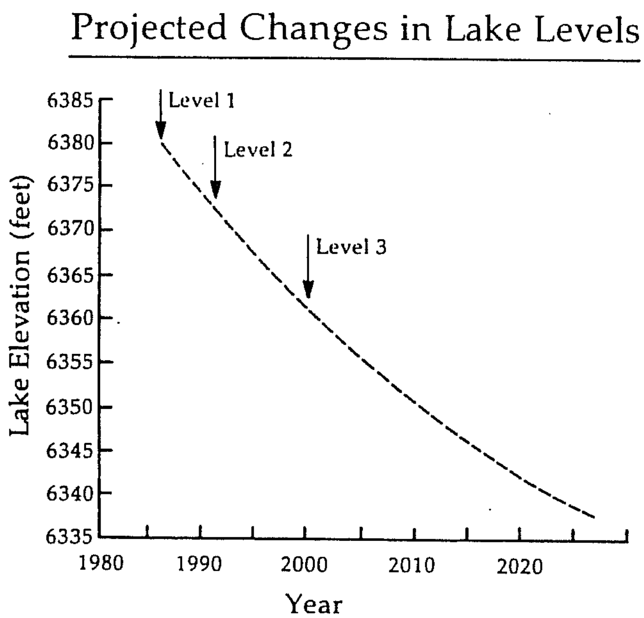

Figure 11. *Projected Changes in Lake Levels. The predicted decline in the level of Mono Lake, assuming that water diversions continue at the maximum rate that current facilities allow, is shown here. The dotted line assumes that the future climate is constant and like the current climate (based on S. Stine report to the CORI panel).*

Flows Required to Maintain Key Levels

To maintain any of the three key buffer levels, surface water flows into the lake would have to be increased. For the period 1969-1985, diversion of water by LADWP was approximately 90,000 acre-feet/yr.[35] It is estimated that to maintain a lake level of 6382 feet (suggested buffer level I), an average of 38,000 acre-feet/yr could be diverted (42% of the recent diversion rate); to maintain an approximate lake level of 6370 feet (2 feet below suggested buffer of level II), an average of 55,000 acre-feet/yr could be diverted (61% of recent diversion rate); and to maintain an approximate lake level of 6360 feet (2 feet below suggested buffer level III), an average of 68,000 acre-feet/yr could be diverted (76% of recent diversion rate). Because the 90,000 acre-feet/yr represents approximately 17% of the city of Los Angeles's total water supply, maintaining a level of 6382 feet would mean that the city would lose 10% of its current water supply. As noted earlier, at the time of this writing a total minimum surface flow of 23-24 cfs is maintained in two streams tributary to the lake, with the rest of the diverted stream flow exported to the City of Los Angeles's water supply.

The values given here are estimates that are limited in accuracy, to a certain extent, by the precision of the current models of the hydrology of Mono Lake. To project the required volumes more accurately, more precise hydrological models would have to be developed for Mono Lake than now exist.

SECTION V. RESEARCH NEEDED TO EXTEND THE UNDERSTANDING OF THE FUTURE OF MONO LAKE AND THAT IS IMPORTANT TO PRUDENT MANAGEMENT OF THE LAKE AND ITS WATERSHED

The funds provided by California Assembly Bill AB 1614 were sufficient only to uncover and synthesize existing data and to support a small amount of new research chosen to answer specific questions required by the bill. Although the panel has been able to draw many conclusions (given in the body of this report) from the existing information, it is also true that wise and prudent management of Mono Lake should involve: (1) continued monitoring of important factors, just as any management of resources or industry maintains a monitoring program of its inputs, outputs, and of the status of its equipment and systems; and (2) the support of research to refine information about specific topics, which would "fine tune" the future management of the lake. In this section, the panel provides a list of the most important monitoring and research activities, which would add to the scientific basis for the management of Mono Lake.

General Issues

1) Basic ecological monitoring of the Mono Lake ecosystem should be part of good management. This monitoring should include lake chemistry, abundances of brine flies, brine shrimp, the key species of birds, and important vegetation communities around the lake.

2) Research to connect changes in the level of Mono Lake to larger issues of global climatic change. For example, it is projected that a global climate warming may take place as a result of carbon dioxide buildup (and the increase in other trace greenhouse effect gasses) in the atmosphere. Current models of climate project that increases in carbon dioxide from the burning of fossil fuels may lead to an increase in the average surface temperature of the Earth by approximately 3° C in approximately 100 years, which would result in the warmest climate in the last several million years. If such changes were to occur, they could have important consequences for the management of Mono Lake (and for California's water supply).

Research on Hydrology and Geology of the Lake

1) Research to improve the precision of estimates from water balance models, including better quantitative information about evaporation, a major variable in all water balance models.

2) Research to increase the understanding of lake chemistry and the precipitation of minerals as the concentration of salts increases in Mono Lake water.

More specifically, it would be useful to confirm by experiment the salinity at which the lake water becomes saturated with salt (as a function of temperature) and to determine what salts precipitate and what impact such precipitation would have on the lake's stratification, and on its acidity.

3) While it has been generally accepted that the salt in Mono Lake was delivered over a half million year period by streams and groundwaters, recent studies suggest that this is not the case. Instead, much of the salt appears to enter with hot waters rising from beneath the lake. Radiocarbon studies suggest that the delivery is rapid and subject to large fluctuations. The salt history of the lake must be rethought in light of this new information.

4) Studies should be conducted as to how the area of fresh water springs and marshes around the lake will change as the lake level drops.

Research on the Biology of The Lake

1) Research to provide more detail concerning the quantitative relationships between salinity and reproduction, survival, and growth of brine flies and brine shrimp.

For example, research supported by the CORI study suggests that brine shrimp reproduction begins to decline at a salinity of 120 g/l and ceases at a salinity of 150 g/l. It would be useful to determine these effects at smaller intervals of salinity levels than are now available. (In these studies, attention must be given to maintaining the pH and pCO_2 of the lake water at the expected lake values in the water used for these studies.) Similar studies should be conducted for brine flies.

2) A modelling study should be undertaken concerning the possibility of long-term meromixis (stratification) resulting from freshwater influx at various levels, because such events could lead to important ecosystem changes.

Research on Birds that Use Mono Lake

1) What are the thresholds of densities of brine shrimp or abundances of brine flies at which bird populations experience limitation? There are actually several important thresholds: that at which the growth rates and survival of gull chicks begin to decline in July, that associated with a reduction in fat-accumulation rates and/or molt in grebes and phalaropes, and that associated with departure of grebes and phalaropes (and perhaps gulls) from the lake.

Initially, these considerations, and an assessment of the role of grebe predation in precipitating the fall decline in shrimp populations, might be examined through bio-energetically based computer models relating projected bird food demands to estimated or simulated resource levels.

2) What is the degree of distributional flexibility of grebes, phalaropes, and gulls? Do individuals use other lakes if displaced from Mono Lake? Is site fidelity well developed in the birds using Mono Lake for breeding or as a migratory stopover or staging area?

3) At a more local scale, what are the components of breeding-habitat suitability to gulls? To what degree will gulls use alternative nesting areas if Negit, Twain, and Java are not available? Can gulls be induced (perhaps by the use of decoys and predator control measures) to use Paoha to a greater extent? What factors currently make Paoha unattractive to gulls?

4) What is the degree of dietary opportunism of Mono Lake gulls, and to what degree do they obtain food and water at some distance from the lake?

5) What are the effects of thermal stress and tick parasitism on the growth and survival of gull chicks? To what degree is the Mono Lake gull population maintained by in situ reproduction versus immigration?

6) Studies of the feeding habits of phalaropes should be conducted in order to determine more about the distribution of the brine flies on which they feed.

7) Studies should be conducted to rank potential gull habitats in an attempt to quantify how the availability of habitat will change as the lake level drops.

Research on Vegetation

1) Research to improve the understanding of the quantity of surface water and the physical and chemical characteristics of riparian habitats that are necessary to restore and maintain riparian vegetation.

2) Research to improve the understanding of potential vegetation growth on newly exposed areas. Vegetation can be useful in reducing the movement of particulates lifted from the playa areas by strong winds.

More specifically, a combined tensiometer and neutron probe investigation would be useful to determine the matrix potential of the soil moisture in the playa areas around the lake. Tensiometers could determine the soil moisture regime relative to unsaturated flow conditions. Should the system become drier than 1 bar of suction, then neutron probes can determine the soil suction ranges down to 90 atmospheres of tension. In this way, one can quickly determine if the wilting point for vegetation is being exceeded.

3) As the lake level decreases, specific geologic beds which conduct water from the surrounding mountainous area to the lake become exposed, and the base flow of groundwater emerges at the surface. By conducting a limited drilling and soil moisture evaluation program along the edge of the playas, it may be possible to determine which beds will become exposed as the lake level decreases, and thus provide surface water to support vegetation.

4) Quantitative studies to determine whether there are any negative consequences resulting from changes in air quality on the natural vegetation in the Mono Lake Recreation area.

Research on Tufa Towers

1) Research to provide a better understanding of the factors which create tufa towers. Current evidence indicates that the tufa towers are no longer growing, but rather are disappearing because of erosion and recent water level increase. The tufa towers originate in specific geologic beds, develop and terminate at a consistent elevation (i.e., their height is the same elevation regardless of how far down the towers extend), and appear in a linear distribution. One explanation is that a fresh water artesian condition associated with a specific up-gradient geologic formation uniformly transmits a hydraulic gradient and through secondary porosity (i.e., fractures and fissures that typically are linearly distributed) leads to the upward movement of salt-laden waters which are necessary for the production of the towers.

Because of the unique geologic character of the tufa towers, a hydrogeologic investigation would be useful to confirm or deny this hypothesis. If the up-gradient source of hydrologic recharge can be identified, and if the potentiometric elevation can be artificially controlled by diversions, the possibility exists that tufa tower growth could be regenerated and the phenomenon preserved.

Paleoecological Research

To help predict effects of future changes in salinity on the aquatic organisms, study of the sedimentary record of the lake should be done to reveal as far as possible how past changes have affected the organisms. Specifically:

1) What changes in salinity have occurred within the last few hundreds of years? How long have

the conditions persisted? How rapidly have the conditions changed?

2) What changes have occurred in brine shrimp and brine fly populations within the last few hundreds of years? To what degree do these changes correspond to those of salinity?

3) Have either the brine shrimp or brine flies disappeared from the lake during the last few hundreds of years? If so, how rapidly was their demise and how quickly and at what salinity did their populations recover?

4) Have other macro-invertebrates, possibly suitable as food for the birds, existed in the lake within the last few hundreds of years? If so, under what conditions were they present?

5) What changes have occurred in the algae, and how are they related to changes in salinity?

Answers to these questions, and particularly knowing whether the shrimp and flies have recovered after periods during which reproduction has ceased, will be of immense value in helping predict the future course of the lake.

SECTION VI: REFERENCES AND ENDNOTES

1. No new studies of the groundwater hydrology were attempted. The groundwater hydrology of Mono Lake and its watershed is complex, the product of interwoven layers of glacial, fluvial, lacustrine, and volcanic deposits, which make up confined and semi-confined aquifers. There has been no significant past study of these factors, and since the structure and spatial patterns are not known, the hydraulic conductivity and storage capacity of the ground water system could not be determined without extensive additional new research. Such studies are so expensive and difficult that nothing productive would have been possible in the development of new models with the limited funds available. Thus the panel concluded that existing water balance models were sufficient at this time to provide a basis to deal with the issues addressed in this report.

2. The National Academy of Sciences study resulted in a publication, *The Mono Basin Ecosystem: Effects of Changing Lake Level*, 1987, National Academy Press, Washington, D.C.

3. Report of the Los Angeles Department of Water and Power, "Mono Basin Geology and Hydrology," Table 6.

4. Cal Trout et al. vs. City of Los Angeles and City of Los Angeles Department of Water and Power, Mono County Superior Court Case No. 8092.

5. Mono Lake Committee vs. City of Los Angeles and City of Los Angeles Department of Water and Power, Mono County Superior Court Case No. 8608.

6. Stine, S., 1987, "Geomorphic and Geohydrographic Aspects of the Mono Lake Controversy," Report to the CORI panel.

7. In 1982, at the time of the "historic low stand" Mono Lake attained a level of 6372 feet. Approximately 1900 years ago, and again about 1000 years ago, the lake reached its "Late Holocene low stand" of 6368 feet. The lake has thus been lower under natural conditions than it has due to water diversions in modern time. Changes in the shape of the lake basin (due to volcanically-induced island building and sediment accumulation on the lake bottom) which have occurred over the past two millennia, preclude a direct comparison of lake volume and some other factors between the Late Holocene and the historic low stand. Because of these changes, the lake in prehistoric time held more water (and was consequently less saline) per given lake level than the modern

lake. Taking into account the changes of the Late Holocene time, it appears that at the time of the historic low stand in 1982 Mono Lake contained less water and was more saline than at any time in at least 4,000 years (see Stine report to CORI reference given above).

8. This estimate is based on the Vorster model, from work done by Stine and Vorster for the CORI panel.

9. Stine report to the CORI panel and personal communications by Stine to the CORI panel.

10. The species names are: eared grebe, Podiceps nigricollis; California gull, Larus californicus; snowy plover, Charadrius alexandrinus; red-necked (or northern) phalarope, Phalaropus lobatus; Wilson's phalarope, Phalaropus tricolor; Caspian tern, Sterna caspia.

11. The information discussed here and elsewhere in this report concerning the birds using Mono Lake depends heavily on the two studies on the birds of Mono Lake funded under the CORI grant: J. R. Jehl Jr., "Caspian Terns, Phalaropes, and Grebes of Mono Lake;" and D. W. Winkler, "California Gull and Snowy Plover Populations of Mono Lake, California."

12. Pelagos Corporation, 1987, "A Bathymetric and Geologic Survey of Mono Lake, California." This report, prepared for the Los Angeles Department of Water and Power by Pelagos Corporation of San Diego, provided important information on the morphometry of the basin. The Pelagos charts were used extensively in the CORI-funded study by S. Stine (reference cited earlier) to determine the elevations at which islands became land-bridged, and the areas of "hard-substrate environment" available at particular elevations.

13. S. Stine report to the CORI panel (work cited previously).

14. S. Stine report to the CORI panel (work cited previously).

15. Personal communication from Eldon Horst, Los Angeles Department of Water and Power, to D.B.Botkin.

16. Vorster, P., 1984, *A Water Balance Forecast Model for Mono Lake, California*. Forest Service /USDA Region 5. Monograph No. 10, 350 pp. is the basic reference; however, in cooperation with S. Stine, Vorster carried out additional analyses for the CORI panel.

17. Discussion with Vorster revealed that the NAS modification of his model: (1) omitted the inflow from Mill Creek, which represents about 10% of the total inflow to the lake; (2) used a value for evaporation of 42 inches/year which required recalibration of the model, a task which was not done; (3) contained assumptions about the export of waters from the Mono Basin to LADWP facilities that were not realistic and did not give accurate estimates; and (4) did not allow for climatic variation but instead used long-term averages of three factors: rainfall at the lake, evaporation rates at the lake, and runoff from the Sierra. As a result, the modified model does not give correct results.

The Mono Basin exports are calculated as the difference between the outflow from Grant Lake and the controlled release (which is varied from 10,000 to 100,000 acre-ft/yr). In years of high runoff and low controlled release the calculated exports will be operationally incompatible with the LADWP plumbing system (due to storage limitations); in addition the actual release into Mono Lake will be higher (because of uncontrolled releases down Lee Vining Creek) than the specified controlled release. In years of low runoff the actual release will be limited by the runoff and thus the high controlled releases cannot be achieved. Thus the release values in Figure 2.7 of the NAS report are a theoretical and not actual release into Mono Lake. (Personal communication from S. Stine.)

18. Letter to W. Broecker from Herbst (member of the Melack study group funded by the CORI grant).

19. S. Stine report to the CORI panel (work cited previously).

20. Herbst report, as part of the Melack subcontract under the CORI grant as cited above.

21. S. Stine report to the CORI panel (work cited previously).

22. J. M. Melack, "Limnological Conditions at Mono Lake," report to the CORI panel.

23. S. Stine report to the CORI panel (work cited previously).

24. T. A. Cahill and T. E. Gill report, "Air Quality at Mono Lake," report to the CORI Panel.

25. The conclusions of this report assume that the goal in managing Mono Lake is to keep the lake ecosystem self-sustaining, maintaining populations of birds and minimizing undesirable conditions without direct human actions. However, there are other approaches to certain problems that mitigate certain effects of changes in lake level. For example, the effects of air pollution might be mitigated by installation of snow fences to reduce the transport of particulates. Such installation, however, could have negative effects on the scenic qualities of the lake and its surroundings.

26. Felando, T., 1984. Attachment to Inyo National Forest Response to Environmental Analysis, Keating Leggett Project. Inyo National Forest Office, Bishop, Ca.

27. *The Mono Basin Ecosystem: Effects of Changing Lake Levels*, 1987, National Academy Press, Washington, D.C.

28. Vorster, personal communication, 1987.

29. Buffer levels assuming a continued release of 29 cfs, as was court mandated at the time of his writing, were calculated by S. Stine, "Geomorphic and Geohydrographic Aspects of the Mono Lake Controversy," Report to the CORI panel, Table 3, p. 90. These give the following values with such a release: the buffer level for 6368 is 11 feet or 6379 feet, the buffer level for 6359 would be 9 feet or a lake level of 6368 feet; and the buffer level for 6352 would be 8 feet or a lake level of 6360 feet.

30. It should be stressed that the conclusions given here are based on available evidence; additional evidence could lead to the modification of some conclusion.

31. Buffer levels are calculated in the report by S. Stine to the CORI panel (report cited previously). Stine reports buffer levels for 10 foot increments of protected level. These results have been rounded in this report. For example, it has been assumed that the interval needed to protect a lake level of 6370 feet is the same as that needed to protect a lake level of 6368 feet.

32. The calculation of the buffer level to protect against levels near 6370 feet is 14 feet.

33. As described in the text for level I, there is a desirable buffer level for each lake level of concern. In this case, this level of 6372 feet acts as a 13 foot buffer for level 6369 feet, assuming there are no releases from existing Los Angeles Department of Water and Power diversion facilities to allow surface flow. When surface flow was court mandated to be a total of 29 cubic feet per second for the maintenance of trout habitat, only a 9 foot buffer was needed to protect against episodes equivalent to the

worst droughts of the 20th century. (S. Stine report to the CORI panel.) At the time of this writing, the current court mandated flow of 23 to 24 cfs would require a slightly higher buffer level.

34. This level acts as a 10 foot buffer assuming there are no releases from existing Los Angeles Department of Water and Power diversion facilities to allow surface flow. When surface flow was court mandated to be a total of 29 cubic feet per second for the maintenance of trout habitat, only an 8 foot buffer was needed to protect against episodes equivalent to the worst droughts of the 20th century. (S. Stine report to the CORI panel.) At the time of this writing, the current court mandated flow of 23 to 24 cfs would require a slightly higher buffer level.

35. Los Angeles Department of Water and Power, "Mono Basin Geology and Hydrology," Table 6.

SECTION VII: APPENDICES

APPENDIX A. SYNTHESIS AND EVALUATION OF RESEARCH CONCERNING THE BIOLOGY OF MONO LAKE

Joseph Shapiro

Some of the most important evidence that demonstrates continued salinity increase will be detrimental to the biota of the lake comes from direct experiments on the aquatic organisms. Thus it has been shown for the brine shrimp (of the genus Artemia)[1] that, between salinities of 133 and 159 g/l, survival to maturity declines rapidly and growth rate decreases significantly. Furthermore, brood size decreases regularly with increasing salinity, and percent hatching of cysts begins to be affected significantly between 118 and 133 g/l and is prevented completely between 133 and 159 g/l.

The brine flies are affected similarly[2], beginning somewhat above 100 g/l when survival of the first instar is significantly decreased. By 125 g/l, 50% acute mortality of this stage occurs within four days, and none survive more than one day at 200 g/l. Even a major food constituent of the flies--the alga Ctenocladus--is affected, with growth rate and yield decreasing significantly from 25 g/l to 100 g/l and being practically nil by 150 g/l. Herbst also showed that decreasing food supply stresses the animals, leading to reduced survival. The algal food of the brine shrimp may also be affected by salinity since studies have shown that primary production and growth fall off with increasing salinity.[3] A computer model based on the studies on Artemia[4] indicates that by 150 g/l Artemia will no longer exist in the lake.

These experiments, while necessarily carried out at fixed salinities in the laboratory, are nonetheless valid in their predictive capability. Laboratory experiments involving scale, such as those attempting to simulate field population concentrations or competition, may be criticized on grounds that this is very difficult to do in the laboratory. But physiological experiments do not suffer from this deficiency, if properly done, and the conditions provided to organisms in the laboratory are as valid as those experienced by them in the field. Thus severe effects on the aquatic biota are inevitable as described.

Other effects of diminished water level may be deduced from knowledge of the ecology of the organisms. One such effect is the reduction of hard substrate for the brine flies. Herbst has shown that tufa surfaces are greatly preferred to sand surfaces by the flies, and thus exposure of the tufa above waterline would decrease availability of substrate for the flies. According to Stine,[5] such littoral area will decrease very rapidly as water levels decline, from 6,834 acres at 6380 feet to 3,010 acres at 6372 feet, and to 1,271 acres by 6360 feet. Although it is not possible to state exactly how much substrate is required to maintain the fly populations, such losses of substrate, coupled with food limitation, could prove strongly detrimental to the flies even before salinity has reached fatal levels.

Although few, if any, detrimental effects on the biota were noted during the 1982 "historic low-level," this should not give confidence that lower levels will not be detrimental. The evidence is very clear that at levels below 6372 feet the populations will begin to be affected and that the shrimp will likely disappear in the region of 6355 feet. If the shrimp and flies do disappear, the flies especially may find refuge to a small degree near the freshwater seeps. This happened at Owens Lake where the lake eventually dried up because of water diversions to Los Angeles.[6] However, the question of whether repopulation of the lake could occur in the time required for it to reach a level required by the bird populations cannot be answered at this time. If the lake level were to decline to the point where salinity eliminated the shrimp and the flies, it is possible that certain algae and bacteria could continue to exist at salinities of 200 g/l or even higher, but it is exceedingly unlikely that other macroinvertebrates would be present to feed upon these and to be fed upon in turn by the birds.

One interesting aspect of the lake as it exists at present is its state of meromixis (stratification), brought about by the inundation in 1983. Its effects may be complex. One might venture that it is beneficial in that the less saline upper waters are more hospitable to the shrimp, flies and algae, as noted. However, at the same time the stable condition prevents nitrogen from being recirculated from beneath and, as the lake is nitrogen limited, this would reduce primary productivity, not only of the suspended algae but of those attached to hard surfaces as well. This would affect food of the shrimp and flies. Furthermore, meromixis results in extended periods of anoxia near sediment surfaces and this results in a failure of brine shrimp cysts to hatch. Assuming this present event of meromixis finally disappears with mixing, further increases in salinity will make meromixis more likely, as density differences will be even more pronounced. However, as the degree and duration will depend so much on climatic factors such as precipitation and wind, no predictions are possible at this time.

APPENDIX B: SYNTHESIS AND EVALUATION OF RESEARCH CONCERNING THE BIRDS OF MONO LAKE

John A. Wiens

Because the birds using Mono Lake have been a special focus of interest to many people, because there remain differences in interpretation of data, and because there were two subcontracts under the CORI grant for the study of different species of birds the panel decided that a synthesis of knowledge about the birds and of the outstanding issues among scientists concerning these bird would be useful to include as an appendix to the report. This synthesis, compiled by Dr. John A. Wiens, one member of the CORI panel, follows.

The major bird species that use Mono Lake (California gulls, eared grebes, Wilson's and northern phalaropes, and snowy plovers) are sensitive to changes in lake levels either through effects on their food supplies or through changes in the availability of suitable nesting habitat. In each case, there is some uncertainty involved in translating changes in resource abundance (shrimp or fly numbers or island area) to the proportion of that resource that is actually available to the birds (e.g. prey at accessible water depths or island area suitable for nesting habitat) and then in determining at which levels the availability of the resource actually becomes limiting to the bird populations. These difficulties, which are critical to an assessment of the consequences of changing lake levels on the bird populations, are considered in the following discussions of California gulls (nesting habitat) and eared grebes (food abundance).

CALIFORNIA GULLS

During the last decade, the California gull breeding population at Mono Lake has fluctuated between 40,000 and 50,000 birds. It is the second largest breeding colony in the world. The NAS Panel concluded that this represented 15-25% of the world population of this species, but Jehl[7] feels that, although it might have contributed as much as 15% in 1980, it constitutes a smaller proportion (10-12%) now because of recent population increases elsewhere. Firm evidence to support any of these estimates is lacking, but it is apparent that the Mono Lake colony represents a major component of the species as a whole. Because the species is reasonably abundant at a number of other breeding locations (most notably Great Salt Lake), however, it is unlikely that a reduction in the size of the Mono Lake colony would jeopardize the species as a whole.

The breeding gull population at Mono Lake has increased from 3,000-4,000 birds at the turn of the century to its present level. Jehl et al.[8] attributed this rise to increases in the availability of nesting habitat, but the historical records analyzed by Winkler and Shuford[9] indicate that gulls were abundant at Mono Lake in the last century and suffered losses due to egg-gathering by miners and settlers in 1860-1880; Winkler and Shuford believe that populations have been recovering gradually since then to the present plateau. In any event, there is no compelling evidence of systematic changes in gull abundance at Mono Lake during the past decade--the observed variation is well within the bounds of sampling error.

Winkler's life-table analysis indicates that the Mono Lake gull population is not normally self-sustaining through reproduction and that the population must therefore be maintained by immigration from elsewhere. This is an important suggestion, for it means that, although the gulls are an integral part of the Mono Lake ecosystem, their population dynamics are linked with those of other gull populations on a regional scale. The National Academy of Science's Report on Mono Lake[10] questioned whether data were presently available to permit such analyses (their estimates of adult longevity are high, according to Winkler), and Shuford[11] argued that the chick production values Winkler used were not reliable. Use of the other values that Shuford suggested, however, has little effect on the outcome of the life-table analyses[12] and, although the results of this exercise must be regarded as provisional, they are nonetheless instructive.

Various procedures have been used to survey the Mono Lake gull populations, and investigators do not agree about which is best or what degree of accuracy is necessary. Some procedures, such as direct nest counts, involve a certain amount of disturbance of the gulls, and there is also disagreement about the effects of such disturbance on chick mortality. Although it would be desirable to determine the magnitude of such effects and of the error accompanying census estimates, it is most important that baseline monitoring of the gull population sizes and chick production be continued following standardized procedures. Because large-order, persistent changes in the gull populations and accompanying changes in lake conditions are of greatest interest, it is not necessary that the estimates be highly accurate. Efforts spent on improving census accuracy would better be devoted to determining critical features of the breeding ecology and habitat requirements of the gulls.

Mortality of adult gulls at Mono Lake is low, but chicks face perils from a variety of sources. As a consequence, chick production rates vary dramatically among years. In general, however, reproduction is low, although a few years of unusually high production (such as occurred in 1986 and 1987) may to some degree compensate for several years of low production. The fluctuations in reproduction may produce strong dominance of particular age classes in the gull populations, but the consequences of this uneven age distribution are not known. There is no doubt that land-bridging of breeding islands and islets, especially Negit, Twain, and Java, has major effects on breeding populations (Fig. B.1). This occurs through (a) direct predation of chicks by coyotes, (b) disruption of the colony and abandonment of nests, and (c) further disruptions of other breeding sites by the displaced gulls. Negit becomes attached to the mainland at a lake elevation of 6375 feet, Twain and Java at 6372 feet. Because coyotes may wade through water a foot deep to reach islands or may actually swim to reach some areas (e.g. Paoha Island), disruption of breeding colonies may occur at lake levels higher than those at which islands become physically land-bridged. Currently, coyotes have been reported to cross in 1-foot water depth, so that at this time Twain and Java must be considered to be accessible to them at 6373 feet, Negit at 6376 feet.

If lake levels fluctuate about these critical levels (as they have during the past decade), gulls may recolonize land-bridged areas when they again become insular. There is clear evidence, however, that different breeding islands are recolonized at different rates. Gulls abandoned Twain and Java in 1982 after they were land-bridged late in 1981. The islands were again isolated from the mainland before the 1983 breeding season, and gulls renested on the islands in that year. Since then, recovery of breeding populations has been rapid. In 1979 and 1980, roughly half of the chicks produced on Negit islets were reared on Twain, and by 1985 (3 years after land-bridging) the population had recovered to again contribute chicks at this level[13].

The recovery of populations on Negit since its abandonment in 1979, however, has been far less rapid. In 1986 (7 years after land-bridging), chick production had only reached 4% of the total production in the Negit area, whereas before abandonment the island's colony produced 56% of the chicks in this area.[14] Winkler hypothesizes that gulls may be more reluctant to recolonize large, vegetated islands (such as Negit) because of the greater difficulty in seeing predators, whereas smaller islands, where gulls can scan much or all of the island for approaching predators, may be recolonized quickly.

There is some debate about the factors that may influence habitat suitability to breeding gulls (Fig. B.1). In the NAS Report, it was simply assumed that the amount of island area exposed at different lake levels was a reasonable measure of habitat availability--one area can substitute for another. This clearly is not the case. Despite statements in the NAS Report to the contrary, there is no firm evidence that Paoha Island, which is a large area, has ever supported large numbers of breeding gulls during historic times,[15] perhaps because it is frequently disturbed by coyotes and/or humans,[16] or because the soil base is inappropriate.

Gulls at Mono Lake avoid nesting on level, featureless terrain, preferring areas with a moderate amount of topographic diversity.[17] Winkler has emphasized the importance of thermal stress to the chicks and the relatively greater suitability of shaded habitats (shrubs) and of low areas near water (greater convective cooling). Jehl and Mahoney,[18] on the other hand, have observed that individuals recolonizing Negit have avoided densely vegetated areas, where, according to their experiments, predation risk from owls may be high. Both thermal stress and predation risk are probably important factors, and both may be sporadic in their occurrence. Winkler believes that heat stress was a major contributor to the high chick mortality that occurred in 1981, although in other hot years (e.g., 1985) such mortality did not occur.[19] Predation risk may assume overriding importance in the habitat selection of birds that have previously suffered disruptions by predators, as occurs when islands become land-bridged.

This interplay of factors becomes especially important if lake levels fluctuate so as to bridge and then reisolate islands frequently (i.e. in the lake-level range of 6372 to 6375 feet). Under such conditions, fear of predation may be a major factor that prevents rapid recolonization of large islands containing suitable habitat, such as Negit. For this reason, we believe that, unless lake levels remain high enough that Negit is only rarely land-bridged, smaller islands such as Twain and Java are actually more critical breeding habitat for the gulls, and the level at which they become bridged is therefore more critical than that at which Negit alone is bridged. If all of these islands were to become bridged (at levels < 6372 feet), only 36 acres of islands (other than Paoha) would be available to the birds, and little new island area would become exposed until lake levels approached 6360 feet.[20] At this level, roughly 100 acres of island would be available, mostly as small islets in a near-shore archipelago. Such islets would be of low relief and would be near to one another and to the shore, and would be separated by relatively shallow water. It is unlikely that very much of this acreage would represent suitable habitat to the gulls.

Other environmental factors may also influence the breeding success of the gulls or the suitability of nesting habitat (Fig. B.1). It has been suggested that ticks may play an important role, but the role of ticks in increasing chick mortality remains unclear. There is no firm evidence that ticks alone are an important source of mortality to gull chicks. There is a correlation between high tick density in some years on some islands and high chick mortality there, but chick mortality has also been high in those same years on islands lacking ticks, and some years of high chick mortality have been characterized by low tick abundance. Only controlled experiments can determine whether ticks weaken chicks, making them susceptible to other forms of mortality, or whether instead ticks infest chicks that are already weakened.

Another source of chick mortality could be wave action, which may destroy

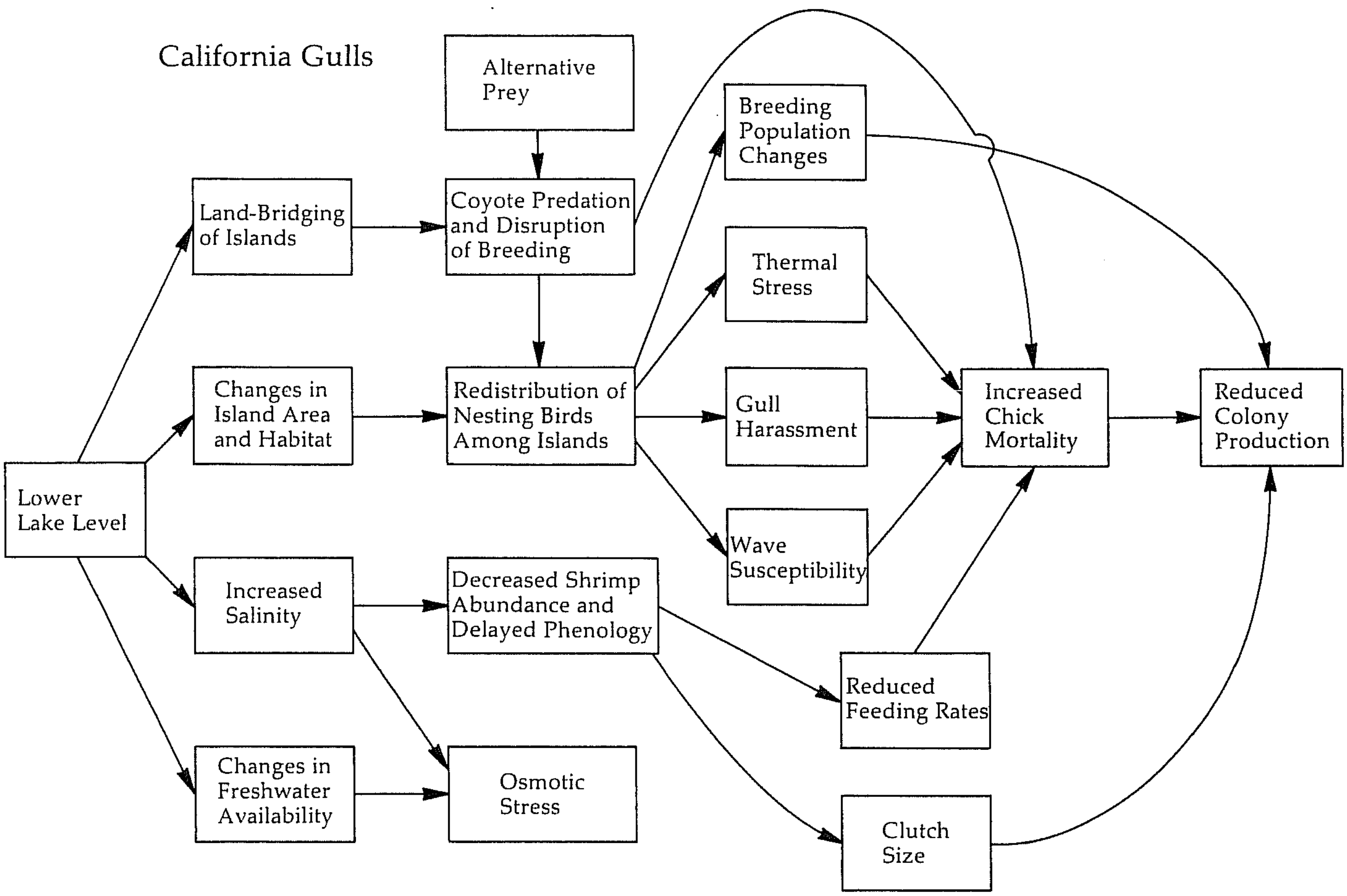

Figure B.1. *Gull Cause and Effect Relationships. This diagram is like Figure 9 in the body of the report. Each arrow indicates a cause and effect relationship between two boxes, with the arrow leading from the cause to the effect. For example, starting at the left, a lower lake level leads to (top to bottom) land-bridging of the islands; changes in island area and habitat; increasing salinity; and changes in freshwater availability.*

some nests that are located close to the waterline during occasional severe storms. It is unlikely that this normally represents a major source of mortality, however, although it might become important if suitable nesting habitat was restricted to low-elevation islets such as occur at lake levels of 6360 feet or below.

Gulls at Mono Lake often congregate about freshwater inflows. It is not clear whether these birds are breeding individuals or nonbreeding adults, and the extent to which gulls are dependent on such freshwater sources in the immediate vicinity of breeding locations is also unclear. The studies of Mahoney and Jehl[21] suggest that gulls at Mono Lake are not normally under osmotic stress, perhaps because they obtain sufficient water from their food and avoid ingesting lake water with their prey.

Whether or not gulls would remain physiologically unstressed should lake salinity increase is not known. The birds also have the capability of using freshwater sources some distance from the lake, although there is no direct evidence that more distant sources could be substituted for local sources should the latter disappear. It appears unlikely, however, that there would be appreciable loss of freshwater sources near the lake with decreases in lake level, at least over the range of levels within which the integrity of the present ecosystem is maintained, especially if the present court-mandated flows in Rush and Lee Vining creeks are maintained.

Jehl[22] has suggested that California gulls rely less on Mono Lake to provide their food than do the other dominant bird species, utilizing instead a variety of more distant sources (e.g. the Mammoth garbage dump). Firm evidence that adults obtain a substantial portion of their food elsewhere, however, is lacking. Gull chicks are fed primarily brine shrimp, although brine flies may be a more important component of their diet than has generally been recognized (Shuford[23] reported that brine flies comprise perhaps 20% of the total prey volume).

Because the gulls breed in late spring, they are dependent on the size and timing of the first-generation shrimp population. Reductions in densities and/or delays in phenology may therefore have major effects on gull chick growth and survival. Because the gulls feed at or just below the lake surface, only a portion of the total shrimp or fly density in the lake is available to them. Lake levels at which food supplies become limiting to other bird species at Mono Lake would also have negative impacts on gull reproduction, and possibly on the survival of, or continued occupancy of the lake by, adult gulls as well.

EARED GREBES

Mono Lake is one of the major migratory stopover areas in the world for eared grebes, supporting about 750,000 individuals on average. The grebes undergo molt and accumulate fat reserves at the lake during their postbreeding migration. Yearly changes in the abundances of grebes at Mono Lake apparently reflect events elsewhere in the range of the species, especially variations in breeding productivity in the same or previous years. Mono Lake may therefore act as a buffer against population declines, by providing a reasonably reliable, superabundant food source and molt/fattening area when conditions elsewhere are poor. During drought years in the breeding areas, for example, grebes arrive at Mono Lake earlier than usual. The lake may therefore be a critical resource in the regional dynamics of this species. Grebes apparently prefer to feed on brine flies, and thus tend to be associated with the near-shore, hard-substrate habitats where fly production and abundance are greatest. Grebes' use of brine shrimp as food increases into late summer and early fall as shrimp numbers increase and as the birds undergo molt and are therefore more confined to forage in areas away from the shoreline where risks of predation are lessened. During the peak of grebe population size in early fall, they consume large quantities of brine shrimp, and some workers[24] believe that grebe depletion of shrimp populations may promote the fall crash in shrimp abundance. The sudden decline in shrimp populations may also be a consequence of a small fall-generation shrimp production.[25] Grebes depart from the lake within 2 weeks of the crash in shrimp abundance, but whether the grebes leave because of the decline in shrimp populations or, alternatively, whether their departure simply coincides with the natural dynamics of the shrimp is not entirely clear.

The major difficulty in assessing the relationship of the population dynamics and movements of grebes (or of any other bird species) to their prey resources is determining the level of prey availability that is actually limiting to the birds. A decline in prey abundance does not necessarily signal feeding difficulties for the birds, as it may reflect a change from one level of prey superabundance to another, lower level of superabundance. Only when prey abundance declines past a threshold at which the supply of food available to the birds no longer is sufficient to meet their energetic demands do negative impacts set in. Unfortunately, we have no firm indication of the level of this threshold for Mono Lake bird populations with respect to either brine shrimp or brine fly abundances. It seems likely that, during recent years, summer and early fall shrimp and fly populations have been superabundant to the birds.

Mono Lake has probably come to attract such large numbers of birds because of its high productivity and stability relative to many other alkaline lakes in the interior west, which make it a predictable source of superabundant food for the birds to use during migratory stopovers and breeding. In other areas where food is less abundant, grebes may delay molt until they reach wintering areas. Jehl[26] is of the opinion that shrimp populations at Mono Lake have been a superabundant food for grebes, even during the historic low lake level in 1981-82, when grebes remained at the lake later into the fall than in any other year of his study. Jehl interprets this prolonged stay as a response to high food levels persisting late into the fall, permitting more birds to remain longer to fatten prior to migration. It is possible, of course, that the birds remained longer that year because food was actually less abundant, and they required a longer period of feeding to accumulate a given amount of fat.

The NAS Panel concluded that grebe populations might "find brine shrimp to be a marginally profitable food on which they could not easily gain weight" at shrimp densities of 20,000 to 25,000 shrimp/square meter and that birds would leave the lake when shrimp densities fall below this level. This conclusion was based on the analyses of Cooper et al.,[24] which Jehl[27] believes was based on "inadmissible techniques." Aside from noting discrepancies in censuses of the birds, Jehl has not stated what these procedural problems are, and he cites the Cooper et al. paper frequently in his own report[26] in support of various statements. Jehl[28] has noted that grebes do not begin feeding on brine shrimp in the spring until shrimp densities exceed 3,000/square meter, and he has concluded that this density also represents a threshold of feeding profitability in the fall, birds leaving the lake when (or shortly after) shrimp densities decline below this level. Jehl also notes that some grebes arrive at the lake and gain weight in the fall after shrimp densities have already fallen to <20,000 shrimp/square meter, which suggests that these densities may not yet be limiting.

Several factors complicate attempts to relate lake-wide shrimp densities to the feeding behavior or movements of the grebes: (a) The shrimp have a patchy distribution, especially in the fall, and lake-wide densities bear an unknown relationship to densities in patches in which the birds feed. (b) A density threshold at which feeding becomes "marginally profitable" need not be the same as a threshold that prompts birds to depart from the lake. Departure may be a function of some combination of daily food intake of individuals and their current fat levels--well-fattened birds are likely to tolerate lower feeding rewards than individuals attempting to build fat reserves for migration. (c) A threshold of shrimp density that leads grebes to begin feeding on shrimp in the spring, when shrimp densities are increasing, may be quite different from a feeding threshold in the fall, when shrimp densities decline (dramatically) below the threshold level. Although supporting data are lacking, it is reasonable to assume that the critical shrimp-density threshold in the fall would be higher than that in the spring. (d) These thresholds apply to the dynamics of shrimp populations increasing to or decreasing from levels of super-abundance to the birds. The effects of maintaining shrimp populations at or near these critical densities (whether they be ca. 3,000/square meter or ca. 20,000/square meter) for long periods during the postbreeding stopover of the grebes would almost certainly be much more severe. It is, therefore, incorrect to infer that shrimp densities that instigate foraging in the spring or are associated with departure in the fall would be sufficient to support the grebe population for weeks or months.

Overall, we conclude that grebes may find foraging on shrimp difficult at lake-wide shrimp densities somewhat less than 25,000/square meter and somewhat greater than 3,000/square meter and that densities in this range may be associated with the timing of the fall departure of birds from the lake. Because this shrimp-density level is unknown, it would not be wise, ecologically, to permit the lake to drop to levels at which salinity effects reduce shrimp densities to values close to 25,000/square meter.

The ability or inclination of grebes using Mono Lake as a staging area to shift to other lakes opportunistically or to interrupt or delay their molt is unknown. The NAS Panel suggested that, should conditions at Mono Lake deteriorate sufficiently, birds might be able to shorten their stay at Mono Lake or interrupt or delay molt with little change in mortality rates and that the population would be redistributed among other stopover sites. These conclusions have little empirical support and must be regarded at this point as speculations.[29] The facts that grebe populations at Great Salt Lake have declined without any associated increase at Mono Lake and that birds leaving Mono Lake in the fall apparently do not appear at the wintering areas until several weeks later argue that the birds may indeed be using other, unknown, stopover areas.

It is not clear that other saline or alkaline lakes in the interior west have either the productivity or the long-term stability (prior to water diversions) of Mono Lake and, therefore, could absorb the population that would be displaced should ecological conditions at Mono Lake become unsuitable. The birds that use staging areas such as Mono Lake or Great Salt Lake engage in a complex and integrated series of behavioral and physiological actions associated with molt and fattening, suggesting that the use of such lakes is of long-term importance to them.

WILSON'S PHALAROPES

Mono Lake is also a major molt/fattening staging area for Wilson's phalaropes, although they use the lake earlier in the year than do the grebes. According to Jehl,[30] perhaps 80,000 Wilson's phalaropes stop at the lake, on average (not 100,000-125,000, as reported by the NAS Panel). This represents about 10% of the world population of adults. The use of the lake for premigratory fattening may be more critical to the birds than its use as a molt area. Jehl[30] argues that the birds at Mono Lake accumulate fat reserves sufficient to migrate to the South American wintering grounds in a single great-circle flight. Any disruption in their ability to accumulate sufficient fat reserves at Mono Lake would, therefore, lead to a fundamental alteration in their migratory patterns, with associated changes in mortality risks. Molt, on the other hand, can be interrupted or delayed until birds reach the wintering grounds, and males frequently undertake migration in a condition of partial molt.[31]

Wilson's phalaropes feed almost entirely on brine flies and brine shrimp at Mono Lake. Early analyses of diet[32] indicated a heavy reliance on brine flies, and this information was used by the NAS Panel to predict the lake levels at which changes in the food base might begin to have adverse effects on the phalaropes (6370 feet). Quite apart from the uncertainties in determining the relationship between food abundance and limitation of the birds (discussed above), Jehl's more recent analyses of diets[30] indicate that female Wilson's phalaropes consume brine shrimp throughout their stay at the lake and that both males and females shift to feed almost entirely on shrimp during the final 2 weeks of their stay at the lake, when they become too heavy to capture the more agile brine flies. Thus, although brine flies are important (and probably preferred) prey, brine shrimp also figure importantly in the diet. Projections of the effects of decreasing food supplies on the birds must therefore include both flies and shrimp.

It has been suggested[33] that Jehl's data, taken when the lake was at its low level in 1981-82, indicated no reduction in phalarope abundance at Mono Lake, and that the conclusion of the NAS Panel that a lake level of 6360-6370 feet is critical to the birds is therefore unwarranted. Jehl's data[30], however, show that numbers of Wilson's phalaropes at Mono Lake were normal in 1981 but substantially lower in 1982 and, especially, 1983; departure was also earlier in 1982.[a] Jehl attributes the low phalarope (and grebe) numbers in 1983 to the high runoff from previous wet winters, which created suitable habitat in other playas in the interior west, attracting birds away from Mono Lake (it is also possible that phalaropes may have experienced greater than normal winter mortality associated with the consequences of the 1982 El Ninõ).

If site fidelity is important in the use of staging areas by Wilson's phalaropes, however, it seems unlikely that the birds would abandon Mono Lake so readily, especially given its normally high productivity relative to other lakes in the region. An alternative hypothesis is that food at Mono Lake was limiting to the birds in 1981-82 and that birds associated with the lake either suffered greater mortality during migration or on the wintering areas or chose not to return. Overall, however, it appears likely that Wilson's phalaropes might begin to experience food-limitation effects at roughly the same levels that grebes would be affected.

Wilson's phalaropes use fresh water at Mono Lake, especially during the period of rapid fat accumulation when they are hyperphagic and apparently ingest large quantities of lake water with their food. If lake salinity were to increase, this dependence on fresh water would presumably become greater.

RED-NECKED PHALAROPES

Red-necked (northern) phalaropes use Mono Lake only as a short-term migratory stopover location. Jehl[30] estimates that, during August and early September, perhaps 60,000 individuals, on average, pass through the lake (the NAS report incorrectly reported lower estimates). Numbers were low in 1983, a drop that Jehl attributed to winter mortality associated with El Ninõ. The Mono Lake population represents perhaps 2-3% of the world population of this species. Adults and juveniles are equally common at Mono Lake. As in Wilson's phalaropes, adult females are the first to migrate, followed by adult males and then by juveniles.

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[a]Note that the numbers provided in Appendix I of Jehl's report do not match the values shown in his Figure 2L.

Individuals remain at the lake for only a few days, during which they feed predominately (although not entirely) on brine flies at or near shore. They regularly use freshwater sources.

Because of the relatively short duration of their stay at Mono Lake and the apparent suitability of a large number of other locations in the interior west, Mono Lake is probably not a critical resource to the species as a whole. On a more restricted regional scale, however, Mono Lake represents an important stopover site.

SNOWY PLOVERS

Considered at a statewide scale, Mono Lake is an important breeding area for snowy plovers. The breeding population is estimated at roughly 380 individuals, which constitutes perhaps 11% of the California population. Because this species has a specialized association with salt flats or the edges of saline or alkaline lakes, it is in a degree of jeopardy everywhere in its interior range, and the Mono Lake population is therefore of broader significance. Populations at Mono Lake have increased with declines in lake levels, as more suitable playa habitat has been exposed on the eastern shore of the lake.

Plovers require relatively broad and unbroken expanses of flat crusted habitat; they feed on brine flies and a variety of other invertebrates associated with the shoreline and with freshwater seeps or springs, which they also use as sources of freshwater. Further declines in lake level would probably benefit this species, although if feeding and watering areas were to become too widely separated from breeding areas it might be difficult for the birds to take chicks to these areas after hatching. More importantly, if the lake were to drop to levels at which incision of the playa expanses becomes widespread (<6368 feet), breeding habitat would be disrupted, increasing both the difficulty of chick movement to feeding areas and the risk of predation.

CASPIAN TERNS

Although Caspian terns are conspicuous elements of the Mono Lake avifauna and increase the attractiveness of the lake to bird-watchers, the breeding population is quite small and declining. The colony clearly represents a short-term expansion from major breeding colonies elsewhere. The species is not critically dependent on Mono Lake, and it does not figure importantly in the ecology of the lake ecosystem.

REFERENCES AND NOTES APPENDICES A AND B

1. Dana, G.L. and P.H. Lenz, 1986, "Effects of Increasing Salinity on an Artemia Population from Mono Lake, California." Oecologia 68: 428-436.

2. Herbst, as part of the Melack report to the CORI panel.

3. This has been shown in the following: Melack, J.M., Y. Liang and P.H. Lenz, 1982, "Ecological Responses of the Plankton of Mono Lake to Increased Salinity." Abstract, Mono Lake Symposium, Santa Barbara, California, May 5-7, 1982; Melack, J.M., P.H. Lenz and S.D. Cooper, 1985, "The Ecology of Mono Lake." National Geographic Society Research Report 1979 Projects; and Chapman, D.J. 1982, "Investigations on the Salinity Tolerance of a Diatom and Green Algae Isolated from Mono Lake." Abstract, Mono Lake Symposium, Santa Barbara, California, May 5-7, 1982.

4. Lenz, P., "Artemia Population Dynamics in Mono Lake at Increasing Salinities." (Part of the Melack report to the CORI panel).

5. S. Stine. Report to the CORI panel, reference cited previously.

6. Herbst, as part of the Melack report to the CORI panel.

7. Jehl, pers. comm.

8. Jehl, J.R., D.E. Babb, and D.M. Power, 1984. "History of the California Gull Colony at Mono Lake." Colonial Waterbirds 7:94-104.

9. Winkler, D.W., and W.D. Shuford (in press). "Changes in the Numbers and Locations of California Gulls Nesting at Mono Lake, California, in the Period 1863-1986." Condor.

10. National Academy of Sciences, "The Mono Basin Ecosystem: Effects of Changing Lake Level," National Academy Press, Washington, D.C. 272 pp.

11. Shuford, pers. comm.

12. Winkler, pers. comm.

13. Shuford, Winkler, pers. comm.

14. Winkler, pers. comm.

15. Winkler, Shuford, pers. comm.

16. Jehl, pers. comm.

17. Jehl, pers. comm.

18. Jehl, J.R. and S.A. Mahoney (in press). "The Roles of Thermal Environment and Predation in Habitat Choice in the California Gull (Larus californicus)." Condor.

19. Winkler, Report to the CORI Panel.

20. Stine, S., 1987, "Geomorphic and Geohydrographic Aspects of the Mono Lake Controversy", report to the CORI panel.

21. Mahoney, S.A. and J.R. Jehl, 1985, "Physiological Ecology and Salt Loading of California Gulls at an Alkaline, Hypersaline Lake." Physiol. Aool. 58: 553-563.

22. Jehl, pers. comm.

23. Shuford, pers. comm.

24. Cooper, S.D., D.W. Winkler, and P.H. Lenz, 1984, "The Effect of Grebe Predators on a Brine Shrimp Population." J. Anim. Eol. 53: 51-64.

25. Lenz, in Melack report to CORI.

26. Jehl, J.R., Jr., 1987, "Caspian Terns, Phalaropes, and Grebes of Mono Lake," report to the CORI panel; and pers. comm.

27. Jehl, pers. comm.

28. Jehl, report to the CORI panel, work cited above.

29. Jehl, Winkler, pers. comm.

30. Jehl report to the CORI panel, work cited above.

31. Jehl, J.R., Jr., 1987, "Moult and Moult Migration in a Transequatorially Migrating Shorebird: Wilson's Phalarope." Ornis Scandinavica 18: 173-178.

32. Winkler, D.W. (ed.), 1977, An Ecological Study of Mono Lake, California." Institute of Ecology Pub. No. 12. Davis, CA, University of California, Institute of Ecology.

33. Lund letter to Patten.

APPENDIX C: SUMMARIES OF THE SUBCONTRACTORS' REPORTS TO THE CORI PANEL:

1. GEOMORPHIC AND GEOHYDROGRAPHIC ASPECTS OF MONO LAKE
Report by Dr. Scott Stine
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2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

A. Photosynthetic Activity of Phytoplankton and its Relation to Environmental Factors in Hypersaline Mono Lake, California
Report by Robert Jellison and John M. Melack
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B. Nearshore and Pelagic Abundances of _Artemia monica_ In Mono Lake, California
Report by F.P. Conte, R.S. Jellison, and G.L. Starret
Summary by Dr. Joseph Shapiro . . . . C. 5

C. Scenarios for the Impact of Changing Lake Levels and Salinity at Mono Lake: Benthic Ecology and the Alkali Fly, _Ephydra hians_ Say (Diptera: Ephydridae)
Report by David B. Herbst
Summary by Dr. Joseph Shapiro . . . . C. 6

D. Ammonium Dynamics in Mono Lake: An Analysis of Vertical Flux, Brine Shrimp Excretion, and Nutrient Enrichment Experiments
Report by Robert S. Jellison
Summary by Dr. Joseph Shapiro . . . . C. 7

E. In Situ Hatching of _Artemia monica_ Cysts in Hypersaline Mono Lake, California
Report by Gayle L. Dana, Christopher J. Foley, Gwen L. Starrett, William M. Perry, and John M. Melack
Summary by Dr. Joseph Shapiro . . . . C. 8

F. _Artemia_ Population Dynamics in Mono Lake at Increasing Salinities
Report by Petra H. Lenz
Summary by Dr. Joseph Shapiro . . . . C. 9

G. Summary of Responses of Salinity Increase by the Biota of Mono Lake
Report by John Melack, Petra Lenz, Gayle Dana, and David Herbst
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3. CASPIAN TERNS, PHALAROPES, AND GREBES OF MONO LAKE
Report by Joseph R. Jehl, Jr.
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4. CALIFORNIA GULL AND SNOWY PLOVER POPULATIONS OF MONO LAKE
Report by Dr. David W. Winkler
Summary by Dr. John Wiens C.13

5. AIR QUALITY INVESTIGATION AT MONO LAKE
Report by Thomas A. Cahill and Thomas E. Gill
Summary by Dr. Lorne Everett C.15

APPENDIX C: SUMMARY OF SUBCONTRACTOR REPORTS

1. GEOMORPHIC AND GEOHYDROGRAPHIC ASPECTS OF MONO LAKE

Report by Dr. Scott Stine

Summary by Dr. Lorne Everett

Dr. Stine's report examines the geomorphic and hydrographic changes that have occurred at Mono Lake due to the diversion of water by the city of Los Angeles, as well as the changes that can be expected in the future if diversions continue unabated. Highlights are as follows:

Mono Lake is hydrologically "closed," and is in a perpetual state of adjustment to changes in the rate of inflow and evaporation. The behavior of the lake since AD 1857 has been documented from historic and cartographic materials. The "historic high stand" of the lake (6428 feet) occurred in July, 1919, while the "historic low stand" (6372 feet) was recorded in January of 1982. These elevations correspond to lake volumes of 4.9 X 10^6 acre-feet, and 2.1 X 10^6 acre-feet, respectively. Since 1982 the lake has risen about 9 feet in response to abnormally wet weather. It currently lies at an elevation of about 6380 feet and holds approximately 2.45 X 10^6 acre-feet of water with a salinity of about 88 g/l.

The decline in lake level that began in the 1940's is clearly an artificial phenomenon. If water diversions had not taken place, the lake surface in January 1982 would have stood at roughly 6,430 feet--nearly 60 feet higher than the elevation actually recorded in that month.

During the past 4,000 years Mono Lake has been as high as 6499 feet and as low as 6368 feet. Taking into account the major morphometric changes that have occurred since the time of the prehistoric high and low stands, these lake levels correspond to lake volumes of roughly 10.1 X 10^6 acre-feet and 2.3 X 10^6 acre-feet, respectively. It can thus be seen that at the time of the artificially-induced historic low stand in 1982 Mono Lake contained less water (and was consequently more saline) than at any time in at least 4,000 years.

The islands of Mono Lake are the product of intrusive and extrusive volcanic activity that occurred episodically over the past two millennia. They can be divided into two groups: the Negit Archipelago (made up of durable volcanic rocks); and Paoha Island and the Paoha islets (composed primarily of soft, easily erodible lake sediments). As the lake shrinks, these islands swell in size, ultimately becoming connected to the mainland by way of a landbridge. Historically island area has varied dramatically, and three islands--Negit, Twain, and Java--have become peninsular. Peninsularization of these islands occurred on at least one occasion in the prehistoric past as well.

The rise in lake level that occurred between 1982 and 1986 resulted in the loss by erosion of large portions of the Paoha islets. Further loss of island habitat can be expected if the lake rises above the 1986 lake level.

If the year-to-year sequence of hydroclimatic conditions that characterized the period 1937-1983 was to repeat itself indefinitely, and LADWP continued to exercise its full diversion capacity, Mono Lake, in approximately one century, would reach a state of "dynamic equilibrium," fluctuating between elevations of approximately 6330 feet (corresponding to a lake volume of about 0.89 X 10^6 acre-feet and a salinity of about 250 g/l) and 6347 feet (corresponding to a lake volume of about 0.89 X 10^6 acre-feet and a salinity of about 170 g/l).

In the course of the decline to "dynamic equilibrium," numerous islands would become peninsular. These peninsularization events would include the following: Negit at about 6376 feet; Twain and Java at about 6373 feet; Coyote at about 6368 feet; Norway, Geographic, Tahiti, Krakatoa, Little Krakatoa, Comma, Saddle, and Anderson at 6357 feet.

The near-shore portion of the floor of Mono Lake typically comprises a gently-inclined platform. Around much of the lakeshore this platform steepens markedly at an elevation of about 6368 feet (about 12 feet below the present-day lake surface), forming a topographic "nick point" (an abrupt down-slope increase in the gradient of the land). Should the lake drop below the level of the nick point the streams and rills that drain the shorelands will incise, a phenomenon that could lead to dewatering of the freshwater marshes that lie adjacent to the lake margin.

Tufa deposits (precipitates of calcium carbonate) at Mono Lake take the form of towers, beach rock, boulder rinds, and castellated sand structures (sand tufa). Hundreds of tufa towers at the "South Tufa Grove" were undercut and toppled by waves during the lake transgression of 1982-1986. Should the lake rise above the 1986 level it can be expected that more of the towers at South Tufa will be lost to wave erosion. Any rise that occurs after the lake drops to below 6368 feet (the elevation of the nick point) will result in the destruction of many more tufa towers; in such a case toppling would not be limited to the South Tufa Grove, but would occur at the other major concentrations of towers as well.

Submerged tufa deposits, as well as the submerged pumice blocks that litter the shorelands at elevations below about 6390 feet, comprise an environment critical to the brine fly. At present-day lake level (about 6380 feet) there exists approximately 6800 acres of this "hard-substrate environment." A drop in lake level to 6370 feet decreases the acreage of hard-substrate environment by approximately 60%; at a lake level of 6360 feet the acreage of hard-substrate environment is just 20% of the present-day value.

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

A. Photosynthetic Activity of Phytoplankton and its Relation to Environmental Factors in Hypersaline Mono Lake, California

Report by Robert Jellison and John M. Melack

Summary by Dr. Joseph Shapiro

The photosynthetic activity (primary production) of phytoplankton algae in hypersaline Mono Lake, California was measured on 183 samples over the three year period, 1983-1985. Annual estimates of total primary production were 340-540 grams carbon/m^2/yr. Production was two to three times higher during the spring of 1983 when the lake became density-stratified (meromictic) from high inflows of fresh water, than in the springs of 1984 and 1985, due to a greater abundance of algae in 1983. While maximal rates of production per unit algae followed water temperatures, and varied over 40-fold over the year, total primary production varied less since periods of high production per unit algae occurred when algal mass was low. Sixty-eight percent of the seasonal variation in the maximal rates was explained by effects of temperature (53%), chlorophyll a (12%), and the carbon:chlorophyll a ratio (3%). Salinity was not considered as it changed little during the period. There was no correlation of rates of production with ambient levels of inorganic nitrogen. The dependence of maximal rates of production on seasonal temperatures appeared to be much greater than that determined using individual samples incubated in the laboratory at several different temperatures. This indicates that production is limited by more than low temperatures in the spring. Equations including only temperature, chlorophyll and depth were sufficient to predict patterns of seasonal and year-to-year variation in total primary productivity. A change in salinity or the disappearance of the meromixis would make it necessary to include measures of nitrogen recycling into a predictive model.

Although there is a deep water region high in chlorophyll, low light levels restrict primary production there to about 5% of the total. Rates of photosynthesis in Mono Lake are comparable to those of other highly saline lakes in the Great Basin.

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

B. Nearshore and Pelagic Abundances of *Artemia monica* in Mono Lake, California

Report by F.P. Conte, R. S. Jellison, and G. L. Starrett

Summary by Dr. Joseph Shapiro

The spatial distribution and abundance of the brine shrimp, *Artemia monica*, in Mono Lake, California, were determined during 1982 and 1983. Peak abundances of shrimp occur in midsummer and reach densities of 15-17 individuals per liter in the nearshore regions and 6-8 individuals per liter in the offshore region. The brine shrimp were nonuniformly distributed both vertically and horizontally. Variation in shrimp abundance among stations within the nearshore region was similar to that found in the offshore region. On two of the nine dates, nearshore densities were 3 to 4 times greater than those in the offshore zone, and, on the average, the brine shrimp appear to be slightly more abundant in the nearshore region. However, including nearshore abundances in lakewide estimates will usually result in a change of less than 10%.

In 1982, the shrimp were more concentrated near the bottom of the upper warm layer (epilimnion) than they were during the summer of 1983. Whether this difference resulted from their use of the deep chlorophyll maximum during 1982, or from the deeper mixed layer in 1983, combined with colder deep temperatures and lower oxygen concentrations, is unclear.

SUMMARY OF SUBCONTRACTOR REPORTS

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

C. Scenarios for the Impact of Changing Lake Levels and Salinity at Mono Lake: Benthic Ecology and the Alkali Fly, Ephydra hians Say (Diptera: Ephydridae)

Report by David B. Herbst

Summary by Dr. Joseph Shapiro

The potential impacts of water diversion on the most common animal of the benthic (bottom) community, the alkali fly Ephydra hians, are discussed here with regard to (1) declining lake level, and (2) elevated salinity.

Lowering of lake levels will result in the elimination of benthic habitat. A decline of 3 meters would result in a loss of 16% of the presently submerged lake bottom, but approximately 60% of the total benthic area would remain at stabilization. However, a greater relative abundance of larvae and pupae on tufa rock than on sand suggests that the availability of specific substrates may be a more important habitat consideration.

Increased salinity has both direct and indirect influences on the alkali fly. Experimental studies show the following effects: (1) Decreased rates of larval survival (first instars are less salt tolerant than third instars), slower larval growth rates, prolonged development, and a smaller size at maturity. (2) Reductions of adult emergence success and lipid stores, poor resistance to starvation, and decreased reproductive success. (3) Inhibition of algal growth in the filamentous green alga Ctenocladus circinnatus at salinities from 100 to 150 g/l, where it dies.

Improved algal food supply may mitigate the debilitating effects of increased salinity somewhat, but reduced food supply creates the same hindrance to larval survival and development (i.e. at 25% time allotted for feeding, larvae and pupae all die by 25 days!). Unpublished data by Thomas are cited to the effect that, in addition to Ctenocladus, the diatom alga Nitzschia decreases growth as salinity increases.

These studies identify the lethal limit for survival of alkali fly larvae as 150 g/l, the highest salinity examined that first instars were able to live in. However, sublethal inhibitory effects on survival and development of larvae, and their algal food resources, exist for any increase in salinity beyond present values.

Continued water diversions appear likely to result in decreases both in benthic habitat availability and productivity for the alkali fly. However, predictive models of the quantitative extent of these changes await a more complete description of the benthic distribution of this insect, and studies of the influence of varied energy budgets on population demographics.

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

D. Ammonium Dynamics in Mono Lake: An Analysis of Vertical Flux, Brine Shrimp Excretion, and Nutrient Enrichment Experiments

Report by Robert S. Jellison

Summary by Dr. Joseph Shapiro

Because phosphorus is abundant in the lake, and because the lake seems to be limited by nitrogen, an analysis of nitrogen recycling by vertical-physical processes and by excretion by brine shrimp was conducted. Also, experiments to study response of algae to enrichment with ammonium nitrogen were done. Of the latter, twenty were on non-acclimated algae, and twenty-two were on algae acclimated to the higher levels of ammonium in the experiments. All experiments, particularly those on samples taken earlier in the year, showed positive responses to ammonium additions.

As shrimp abundance increases, algae decreases and higher concentrations of chlorophyll are found only in the deep maximum layer. Vertical ammonium flux was determined at three depths: the bottom of the mixed layer where the temperature gradient exceeds 1 degree centigrade per meter; the grazed layer where chlorophyll was reduced to 10 micrograms per liter; and the nutrient boundary layer where ammonium had accumulated to a concentration of 10 micromolar.

The method used was the flux-gradient heat method. In summer, fluxes at the nutrient boundary were relatively large compared to those at the mixed and grazed layers. This suggests a sink between the nutrient boundary and the other layers (probably the chlorophyll maximum). Thus regeneration from below in summer may be of limited value to algae in the upper part of the lake. However, experiments with brine shrimp show that the shrimp do excrete enough nitrogen to drive the primary production observed in this region.

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

E. In Situ Hatching of Artemia monica Cysts in Hypersaline Mono Lake, California

Report by Gayle L. Dana, Christopher J. Foley, Gwen L. Starrett, William M. Perry, and John M. Melack

Summary by Dr. Joseph Shapiro

Two emergence trap designs were tested in Mono Lake, California, to measure in situ hatching of Artemia monica cysts on the lake bottom. One design incorporated a removable sample bottle; the other had a catch tube which was pumped from the surface. Both traps rested on the bottom and had a narrow gap between the collecting funnel and bottom flange to allow the chemical conditions within the trap to be similar to those outside. This gap was open during April and May but, because some animals entered from outside the area enclosed by the trap, the gap was covered with 400 um or 800 um screen during June and July. The two trap types without screens sampled a station in oxygenated water 7 m deep similarly in April and May 1985. Mean daily hatching rates from April to May 1985 ranged from 720 to 25,340 shrimp m^2/day. In contrast, mean daily hatching rates during the same period at a station in water devoid of oxygen 21 m deep were from 3 to 138 shrimp m^2/day. June and July hatching rates in the shallow station were lower than in the spring, usually fewer than 1,000 shrimp m^2/day.

The authors cite unpublished data indicating that salinities of 45 to 90 g/l result in 80 to 90% hatching success of the cysts. They also cite Dana and Lenz as showing that, from 90 to 130 g/l, hatching is delayed and reduced, and that above 130 g/l, it is prevented completely. Drinkwater is referred to in a personal communication as showing that salinities of 140 to 160 g/l affect hydration of the cysts and thus prevent the hatching mechanism from occurring.

SUMMARY OF SUBCONTRACTOR REPORTS

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

F. Artemia Population Dynamics in Mono Lake at Increasing Salinities

Report by Petra H. Lenz

Summary by Dr. Joseph Shapiro

This paper continues past the work of Dana and Lenz in the construction of a model to do the following:

(1) assess current understanding of the Artemia population dynamics in Mono Lake;

(2) determine how the population will change as salinity increases; and

(3) determine at what salinity Artemia will disappear. The model is based on field observations and on data presented by Dana and Lenz from the laboratory.

The model simulates present conditions reasonably well and predicts that annual cyst production will decline from 8 million per square meter, at present, to zero at 150 g/l salinity. This is predicted to occur despite an initial compensating increase in peak Artemia densities in the second generation. This increase is predicted to decline at salinities greater than 120 to 130 g/l, following which there is a more rapid decline. The suggestion of Artemia disappearance at a salinity of 150 g/l is corroborated.

SUMMARY OF SUBCONTRACTOR REPORTS

2. REPORTS CONCERNING LIMNOLOGICAL CONDITIONS AT MONO LAKE

G. Summary of Responses of Salinity Increase by the Biota of Mono Lake

Report by John Melack, Petra Lenz, Gayle Dana, David Herbst

Comments by Dr. Joseph Shapiro

This is a particularly important paper. The authors, in a series of extremely careful studies in the laboratory, have shown that the Artemia is strongly affected by increasing salinities. For example, percent survival declined beginning at 133 g/l salinity, decreasing sharply at 159 g/l and 179 g/l. Growth rates for the first 26 days are affected systematically at all salinities beyond 76 g/l, but especially at 159 and 179 g/l. Growth rates from days 30 to 64 behave similarly.

With regard to reproduction, increasing salinities at all levels slow the first brood of the females, but especially between 133 and 159 g/l salinity. That is, there is delay in reproduction. Furthermore, the brood size decreases with increasing salinity and there is a shift toward a higher percent of ovoviviparity with increased salinity. This may result from a decrease in the energy required over cyst production, but could result in fewer cysts being present for the next year.

Some of the greatest effects are on hatching which decreases with salinity, especially beyond 118 g/l to a level of zero at 159 g/l. At 133 g/l, only about 25% of the cysts hatch.

The suggestion is made that timing delays in reproduction and hatching may be exacerbated by low spring temperatures and therefore may be important in the habits of the birds that prey on the Artemia.

The authors have calculated what they call a reproductive potential, taking into account losses at all stages of growth, reproduction and hatching, and find that it decreases at all salinities, reaching zero at 150 g/l.

3. CASPIAN TERNS, PHALAROPES, AND GREBES OF MONO LAKE

Report by Joseph R. Jehl, Jr.

Summary by Dr. John Wiens

Over 100 species of waterbirds have been recorded at Mono Lake, but few of these are able to tolerate the high salinity of the lake and therefore stay there only briefly. Of the species that do cope with the lake conditions, eared grebes, Wilson's phalaropes, red-necked (northern) phalaropes, and Caspian terns are of particular interest.

EARED GREBES

Mono Lake is one of four known large concentration areas for eared grebes in the world. During their fall stopover at the lake, the grebe population reaches ca. 750,000 birds, roughly 30% of the North American population of this species (and a much larger percentage of the western population). At its peak, the grebe population accounts for 99% of the avian biomass present at Mono Lake. Census error is estimated not to exceed 20% when the population is less than 100,000 birds or 30% during periods of peak abundance. Among summering birds, yearlings predominate and males are roughly twice as abundant as females. During fall, juveniles comprise 10-40% of the population; yearly variations are apparently associated with variations in the productivity of breeding populations elsewhere.

The birds use Mono Lake primarily as migratory stopover site where they undergo molt and accumulate fat and energy reserves required to complete their migratory movements. During this period, individuals are flightless for 35-40 days, their breast muscles atrophy, and they accumulate fat. Body weight may increase from 280 g to more than 600 g, peaking in October. When brine shrimp abundance crashes in late fall, the birds fast, drawing from these reserves to build breast musculature before migration. They depart at weights somewhat above 400 g.

The phenology of the Mono Lake population is determined by both regional and local events. During drought years in breeding areas, grebes arrive at the lake earlier than in nondrought years, while in years of high brine shrimp abundance at the lake the birds may remain there later in the fall than usual. If birds remain at the lake late into the fall they may experience a greater mortality risk because they are more likely to encounter early winter storms during migration. Otherwise, mortality at the lake appears to be slight, averaging perhaps 0.5% of the fall population.

Eared grebes feed both on benthic substrates and in the water column, especially near the surface. Their activity is concentrated in nearshore habitats where they feed upon their preferred prey, brine fly adults, larvae, and pupae, that are associated with hard substrates (e.g. tufa shoals). Their distribution therefore reflects the patchy distribution of both their brine fly and brine shrimp prey, although during the molt period birds stay well away from shores to avoid predators. When population numbers peak in October, the birds may consume 60-100 tons of brine shrimp per day. Grebes generally do not feed on brine shrimp when shrimp densities are less than 3,000-4,000 m^{-2}, as in spring or late fall. The birds do not visit fresh-water sources and avoid ingesting lake water with their food, which satisfies their water demands. There are no indications that grebes at Mono Lake suffer osmotic stress.

Mono Lake is an important staging area, but its linkage with other staging areas or migratory destinations in western North America is undetermined. Recent dramatic reductions in grebe abundance at Great Salt Lake are not accompanied by increases in the numbers of birds using Mono Lake, nor have these reductions led to a population-wide decline in abundance.

WILSON'S PHALAROPES

Mono Lake is one of the largest concentration areas of Wilson's phalaropes in the world, peak numbers reaching 50,000-65,000 and a total of perhaps 65,000-78,000 individuals moving through the lake. Adult females comprise roughly 70% of the flock. The Mono Lake population represents approximately 5% of the world population of the species, although its importance is greater to adults (10% of the world population), especially females (14%).

Adults use the lake as a stopover site for molting and premigratory fattening; juveniles do not use the lake in this manner, and spend only a short time at the lake. The population peaks in late July and most birds depart by late August or early September. Individual adults remain at the lake for 25-40 days, during which they molt and nearly double their body weight. They prefer brine flies, although adult females feed primarily on brine shrimp in open water, while adult males feed to a greater extent on brine flies on or near shore; juveniles feed almost entirely on brine flies. Use of shrimp as prey increases toward the end of the birds' stay at the lake. They generally do not require fresh water, although during the period of rapid fattening they become hyperphagic and may ingest considerable lake water along with their prey. At this time, flocks aggregate about fresh-water sources, which may be critical to them.

RED-NECKED PHALAROPES

Unlike Wilson's phalaropes, rednecked (northern) phalaropes do not use Mono Lake as a staging/ molt/fattening site, but only as a short-term migratory stopover location. The peak of migration occurs in August and early September, when ca. 52,000-65,000 individuals pass through. This represents roughly 2-3% of the New World population of this species. Adults and juveniles are equally common, although adult females are the first to migrate, followed by adult males and then by juveniles. Individuals remain at the lake for only a few days, during which they feed on brine flies on or near shore.

CASPIAN TERNS

A small colony of Caspian terns has bred on small sandy islands in Mono Lake during recent years. The colony has never been large and, like many interior colonies in western North America, has recently been declining. At Mono Lake they nest amidst California gulls, which harass them and prey on tern chicks. The species is clearly peripheral in its occurrence at Mono Lake.

4. CALIFORNIA GULL AND SNOWY PLOVER POPULATIONS OF MONO LAKE

Report by Dr. David W. Winkler

Summary by Dr. John Wiens

California gulls are widespread at freshwater and saline or alkaline lakes in the Great Basin, although the breeding colony at Mono Lake is one of the largest. The population of adult gulls at the lake has increased during this century from roughly 3,000 to ca. 50,000 birds. During the past decade, the population has remained relatively stable, although there are some indications that populations in the mid-1970's may have been somewhat larger than at present. Population estimates vary among years, but these variations are well within the limits of census error. A variety of survey techniques have been employed in the past, and these have produced remarkably similar estimates of breeding populations and reproductive output. Winkler recommends censuses of the population early in the breeding season as being most reliable and estimates of total fledging production as the most relevant measure of population productivity.

Gull production of young varies substantially among years. In 1981, only ca. 1,600 chicks were fledged; in 1982 and 1984, roughly 4,000 chicks were produced; and in 1976 and 1986 over 25,000 young fledged. Breeding success during this time varied from ca. 3% to ca. 50-60%. Several factors may contribute to these variations in production. To begin with, Mono Lake gulls have an abnormally small clutch size (2 eggs per female), which may be related to the meager food supply available to females during egg formation early in the spring. This sets an upper limit on population production that is lower than that in most gull populations. Predators are probably the major source of chick mortality, at least in some years. At Mono Lake, raptors (eagles, owls) may have slight effects, especially on gulls nesting in dense shrubbery. Coyotes are major predators when they have access to breeding islands. This occurred during 1979, when a land bridge to Negit was created by low lake levels, and in 1982, when Twain and Java islets were land-bridged. When coyotes gain access to breeding colonies they not only prey upon young but disrupt breeding activities, leading to colony abandonment. These displaced birds may, in turn, harrass other breeding gulls, exacerbating the effects on overall productivity during that year. The disruption of the Negit colony involved ca. 65% of the total Mono Lake population and was associated with a chick production that was 59% lower than that in the previous year. The disruption of the Twain and Java colonies affected perhaps 30% of the previous year's breeding population. Chick production was actually 143% of the 1981 production (which was the lowest observed during studies at Mono Lake), but was only 30% of 1983 production. The reproductive failure during 1981 was associated with delayed phenological development of brine shrimp populations and with unusually high temperatures during the chick period, and both food scarcity and thermal stress may have contributed to the low production in that year. Chicks are sensitive to high temperatures and shaded breeding sites would therefore appear to be more suitable than exposed locations. Little such habitat is now available on Mono Lake islands, especially when lake levels are low. Other sources of chick mortality may include wave action on low islands and tick parasitism, but the importance of these factors is unclear. There is some correlative support for an association between tick infestations and chick mortality, but there is also other contrary evidence. In particular, tick levels were low in 1981, when chick mortality was greatest.

From the limited data available, it appears that adult survival in the Mono Lake population may be on the order of 0.80 per year, while fledged young realize a 0.60 annual survival. Recruitment averages 0.33 young per bird per year. Life-table analyses based on these data indicate that net annual population growth lies between 0.66 and 0.91. Because these values are less than 1.0, the recruitment and survivorship of the Mono Lake gull population are not sufficient for self-maintenance, suggesting that the current coarse stability in total population size may be maintained by immigration of gulls produced elsewhere.

Gulls at Mono Lake feed on a variety of prey, but because this variety is limited, brine shrimp are critically important, especially to the chicks. The gull chicks are fed primarily brine shrimp during June and July, and they are therefore dependent on both the size and the timing of the first generation shrimp population. Adult gulls use fresh water sources at the lake margins, although it is not clear that the gulls are osmotically dependent on these water sources.

SNOWY PLOVERS

The snowy plover population at Mono Lake in 1978 consisted of ca. 380 individuals, making it the second largest breeding aggregation in the state, containing ca. 11% of the total California population of this species. Adult survival was calculated to be ca. 0.74, juvenile survival ca. 0.64. Roughly 0.7 young are produced per breeding female per year. Most losses of nestlings are to predators, especially California gulls. The data are not sufficient to permit a life-table analysis.

The plovers feed primarily at the lake shore and at freshwater seeps, favoring brine fly adults. Chicks are mobile shortly after hatching, but require access to feeding areas within a few days of hatching.

5. AIR QUALITY INVESTIGATION AT MONO LAKE

Report by Thomas A. Cahill and Thomas E. Gill

Summary by Dr. Lorne Everett

This work consisted of two points: 1) a synthesis of all previous research on air quality issues at Mono Lake; and 2) forecasts of future changes in air quality with fluctuations in the lake surface elevation between 6,300 and 6,400 feet. Since conventional computer models of atmospheric particulate generation could not even qualitatively reproduce the conditions at Mono Lake, a semi-empirical model of dust events called MODDM (Mono-Owens Davis Dust Model) was developed, calibrated and tested for predicting concentrations of dust across the playas and downwind.

Extensive field testing, both photographically and chemically, has confirmed that the source of dust is the playa deposits of evaporite mineral and fine clastic materials deposited below the previous water level on the lake shore. The largest playa reaches are located on the north and east edges of the lake where topography is the least steep. In recent decades, exposed playas from Paoha Island have become a source of blowing dust for intermittent storms.

While the California 24-hour total suspended particulate standard (TSP) is 100 micrograms per cubic meter, 11% of all days recorded at Mono Lake showed a 24-hour mean TSP value averaging 580 micrograms per cubic meter, and 5% of all days showed an average TSP value near 1,000 micrograms per cubic meter, which is the Federal emergency limit for particulates and generally the second highest TSP values measured annually in California (behind only Owens Lake playa dust storms). When no dust was observed (89% of the time) the TSP values averaged less than 20 micrograms per cubic meter, which is amongst the cleanest air in California. The State sulfate standard of 25 micrograms per cubic meter is violated downwind of Mono Lake during most dust events; however, this standard was developed for acidic particulates while the Mono Lake dust sources are alkaline. No research data is available for health effects of alkaline high sulfate particulates. Arsenic in the Mono Lake aerosols must be considered a health hazard. The average concentration of arsenic in days when any amount of dust at all is present (11% of the time) is higher by two orders of magnitude than the California Air Resources Board's recommended acceptable levels for cancer risk. These standards are enforced in California whether a human being is inside the area or not.

The most obvious way to mitigate Mono Lake dust events is to place the playas under water. The five essential conditions for initiating Mono Lake playa dust storms are the following: 1) wind velocity threshold of approximately 25 miles per hour; 2) high wind shear on the flat; 3) unobstructed playa surface; 4) sufficient fetch length across the playa, (at least 1 mile); 5) efflorescent playa crust capable of generating silt and clay sized dust particles, and supply of coarse sand that helps break up the efflorescent crust into dust. Of these five essential conditions, only two may be capable of effective modification. These two factors are wind shear and presence of large coarse singular saltating particles. Wind shear can be reduced by increasing the roughness factor through the introduction of vegetated areas along the playa areas as the lake levels slowly recede. Both wind shear and saltating sands could be controlled by placing snow fence type structures, which would result in quasi-permanent dunes that might support vegetation, perpendicular to the prevailing winds across the playas.

The MODDM prediction for 6,400 feet shows that of the S, SW, and W winds, only the SW wind prediction violates the California Standards for TSP over a very small area. For a 6,390 foot water level, only the SW wind, and not the S or W winds, violates the TSP standard over a very small area. For a 6,380 foot water level, the S wind violates the TSP standard and covers a much larger area; and the W wind violates the TSP standard by 5 times and threatens the Simis property. At the 6,370 foot water level, Highway 167 and the Simis area are above the TSP standard. Clearly, at the 6,370 foot level, the TSP air quality standards would be violated and should not be acceptable. At the 6,380 foot water level, both people travelling on Highway 167 and habitants at Simis will be affected. Since only one direction (SW) of wind flow at the 6,390 foot level violates the TSP standard, a cut off level of 6,380 feet should be maintained to preserve the California Air Quality Standards.

Evaluation of these model predictions should include the realization that these dust storms at a maximum occur 11% of the days of the year. In addition, the traffic on Highway 167 is very sparse and the Simis area represents a single family farm. Further, it should be recognized that the erection of snow fencing is a minimal cost that could reduce the extent of the TSP violations. If the 6,380 foot level is not to be maintained, then further model predictions and field testing is recommended to see the mediating effect of reducing wind shear and reducing the availability of coarse particles.

APPENDIX D: FINAL REPORTS FROM SUBCONTRACTORS

1. Stine, S., Geomorphic and Geohydrographic Aspects of the Mono Lake Controversy

2. Melack, J.M., Limnological Conditions at Mono Lake

3. Jehl, J.R., Jr., Caspian Terns, Phalaropes, and Grebes of Mono Lake

4. Winkler, D.W., California Gull and Snowy Plover Populations of Mono Lake

5. Cahill, T.A., Air Quality at Mono Lake

These reports are published separately from the summary report, and can be purchased from the CORI office, University of California, Santa Barbara, California, 93106.

Attachment 4

LIMNOLOGY OF MONO LAKE, CALIFORNIA

BY

DAVID T. MASON

UNIVERSITY OF CALIFORNIA PUBLICATIONS IN ZOOLOGY
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BERKELEY AND LOS ANGELES
1967

TABLE 19

COUNTS OF BRINE SHRIMP TAKEN BY CLOSING BOTTLE OR NET AT MONO LAKE

adult shrimp/m^2 to 15m

Date and time	Depth interval	Brine shrimp per cubic meter	Nauplii (where counted separately) per cubic meter	Total adults to 15 meters per square meter
1961				
7 June	0–15	3,120		
1000				
1963				
2 July	0	125	2,000	
	2	600	1,400	
	5	1,250	1,100	
	8	600	2,000	13,675
	12	1,400	1,500	
	16	1,400	12,500	
	20	none	2,000	
20 July	0–5	1,080		
	5–10	1,480	57,244	21,550
	10–15	1,750		
10 August	0–5	650		
1100	5–10	950		13,250
	10–15	1,050		
	15–20	none		
23 August				
0530	0–2.5	360		
	2.5–7.5	320		27,350
	7.5–10	1,340		
	10–15	4,300		
0750	0–3.3	200		5,850
	3.3–6.7	340		
	6.7–10	430		
	10–15	530		
27 August	0–5	270		
1500	5–10	530		4,750
	10–15	150		
31 August	0–5	135, 165		
	5–10	200, 120		3,025, 2,575
	10–15	270, 230		
	15–20	75, (−60)		
5 September	0–5	240		
	5–10	15		3,525
	10–15	450		