AN ECOLOGICAL STUDY OF MONO LAKE, CALIFORNIA

Edited by
David W. Winkler
for the Mono Basin Research Group

Institute of Ecology Publication, No. 12
June, 1977
University of California, Davis

Reprinted November, 1979 by the Mono Lake Committee, PO Box 29, Lee Vining, CA 93541

Note for the Electronic Version:

August 2006

This electronic Adobe PDF version of the 1976 Ecological Study of Mono Lake (including the 1980 update at the end) was created by the Mono Lake Committee in August 2006 for the 30th anniversary of the study.

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In July 2006, the Mono Basin Research Group held a 30-year reunion. At a picnic at Mono Lake County Park, a copy of the study from the Mono Lake Research Library was circulated for signatures, resulting in the following page.

If you have any questions or comments regarding the electronic version of this document, please contact: Mono Lake Committee, P.O. Box 29, Lee Vining, CA 93541.

Long Live Mono! Thank you for nearly 30 years of preservation work. Great to be back!

Tom Wainright
15 July 2006

For the Mono Lake Committee
thank you so much for being the facilitator of everything that has come after that fateful summer of 1976 and seeing that the science became part of what has brought attention and preservation to Mono Lake

Dave Herbst July 15, 2006

From M DRG to MLC. What a wonderful long trip it continues to be! To all that come, Walt

To the MLC.
Thank you for all your hard work & great successes to save Mono.

Jeff Robins
7/15/06

To the Mono Lake Committee
Thanks & congratulation for your successful work in preserving & restoring Mono Lake. I am hopeful that the next 10-25 years will see a substantial increase in spring activity around the lake.

Akito Otsuki 7/15/06

Bonjour tout le monde.

To the M.L.C.
thank you so much for taking the science & turning it into conservation
Keep up the good work.

— Bob Loeffler 7/15/05

To the M.L.C.
your conservation efforts have been so incredibly important to the Mono Lake Ecosystem. Keep on restorin'!

Gayle "Brine Shrimp" Dana
July 15, 2006

Dear MLC,
Congradulations for all the hard work over the years! You have exceeded our wildest dreams & expectations. cheers

Jefferson Burch

To the M.L.C.
Mono Lake is an inspiration throughout the world. We tune into your Webcam from Quebec City Canada. Merci beaucoup, Warwick Vincent 15/7/2006

Long Live Mono Lake & The MLC! It's been a great 30 years & wonderful to see the lake afloat
Elliot BURCH

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FOREWORD : A NOTE ON THE HISTORY OF MONO LAKE

David Gaines

Give me silence, water, hope
Give me struggle, iron, volcanoes

Pablo Neruda

East of Yosemite National Park lies one of the most beautiful and scientifically interesting regions in California. This land of granite escarpments, glacier-scoured canyons, volcanoes, and lava flows is dominated by the blue expanse of Mono Lake.

For at least 700,000 years Mono Lake has lain at the foot of the Sierra Nevada's steep eastern escarpment. During the Pleistocene glaciations, the lake waxed to several times its present size and depth. Perhaps as recently as 13,000 years ago, tongues of ice reached its shores and icebergs drifted on its surface. At times its waters overflowed into Owens Valley and even into Death Valley. Conversely, during interglacial periods, Mono Lake shrank into its tectonically-formed drainage basin and became a lake without an outlet to the sea. A series of wave-cut terraces on the slopes above the lake have left us a record of its expansions and contractions. Despite these fluctuations, Mono Lake never dropped much below its present volume. It survived perhaps a million years of glacial and interglacial climatic cycles to become one of the most ancient inland bodies of water in North America (Lajoie 1968).

Now the water demands of a metropolis 300 miles distant threaten the future of Mono Lake. Since 1941, water from four of the five major streams that feed the lake has been diverted into the Los Angeles aqueduct. The consequence is strikingly apparent. Mono's shores are marked by a conspicuous band of white, alkali-encrusted rocks and sand--a bathtub ring left by the shrinking lake.

What will happen if these diversions continue? According to the Los Angeles Department of Water and Power, Mono Lake will eventually stabilize at a lower level (Lane et al. 1974):

> . . . assuming a continuation of the dry cycle that began in 1920, the level of the lake would stabilize in about 100 years at a level 50 to 60 feet lower than its present elevation with a surface area of about one-half the present size. A repeat of the wet cycle which occurred prior to 1920 could mean that the lake would stabilize at an elevation only 30 feet lower than its present level.

These predictions are controversial. Dennis Williams, hydrologic engineer with the Department of Water and Power, has conceded that they are based on an informal study in which the Department does not have 100 percent confidence. Data on evaporation rates, precipitation, and inflow from underground springs is little more than guesswork (Harding 1964). Even the diversion rate used in obtaining these predictions is equivocal. Was the nearly two-fold increase in diversion which began in 1970 taken into account?' In the opinion of Ken Lajoie, Chairman of the Sierra Club Mono Lake Task Force, the future of the lake is probably much more uncertain than the Los Angeles Department of Water and Power is willing to admit. Unfortunately, unless more thorough studies are undertaken, the truth may not be known until irreversible changes have occurred.

During the summers of 1974 and 1975, several undergraduate biology students working at nearby Tioga Pass became interested in Mono Lake and its ecology. Struck by the dearth of descriptive and quantitative data about the region, especially with regard to bird populations, these students applied for and received a grant from the National Science Foundation. The resultant Mono Basin Research Group, twelve undergraduates from Stanford University, the University of California at Davis and at Santa Cruz, and Earlham College, pursued an energetic program of field and laboratory research during the summer of 1976. Their work has produced reliable data and analysis of littoral vegetation, the effects of salinity increase on plankton and brine flies, the density, species composition, and food sources of birds, and other important physical and biotic parameters. This research, presented here with summaries of previous studies, warrants the interest not only of biologists and naturalists, but of all those concerned with Mono Lake's future.

This product of the Mono Basin Research Group's efforts does not obviate the need for further study; rather, it makes that need all the more imperative. Three months of field work could uncover only the beginning of an answer to the question of how water diversions are going to affect the lake and its-basin.

AN ENDANGERED ECOSYSTEM?

Early white travelers were awed by the panorama of peaks and volcanoes which graces Mono's shores. Geologist Israel Russell (1889) described the view as follows:

> In the middle distance there rests upon the desert plain what appears to be a wide sheet of burnished metal, so brilliant and even is its surface. It is Lake Mono. At times the waters reflect the mountains beyond with strange distinctness. . . No prosaic description can portray the grandeur of fifty miles of rugged mountains, rising beyond a placid lake in which each sharply cut peak, each shadowy precipice, and each purple gorge is reflected.

Alkali dust may obscure such a view in the future, although the Los Angeles Department of Water and Power has argued that the lake and its basin will continue to provide visitors with "an impressive sight" (Lane et al. 1974). The alkaline chemistry of the dust is especially insidious. It may-affect vegetation far from Mono Lake itself, including valuable Jeffrey Pine forests. A hundred miles to the south, the desiccation of Owens Lake, formerly a lake similar to Mono, serves as an example. There air pollution has become so severe that "the dust commonly reduces horizontal visual range to less than one mile some 60 miles from its source" and "number and mass concentrations of the particulates. . . are a hazard to health" (Reinking et al. 1975).

The future of the many living organisms which depend on Mono Lake for sustenance is of equal concern. The lake which Mark Twain called "solemn, silent and sailless" is in reality neither dead nor silent (Clemens 1872). Although ignorant of the enormous fecundity of Mono Lake's phytoplankton, early visitors remarked on its large flocks of birds. In 1865, J. R. Browne wrote the earliest published reference to the California Gull rookeries on Mono's islands:

> Immense swarms of gulls visit these islands during the spring of the year and deposit their eggs on every available spot. Myriads upon myriads of them hover over the rocks from morning till night, deafening the ear with their wild screams, and the water is literally covered with them for a circle of many miles.

The threat to the Negit Island California Gull rookery, the largest in the state, has already been recorded (Stallcup and Greenberg 1974):

> A breeding colony of 20-30,000 California Gulls is located on 160 acre Negit Island. . . the water level (of Mono Lake) is decreasing at an alarming rate. . . it is estimated that by 1976 a land bridge will have emerged between the shore and Negit Island allowing predators to commute and insuring. . . total destruction of the population.[2]

In addition to gulls, hundreds of thousands of grebes and phalaropes visit Mono Lake on their migratory journeys. The fate of Mono Lake's bird populations is closely linked to that of the brine shrimp and brine flies on which they feed. These, in turn, are dependent on the half-a-dozen photosynthesizing phytoplankton species which comprise the base of the food chain (Mason 1965). Changes in Mono Lake chemistry will be of critical importance here. If, as predicted, Mono Lake drops to an elevation of 6,320 feet, it will retain only one-fourth its present volume. Already, evaporation has concentrated its waters to twice the salinity and ten times the alkalinity of seawater (Mason 1965). If diversions continue, carbonates and other solutes could increase to about four times their present densities. Will this irreparably harm the lake's inhabitants? Will birds be able to bear the salt stress? Nobody seems to have definite answers to these questions.

Because the Los Angeles water projects in the Mono Basin were completed before federal and state environmental impact assessment legislation was passed, the city has never undertaken an environmental impact study. If such a study were conducted, it would need to evaluate the following attributes of the Basin environment:

1. Among the lakes of the world Mono is unique geologically, chemically, and biotically.

2. Mono is one of the oldest continuously existing lakes in North America.

3. Volcanoes, fault scarps, glacial moraines, tufa formations, and other features make the Mono Basin geologically valuable for study.

4. Because of its small but highly productive planktonic community, Mono Lake is an ideal outdoor laboratory for limnological-ecological studies of food-web dynamics.

5. Mono Lake supports a species of brine fly (*Ephydra* hyans) and a physiologically unique population of brine shrimp (*Artemia* salina) which are interesting for their physiological adaptations to an alkaline environment.

6. Negit and Paoha Islands may harbor genetically unique populations of organisms that could provide valuable information on speciation. At least one flightless beetle, for example, occurs on Paoha (Derham Guiliani, pers. comm.).

7. Sizable proportions of the world populations of the Eared Grebe, Northern Phalarope, Wilson's Phalarope, and California Gull depend on Mono Lake for shelter and sustenance. Many other water birds stop there to rest and feed during their migrations.

8. Many thousands of travelers walk, hike. photograph, birdwatch, botanize, and relax along Mono's shores each year. Many others marvel at Mono's pristine setting while passing on the highway or looking down on it from the crest of the Sierra.

Can these natural and scientific values of Mono Lake be weighed against the benefits of providing its water to Los Angeles? This question poses the familiar contemporary dilemma of balancing the largely intangible values of environmental preservation with the tangible ones of development. A non-partisan solution will entail (1) careful and thorough study of the Mono Basin's scientific, esthetic, and economic values and (2) assessment of these values by a state-wide or nationwide constituency.

Historical Background

The identity of the first white man to see Mono Lake may never be known. In 1853 Lieutenant Tredwell Moore was dispatched from Fort Miller in the San Joaquin Valley 'to finish off the Yosemite Indians once and for all.' Moore pursued the leader of the Yosemites, Teneiya, across the Sierra via Tuolumne Meadows and Mono Pass to the shores of Mono Lake (Farquhar 1965). With the aid of the Kuzedika Paiutes dwelling along the lake, Teneiya escaped his pursuers. Moore left his mark on the history of the region, however, when he discovered 'gold and gold-bearing quartz, obsidian and other minerals, while exploring the region north and south of Bloody Canyon and of Mono Lake' (Bunnell 1880).

The prospectors and settlers who streamed to the shores of Mono Lake and to the surrounding mining districts in the following decades disrupted the culture of the Kuzedika Paiutes. The little that is known about the Kuzedika, "the Kutsavi or fly-pupae-eaters," is summarized by Davis (1965). Every early visitor was amazed that the Kuzedika relished the pupae of the Mono Lake brine flies as a source of nourishment. Unfortunately, the stories, legends, mythologies and beliefs of the Kuzedika were never recorded. Even the aboriginal names for Mono Lake and its islands have been lost.

In naming the islands, Russell (1888) "preferred to record some of the poetic words from the language of the original inhabitants of the valley":

> ... There is a story about diminutive spirits, having long, wavy hair, that are sometimes seen in the vapor wreaths ascending from hot springs. The word pa-o-ha, by which these spirits are known, is also used at times to designate hot springs in general. We may therefore name the larger island Paoha Island, in remembrance, perhaps, of the children of the mist that held their revels there on moonlit nights in times long past.

Mono Lake's wealth of bird life was exploited to supply Lundy, Mono Mills, Aurora, Bodie and other nearby mining towns with fresh meat and eggs. During the latter half of the nineteenth century, 'Mono Lake ducks' were sold house to house in Bridgeport for 20 cents apiece (Cain 1961). Local entrepreneurs recognized the opportunity to make more money selling gull eggs than they could working the mines. Between 1862 and the stock market crash of 1889, the population of Mono County was many times larger than it is at present. Aurora had 5,000 people in 1863 (Kersten 1964) and Bodie 10,000 in 1880 (Cain 1956); both are ghost towns today. Several decades of "egging" may well have depleted Mono Lake's gull colony.

In later years other commercial endeavors occurred at Mono Lake. A five-ton steamer was hauled from San Francisco Bay to Mono in 1879 for the purpose of transporting wood from Lee Vining Creek to Bodie. On Sundays, "the Rocket. . . was used as an excursion craft. . . for people who wanted to visit the islands" (Cain 1961). In about 1910 an oil seepage was discovered on the southern tip of Paoha Island. A well drilled through two thousand feet of lake sediments did not produce "black gold," but it did tell geologists that the lake was ancient (Calhoun 1967). In 1917 Paoha's first and only homesteaders, the Wallis D. McPherson family, built a seven room house on the island and raised goats. The McPhersons departed in 1922, but their goats remained to populate Paoha's greasewood-covered hills.

The first serious scientific research at Mono Lake focused on the geological features of its basin. In the spring of 1881, Israel Russell initiated a study that was to occupy him off and on for the next-two years. His Quarternary History of Mono Valley, California, published in 1889, remains an outstanding contribution in its field. Russell was the first to deduce, for example, that Mono Lake had expanded more than once, that there had been multiple glaciations in the eastern Sierra, and that Mono Craters and the islands were of recent-origin. His report is still the-most lucid general introduction to the region. In his honor, another geologist, W. C. Putnam (1950), proposed that Pleistocene Mono Lake be named Lake Russell.

Although the geology of the Mono Basin has continued to attract the interest of scientists, its biology has been neglected. Of twelve doctoral dissertations on studies conducted in Mono Basin during the past fifteen years, only Mason's 1965 Limnology of Mono Lake has dealt with living organisms, primarily plankton. The remaining body of data on the lake's biology consists almost entirely of casual, sometimes contradictory, observations.

While the interest of the biological community lagged, that of the City of Los Angeles increased. The decade of drought which opened the twentieth (century convinced the city fathers that southern California's sparse water supply, less than two per cent of the state's total, threatened their plans for the city's future growth. In 1904, the superintendent of the Los Angeles water system, William Mulholland, camped along the green fields and Sierra-fed streams of the Owens Valley, a burgeoning agricultural community 250 miles north of Los Angeles and 50 miles south of Mono Lake. In only nine years his department was able to divert much of the valley's water to Los Angeles through the newly-completed Los Angeles aqueduct.

During the 1920's, however, the city's unquenchable thirst led to a bitter, sometimes violent struggle with Owens Valley farmers over water rights, The full story of the "embattled farmers" who "seized the Los Angeles aqueduct and made a sport of blasting it with dynamite" is told by Nadeau (1974) and Wood (1973). The city eventually triumphed, creating a desolate scene of abandoned houses and barns, "dead trees, weed-grown fields, neglected fences, and empty ditches" as "poignant reminders of shattered hopes and dreams" (Schumacher 1969). Even before this transition was completed, as early as

1913, the city cast its eyes on the waters which fed Mono Lake (Lane et al. 1974).

The plans of the Los Angeles water seekers were grandiose: diversion of four major streams into the Owens River via an eleven mile tunnel under the Mono Craters. In 1930 the people of Los Angeles approved a $38,000,000 bond measure to finance the project. Public Law 864, passed by Congress on March 4, 1931, withdrew public lands in the Mono Basin "from settlement, location, filing, entry, or disposal under the land laws of the United States for the protection of the watershed supplying the City of Los Angeles." In a maneuver to force ranch owners to sell to the city for lower prices, Los Angeles brought suit to condemn property and water rights in the basin, eventually spending over five million dollars (Lane et al. 1974).

Construction of the Mono Craters tunnel, begun in 1934, was slowed by steam, hot water, volcanic gases, and ground caving. Finally, after great difficulties, the project was completed in 1940. One year later the first Mono Basin water was diverted into the Owens River, thereby extending the aqueduct system to an intake 338 miles from Los Angeles, farther north than San Francisco,

In 1963, Los Angeles announced plans to construct a second Owens Valley aqueduct. According to the Department of Water and Power, the water for this aqueduct would derive from "further utilization of the ground water resources of the Owens Valley by increased pumping" and " salvage of the water in Mono Basin being lost into the saline water of Mono Lake." Since the completion of this aqueduct in 1970, mean annual export of water from the Mono Basin has increased from 78 cfs (1941-1970) to approximately 140 cfs. Releases into Mono Lake have fallen from approximately 55 cfs to practically zero (Lane et al. 1974).

Still the fate of Mono Lake is not finally determined. On June 29, 1976, land owners, environmentalists, scientists, and interested citizens stood at a California Water Resources Agency hearing in Bishop to express their concern for the lake's future. Environmental groups, in conjunction with Inyo County, are planning litigation to assure the lake's survival. The following studies give ample evidence of the richness and uniqueness of Mono Lake's ecosystem which, once lost, cannot be duplicated.

TABLE OF CONTENTS

Page

Note to the Reader 1

Chapter 1. Overview . . . . . . , ... 2

Chapter 2. Geology and Hydrology

Geology 6
Hydrological Processes 12
Hydrological Model 23
Summary 37

Chapter 3. Limnology

Introduction and Summary 39
3.1 Physical and Chemical Limnology. 40
3.2 Primary Producer Level 42
3.3 Secondary Producer Level 57
3.4 Salinity Tolerance in Ephydra and Artemia. 63

Chapter 4. Entomology 70

Chapter 5. Ornithology. 88

Chapter 6. Botany 114

List of Participants 143

Acknowledgements 144

Bibliography

Overview. 146
Geology and Hydrology. 147
Limnology. 148
Entomology 150
Ornithology. 150
Botany. 152

Appendix 2-l. A Water Budget and Energy Budget for Mono Lake. 154

Appendix 5-l. Depth Profiles. 163

Appendix 6-l. Details of Field Techniques for Physical Factors in the Plant Study 164

Appendix 6-2. Listing of Raw Data for Plant Study · · · · · · · · 165

Appendix 6-3. Abundance and Distribution Data for Plant Species · · · · · · · · 174

Appendix 6-4. Plant Species List and Herbarium Collection Numbers · · · · · · · · 180

NOTE TO THE READER

Specific information and further unpublished data for certain sections may be obtained from David Herbst (limnology and entomology) and David Winkler (ornithology). (See addresses on list of participants, p. 143) Further data and printouts from the hydrological model are available from the Institute of Ecology, University of California, Davis 95616. All requests for copies of this report should be sent to the Institute of Ecology.

Chapter 1

OVERVIEW

David W. Winkler, Jefferson B. Burch and David B. Herbst

Mono Lake lies in a closed basin. Within the confines of this basin is a network of physical and biological interactions which together sustain its ecological system. Fluctuations in these components may produce a new equilibrium or they may create an entirely different system. At Mono Lake the physical environment is undergoing changes because of water management programs. These changes in the Mono Lake ecosystem are reversible if corrected before the ecosystem is overburdened. It is our intention to provide information to assess the impact of those programs on the Mono Lake ecosystem.

The members of the ecosystem stabilize it through cycling and recycling matter and transferring energy. A look at the geology and hydrology of the lake and its basin and at the structure of the community follows.

A remnant of a larger ancient lake, Mono Lake lies in a volcanic depression. Although Mono Lake underwent great fluctuations in its level during Pleistocene times, it has been relatively stable since the last period of glaciation approximately 500,000 years ago.

In 1940, the Los Angeles Department of Water and Power began diverting the major inflowing sources of fresh water. By 1970, the water in these streams was all being diverted to Los Angeles and the result was an average decline in lake level of one to two feet per year. Our computer simulation indicates that if the present climatic cycle and water diversion rates continue, Mono Lake will sink 53 feet, to 54 percent of its present surface and 29 percent of its present volume, by the middle of the next century. Negit Island (the site of the California Gull rookery) will be connected to the lake's shore by a land bridge within two years, and Paoha Island within 50 years. If allowed to continue to its predicted stabilization level, the receding lake will have exposed nearly 20,000 acres of fine lake sediments. In addition, as the lake level drops, the concentration of dissolved solids will increase, stabilizing at over three times the present concentration. This increasing salinity will have a profound influence on the organisms which live in the lake. Mono Lake is both very salty and highly alkaline (pH = 9.7). These extreme conditions can be tolerated by only a few kinds of organisms (low diversity), but those organisms which do inhabit the lake support great numbers of individuals (high productivity).

Planktonic algae reach high levels of productivity in the deeper waters of Mono Lake during the summer. The great numbers of algae support large populations of consumer organisms (planktonic brine shrimp and bottom-dwelling brine fly larvae). Salinity tolerance experiments show a significant reduction in photosynthetic rates of the algal populations with a 25 percent increase in salinity. High mortality occurs among brine shrimp exposed to salinities two times as concentrated as that of present lake water, while brine fly larvae appear to survive only by entering a state of suspended animation. When the lake water is three times more concentrated than it is today, probably none of these organisms will be able to maintain present production rates, and they may die off completely.

Shore insects in the vicinity of the lake partition themselves according to three habitat types. Brine flies predominate in areas of wet mud, frit or chloropid flies prefer moist sand and gravel areas, and shore bugs occur largely on the extensive areas of dry alkali sand. Large spring-fed streams (e.g., Gull Bath) carry great numbers of insects normally associated with habitats distant from shore into the lake. This inflow of insects may act as an additional food source for birds.

Of all the animals in the Mono Basin, birds are probably the only ones seen or remembered by most visitors. The birds of the lake are the easiest life-forms to study, and predictions of the probable effects of the lowering lake are relatively easy to make, thanks to the plentiful information about birds in the literature. Mono Lake's gull colony is apparently the second largest of its kind in the world. The populations of Eared Grebes and Northern and Wilson's Phalaropes which rest at the lake are among the highest reported for any locality in the western half of the continent. Our evidence shows that the gulls and probably the grebes subsist on a diet predominantly of brine shrimp, whereas both phalaropes eat brine flies. Thus, the birds living on the lake are not just using its physical characteristics as a setting for activities such as breeding, molting, and resting; they are bound to the lake's "lower" trophic levels through the invisible chains of food-dependency. In a manner not immediately obvious, the birds are sensitive to alterations in the lake environment through the (consequent increase or decrease in their food supply.

As Mono Lake shrinks, its islands will be connected one by one to the mainland. Negit Island, the home of over 80 percent of the nesting gulls on the lake, will be connected to the mainland within the next two years. The other islands will be connected by the middle of the next century. No colony the size of the present Negit colony has been able to withstand the encroachment of land predators once its island has been connected to land, and it appears that the Negit colony will soon have to move to Paoha Island or suffer a reduction in numbers. As salinities and alkalinities in the lake increase, the birds will have osmoregulatory problems. The birds' ability to meet these excretory demands will depend on their ability to minimize the intake of Mono water and to use fresh water efficiently enough to have time for other vital activities. The brine shrimp and fly not only supply the birds with their major food source, but also serve as a reservoir of moderate salt content which aids in the amelioration of osmotic stress imposed by the lake's water. If the populations of these food organisms disappear from the lake, the bird populations which depend on them are almost sure to follow.

Plant life of the Mono Basin is varied, ranging from Sierra Nevada mountain species to the Great Basin Sagebrush Scrub species which dominate the floor of the basin. With the dropping lake level, vast expanses of lake bottom will be exposed. Terrestrial plants were investigated in areas near the lake shore to determine the succession (i.e., movement) of plants onto the exposed lake bottom. Knowledge of the current and future vegetation of these near-shore areas is important, for plants are the primary food producers for the terrestrial ecosystem, serve to stabilize the soil against wind erosion and provide valuable habitats (specifically marshes, which are rare habitats in the rest of the Great Basin) for other organisms. Scrub, marsh, and non-vegetated zones characterize these near-shore areas. A sharp boundary around the lake currently limits the distribution of the scrub species which spread across the rest of the basin. This boundary was found to correspond to the highest recent lake level (reached during 1919) and indicates that the movement of scrub species onto future exposed areas will take at least sixty years. The marshes, on the other hand, were found to move quickly onto newly exposed areas following the movements of the groundwater seepage zone, Although the marshes are efficient in stabilizing the soil and minimizing dust, they represent only five percent of the current exposed areas. Most of the future exposed areas will resemble the open alkaline mud flats which dominate the immediate shoreline areas today. The sparseness of the vegetation in these areas and the fine-textured lake sediments cause dust storms. Overall, vegetation will be slow to stabilize these exposed areas, and under the forecasting range of this study, an increase in the now-common dust storms is probable.

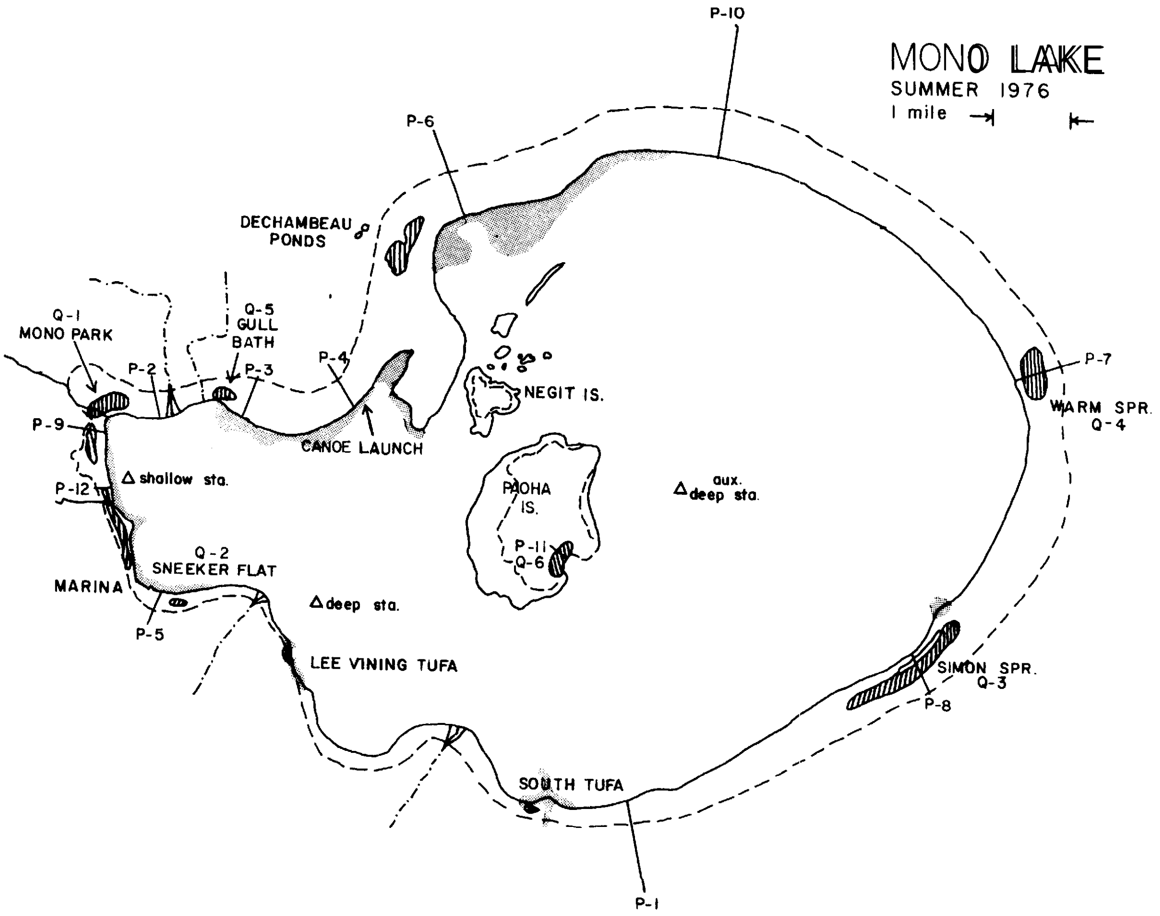
Although this investigation concentrates on the Mono Lake ecosystem, we stress that the Mono Lake ecosystem is not isolated. Mono Lake, with its vast populations of breeding and migrating birds, is connected directly with the other ecosystems which support these populations during different seasons. One can only speculate on the impact of the changes that the other ecosystems will undergo if Mono is unable to meet the needs of these bird populations. The dust storms, in addition to causing severe air pollution problems in the Mono Basin, can easily transcend the boundary of the basin on the prevailing winds. The caustic and alkaline dust can have a devastating effect on acid-loving plants. Observations from the crest of the Inyo Mountains overlooking the dry bed of Owens Lake report limberpines "literally whitewashed with a coat of alkaline dust" with "sparse foliage rather than the full-needled appearance typical of limberpine" (Mary DeDecker, botanist, 1976, pers. comm.). The drying of Owens Lake was caused by water diversions.

Each ecosystem has value because its living organisms have evolved into a delicate balance with the environment. Its populations contribute to the earth's overall genetic diversity, which insures that genetic resources will be available for future evolution and adaptation. The possibilities that the California Gull and brine shrimp populations of Mono are genetically distinct from others of their kind serve to emphasize this ecosystem's contribution.

The following pages are essentially a compilation of fact. We conducted the summer's research as an objective evaluation of the lake's present situation; but much of what we learned this summer cannot be quantified or placed within the conceptual framework of science. Mono Lake is a scene of subtle sunset hues, of towering thunderclouds, of circling hordes of birds. We hope that it will be preserved to enlighten generations to come.

Figure 1-1 (facing page). LOCATION AND HABITAT MAP, MONO LAKE, CALIFORNIA. The names listed on the figure are those used in the remainder of the report. Sample sites used in Chapter 6 are represented by the lines perpendicular to the lake shore and are designated P-1 through P-12. Sample sites used in Chapter 4 are designated Q-1 through Q-6. The shallow station, deep station, and auxiliary deep station are referred to in Chapter 3. Areas of the lake shore where tufa occur are denoted by light shading, and marsh areas are represented by hatching. The shoreline for the summer of 1976 is indicated by a solid line, and the scrub border is denoted by the dashed line. A dotted and dashed line represents intermittent streams, and a solid line indicates a stream which flowed for the entire summer.

Figure 1-2 (below). LOCATION OF MONO LAKE.


MONO LAKE
SUMMER 1976
1 mile
P-10
P-6
DECHAMBEAU PONDS
Q-1
MONO PARK
P-2
Q-5
GULL BATH
P-3
P-4
P-9
NEGIT IS.
CANOE LAUNCH
P-7
WARM SPR.
Q-4
P-12
Δ shallow sta.
PAOHA IS.
Δ aux. deep sta.
P-11
Q-6
Q-2
SNEEKER FLAT
MARINA
P-5
Δ deep sta.
LEE VINING TUFA
SIMON SPR.
Q-3
P-8
SOUTH TUFA
P-1

Chapter 2

GEOLOGY AND HYDROLOGY

Robert M. Loeffler

INTRODUCTION

When Mono Lake undergoes a change, the entire basin is affected. In order to understand the effect of a shrinking lake upon the ecosystem, it is important to know how the lake will change. A look at the hydrology of the basin--the streams, springs, rainfall, and groundwater, is necessary. This examination produces a mathematical model showing the effects of water diversion.

The lake cannot be understood in isolation from the basin, as the geologic structure and processes of the basin form the larger context in which the lake exists. To understand the hydrologic processes of the basin, one must first examine its geology. This examination is especially important in understanding groundwater occurrence. It also gives an idea of the time scale in which these changes occurred.

This chapter is divided into three sections. The first section deals with the geology of the basin and discusses the geologic history, the geologic processes, and the historic lake fluctuations. The segment on geologic processes includes a discussion of the dust problem in the basin. The second section deals with hydrologic processes, the lake's water inflow and outflow. The third section explains the mathematical model of these flows. The model's predictions of future lake levels are the most important conclusions of this chapter of the report.

GEOLOGY

Geologic History

Although technically referred to as a closed tectonic depression, the present Mono Basin can be conceptualized as a bowl filled with mud. The sides and bottom of the bowl consist of very hard volcanic rock. The mud is mostly alluvium washed from the hard rock sides and deposited in the interior of the basin either by streams or by the lake itself. The western side of this bowl is formed by the Sierra Nevada, which is composed of hard, intrusive granitic and metamorphic rocks. The north, south, and eastern sides are different Pliocene-extrusive volcanic flows. The bottom of the basin is crystalline bedrock, although its exact nature has never been determined.

Deformation began almost 10 million years ago, after the first glaciation and volcanic eruptions. A major uplift took place between 9 and 3 million years ago. At this time many of the volcanic rocks which surround all but the western margins of the basin were extruded (Lajoie, 1968). Approximately three million years ago, the area became a closed basin. At this time the fault which forms the east scarp of the Sierra Nevada became active. Coincident with this, a gentle downwarping of the north and south sides of the basin occurred. Together, these movements define the present Mono Basin. Recent minor fault scarps indicate that the structural downwarping and faulting are still active. (Lajoie, iii)

Two models have been proposed to explain the bowl-like structure of Mono Basin. One postulates a tectonic-volcanic origin, a caldera-like collapse. The second emphasizes broad structural downwarping.

In response to steep gravity gradients, Pakiser and others (1964) concluded that volcanic eruptions extruded magma from a large chamber which they feel underlies both Mono Basin and Long Valley to the south. The loss of magma from this underground chamber withdrew support from the surface rock, which then collapsed. They picture the present basin as being 18,000 ±5,000 feet deep and the collapse as occurring along vertical bounding faults (Figure 2-1).

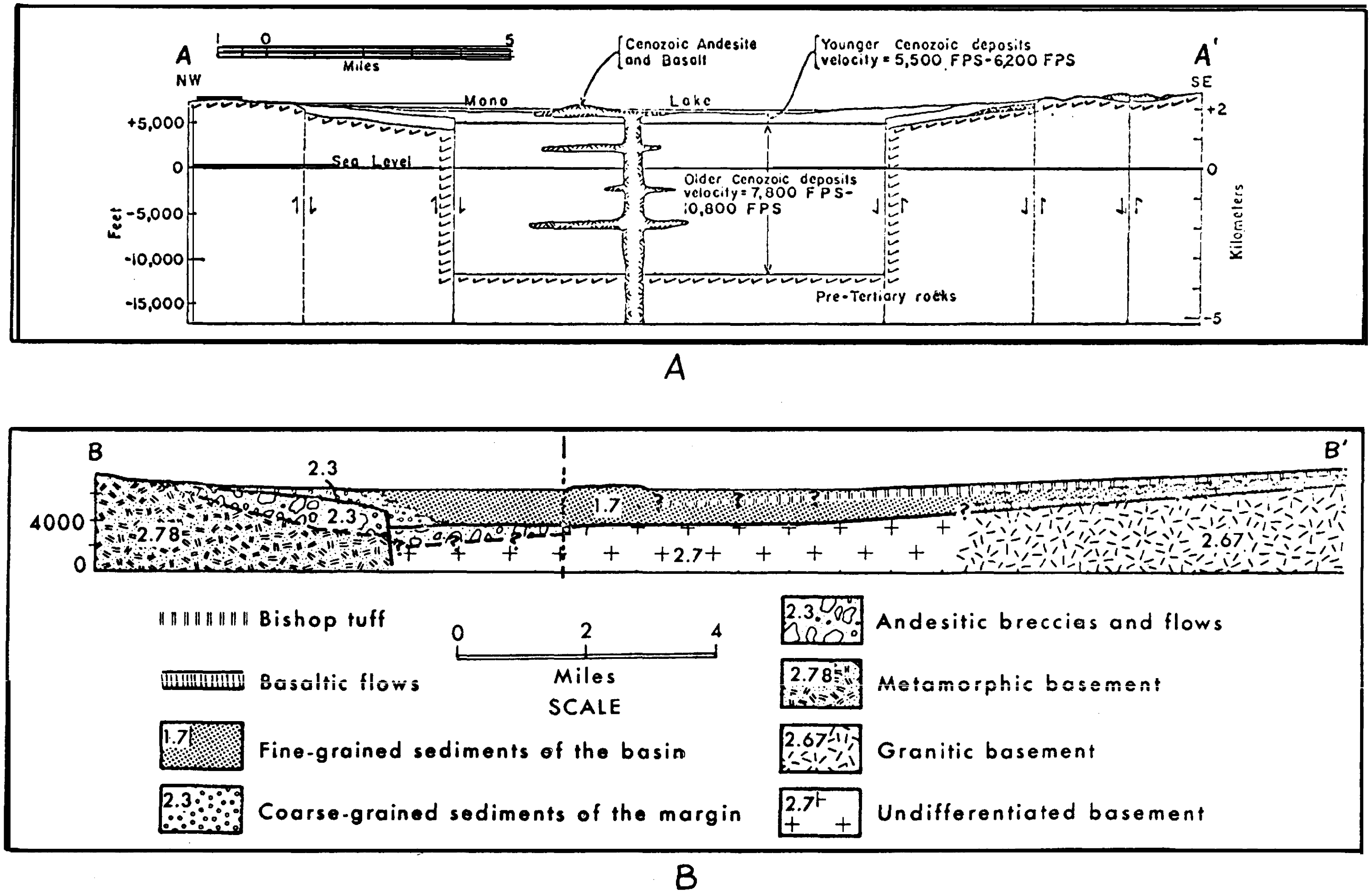


Figure 2-1. TWO STRUCTURAL MODELS OF MONO BASIN. (Taken from Lajoie, p. 40)

There are two problems with this interpretation. First, it requires 200 cubic miles of material, an inordinately large amount, to have been volcanically extruded in order to create room for the collapse. Second, the postulated vertical bounding faults have no surface expression.

Gilbert and others (1968) proposed a model emphasizing structural downwarping. They conclude that, beginning three to four million years ago and continuing to the present, the sides of the basin have been folding inward toward an axis plunging southwest to the great Sierran fault. The basin of their model is less than 4,000 feet deep. The authors propose no cause for the downwarping,

It is worth noting that recent wells drilled for geothermal exploration in the basin have hit bedrock in the 2,000 to 4,000 foot range (Axtell, 1972). This is not conclusive evidence for the downwarping model, however, for it is possible that the wells were drilled outside the bounding faults postulated by Pakiser.

Extensive volcanic activity also occurred in the basin. For the last 33,000 years, Mono Craters have been intermittently erupting. Most of the sand which dominates the surface soil of the south and east portions of the basin originated there. The most recent eruption was that of North Crater, 1,300 years ago. Black Point, the flat-topped black cinder cone near the northwest corner of the lake, erupted underwater 13,800 years ago when the lake stood at 6,880 feet (Lajoie, p. 152).

The islands in the lake are also volcanic in origin. In the recent geologic past, volcanic action lifted lake sediments above the surface of Mono Lake to form Paoha (Lajoie, p. 112). The white deposits on the island are these lake sediments, and the darker rocks in the northeast and southeast corners are volcanic cones and flows from the activity which formed the island. Negit, and the smaller islands to the northeast of it are exclusively volcanic.

The ages of the islands are not known. Their generally youthful, unweathered appearance indicates that they are recent. The broad terrace formed 4,000 to 7,000 years ago which appears in the remainder of the basin does not appear in the soft unconsolidated sediments of Paoha; this indicates that the islands are less than 4,000 years old. Other evidence indicates they may be less than 3,000 years old. (Lajoie, p. 147). The earthquake of 1890, the hot springs on Paoha, and those east of Black Point demonstrate the latent presence of these volcanic forces even today.

Glaciation has also left its mark on the basin. Although a comprehensive history of the glaciation in the basin has never been determined, evidence of the most recent glaciations is obvious in the beautifully sculptured canyons and moraines of the Sierra Nevada.

Geologic Processes

Erosion and deposition of sediments are brought about by three agents: the streams, the lake itself, and the wind, Each of the three agents predominates in one or more sections of the basin; their distribution carries specific implications for the dust problem in the basin and for the analysis of groundwater flow.

One can divide the basin into five sectors (Figure 2-2). In sectors one and two, on the west side of the basin, streamflow and glacial action have been the principal agents of deposition. Most of the basin's rainfall and most of the streams occur here. These steep, fast flowing streams carry sediment from the Sierra Nevada to the lake. Upon crossing less steep terrain, they slow, lose energy, and drop most of their load. Only the finest sediment reaches the lake water itself. Consequently, coarse sediment is found where the streams have been and fine sediment is found where the lake has been. Because the lake level has been fluctuating over geologic time, the interface between these two depositional environs has shifted (See Figure 2-3).

Sector three, east of Mono Craters, is dominated by the wind. Throughout the last 33,000 years the craters have extruded thousands of tons of sands and ashes. The generally northeasterly wind has blown these sediments into sector three, where they form the dominant sediment. Below the windblown sands lies bishop tuff bedrock.

On windy days, erosion and deposition by the wind cause significant air pollution

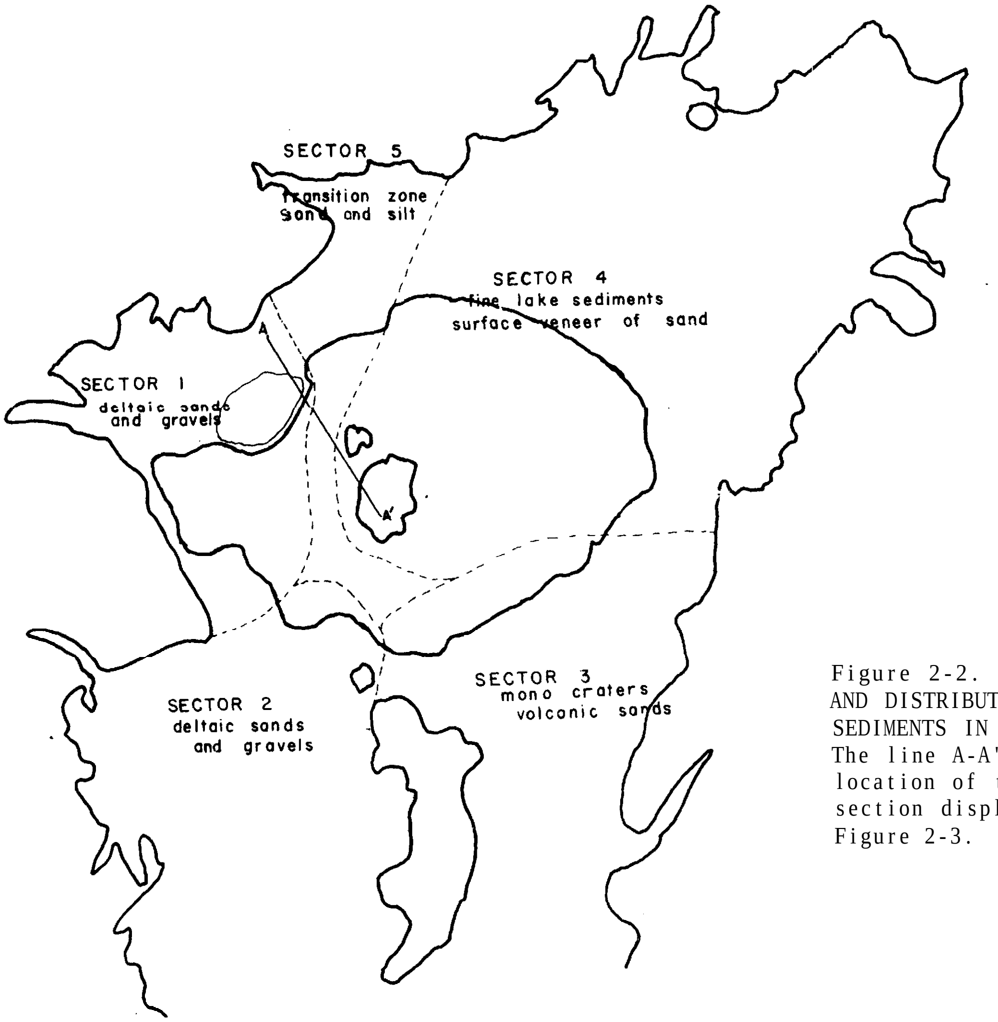
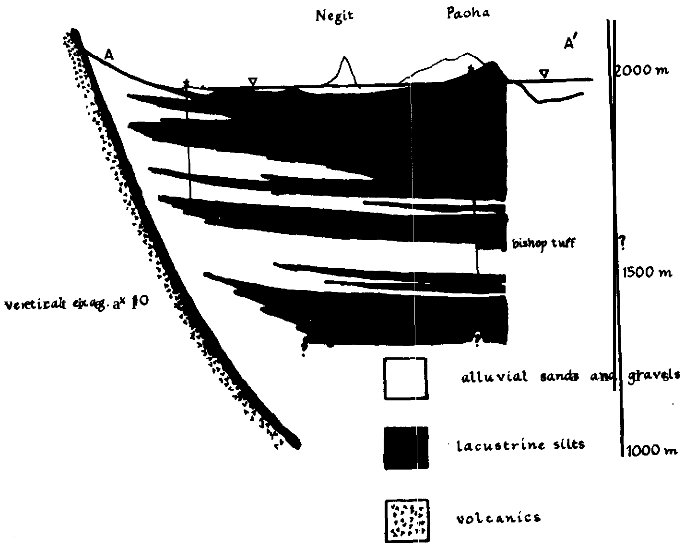


Figure 2-2. THE NATURE AND DISTRIBUTION OF THE SEDIMENTS IN MONO BASIN. The line A-A' shows the location of the cross-section displayed in Figure 2-3.

Figure 2-3. A GENERALIZED CROSS-SECTION OF SECTOR ONE. (Taken from Lee, 1969, p. 87).



problems. A high wind can lift clouds of sand and lake sediment thousands of feet into the air from Paoha and the eastern portion of the basin. During these storms, travel on the eastern side of the lake becomes nearly impossible.

While this dust problem is the wind completing its age-old geologic work, it is aggravated by the falling lake level. It is evident to those who travel on the east side of the lake that these violent dust storms pick up much of their content from the bare-soil areas which the receding lake has just exposed. On some parts of the eastern shore, the strip of exposed soil is more than a mile wide. The rate and process by which the plants colonize the newly exposed soil will be discussed in Chapter Six.

Plants act as stabilizing factors against the wind, Their resistance slows the air next to the ground. In the bare areas, the faster-travelling air picks up the sand and lake sediment. In addition, the sediment in this section of the basin (sectors 3 and 4) is made up of either light volcanic sands or very fine lake sediment. Both are easily moved by the wind.

On the south side of the lake is an excellent example of the wind's work. A few hundred feet from the lake are bizarre pipe-like sand formations named "piping structures." These were formed underneath the lake bottom when the fresh ground water met the lake water and, being lighter, moved upward toward the bottom of the lake (Lajoie, pers. comm.). It used these routes over a long period of time, and eventually the chemicals in the water cemented pipes of sand around its path.

These structures must have formed underground, yet today some of them stand six feet high. The surrounding sediment has been blown away, leaving these slightly sturdier forms exposed.

The sediment of sector four has been deposited primarily by the lake. The area is characterized by a surface veneer of wind-blown sand from Mono Craters over fine (lake-deposited) sediment and shallow bedrock.

Sector five is a transition area. Here no process is dominant. No wells have been drilled in the area to test the underlying sediment. Most likely it is a combination of the other sectors.

The five sectors taken together imply some qualitative conclusions concerning the occurrence of groundwater in the basin. These will be discussed in the section dealing with groundwater, but it is sufficient to note here that the coarse stream-deposited sediments are all concentrated along the west side of the basin and that one would expect these sediments to have a higher transmissivity than the lacustrine sediments which form the remainder of the basin floor. (Transmissivity is roughly defined as the ability of groundwater to flow through the sediment.)

Historic Lake Fluctuations

A lake has existed in Mono Basin for a long time. The lake sediments encountered while drilling a well on Paoha Island indicate that the lake existed one million years ago (Lee, 1969, p. 26) and has not dried up within the last 500,000 years (Lajoie).

During the last glacial times (Wisconsin) Mono Lake was much larger than it is at present. This larger lake is known as Lake Russell after I. C. Russell, the nineteenth century geologist who completed perhaps the most comprehensive work on the basin. The fluctuation of Lake Russell during the last glacial advance 23,000 through 12,500 years ago (The Tioga advance, during late Wisconsin times) is well summarized by Lajoie. During this glaciation the lake rose to relatively high stands 22,000, 19,000 and 13,000 years ago. The lake may have overflowed the basin 22,000 years ago. If it did, it must have flowed into the Owens Valley and must ultimately have become part of a drainage pattern which ended in Death Valley (Lajoie, p. ii).

At its maximum extent, the lake was over seven times deeper than it is now, and it had almost five times the surface area (Russell, 1887, p. 299, Plate XXIX; Figure 2-4). At its minimum level during glaciation, it probably stood very near 6,600 feet (225 feet above its present level) (Lajoie, p. 188). Lake terraces can be seen cutting into the basin below 7,180 feet, the elevation of the overflow from the basin. Two prominent depositional terraces were formed roughly 14,000 and 18,000 years ago (Lajoie, p. 188).

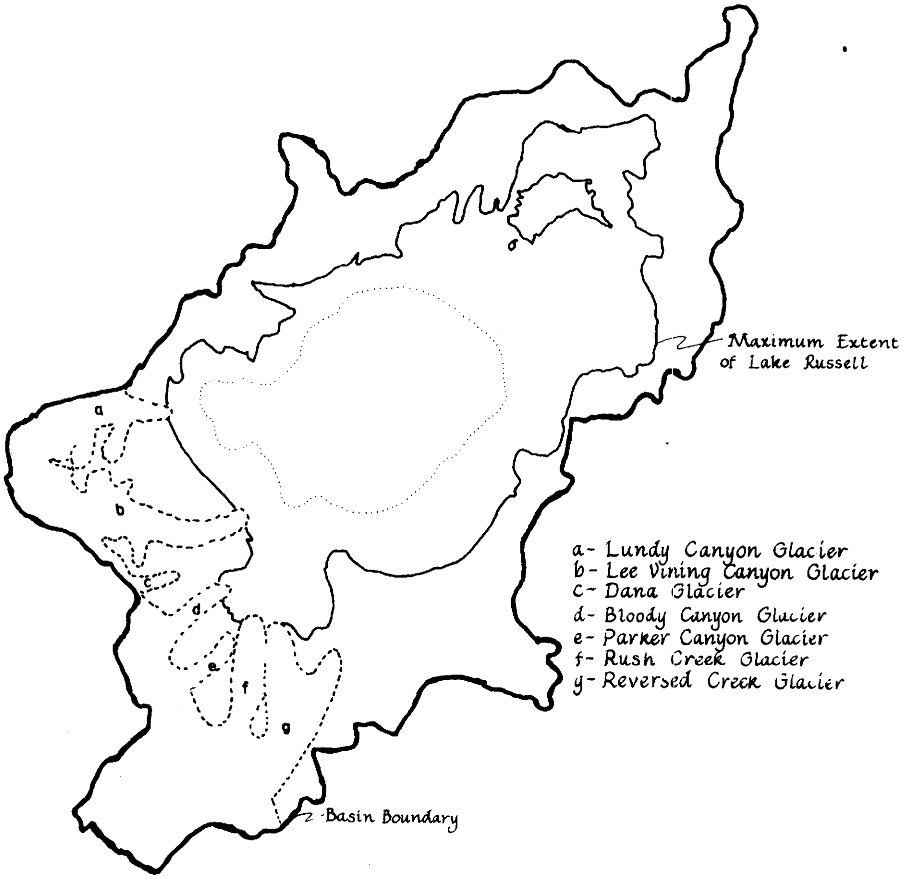


Figure 2-4. THE MAXIMUM EXTENT OF MONO BASIN'S PLEISTOCENE GLACIERS AND OF LAKE RUSSELL. The dotted line in the center of the basin represents the present lake. (Taken from Russell, 1887, Plate XXIX)

The town of Lee Vining lies on the first terrace at 6,680 feet; the second can be seen crossing Pole Line Road just northwest of Black Point at 6,800 feet.

The lake fell rapidly 12,500 years ago at the end of the glaciation. During the warm post-glacial period 4,000 to 7,000 years ago, a broad terrace was formed approximately ten feet below the present (1976) level of 6,376 feet. Since that time the lake has fluctuated only between 6,365 and 6,480 feet (Lajoie, p. 189).

Records of the lake's elevation have been kept by the Los Angeles Department of Water and Power (LADWP) since 1912 (Figure 2-5), and previous lake levels were estimated by S. T. Harding (1962). Only recently has the lake dropped below its 1860 level. The rising and falling lake levels shown in the figure have been caused by climatic changes. Precipitation between 1857 and 1920 averaged almost one and a half times that of the 1920-1940 period (Moe, p. 3). Other great basin lakes show fluctuations similar to those of Mono (Harding, 1969).

HYDROLOGICAL PROCESSES

Overview

The science of hydrology deals with the occurrence, distribution, and circulation of water on the earth. The major purpose of studying the hydrology of Mono Basin was to predict the lake's fluctuations, specifically how the lake level will decrease and where it will stabilize, and the effects of different diversion rates on the lake. The previous section on geology was included as a necessary prerequisite to an understanding of the lake's hydrology.

The hydrology of the lake will be analyzed by an equation similar to that used to model the lake, the water budget equation:

1. (Outflow from the lake)-(Inflow to the lake)=(Decrease in volume of the lake)

The only outflow from the lake is evaporation. The basin is closed, and there is no seepage loss, as the basin bottom is crystalline bedrock.

The inflows are three: rainfall, streamflow, and groundwater flow. The greatest of these flows comes from the streams of the Sierra Nevada.

Outflow

Evaporation at Mono Lake follows a cyclical pattern with a low in 'January and a high in July (Figure 2-6). The total evaporation from the lake is the linear rate (inches/year) times the area of the lake. As the lake drops and its surface area decreases, the total evaporation from the lake (or the total outflow) decreases.

Evaporation has been estimated by using many different techniques. S. T. Harding (1965) estimated 39 in/yr by comparison with other great basin lakes. Both the California State Department of Water Resources and the Los Angeles Department of Water and Power use an estimate of 39 in/yr in their calculations.

The LADWP has completed several evaporation studies on Mono Lake and Grant Lake (a nearby fresh water lake). Since August 1968, they have monitored a U. S. Weather Bureau Class A land evaporation pan near Grant Lake. According to Keenan Lee (p. 17):

> Measured evaporation from this site averages 42.9 inches during the May through October interval. Evaporation during this period represents 79% of the annual total, and lake evaporation is equal to 71% of the pan evaporation (Kohler and others, 1959). Using these figures, the annual lake evaporation reduces to 39.6 in/yr.

Because Grant Lake is a fresh water lake, it might have a greater evaporation rate. But since it is also over 600 feet higher and in a colder and more humid part of the basin, it might evaporate less. Although there is no way to correct for these factors, the error introduced is probably small.

Floating pan records on Grant Lake were kept from 1942 through 1969. The May through

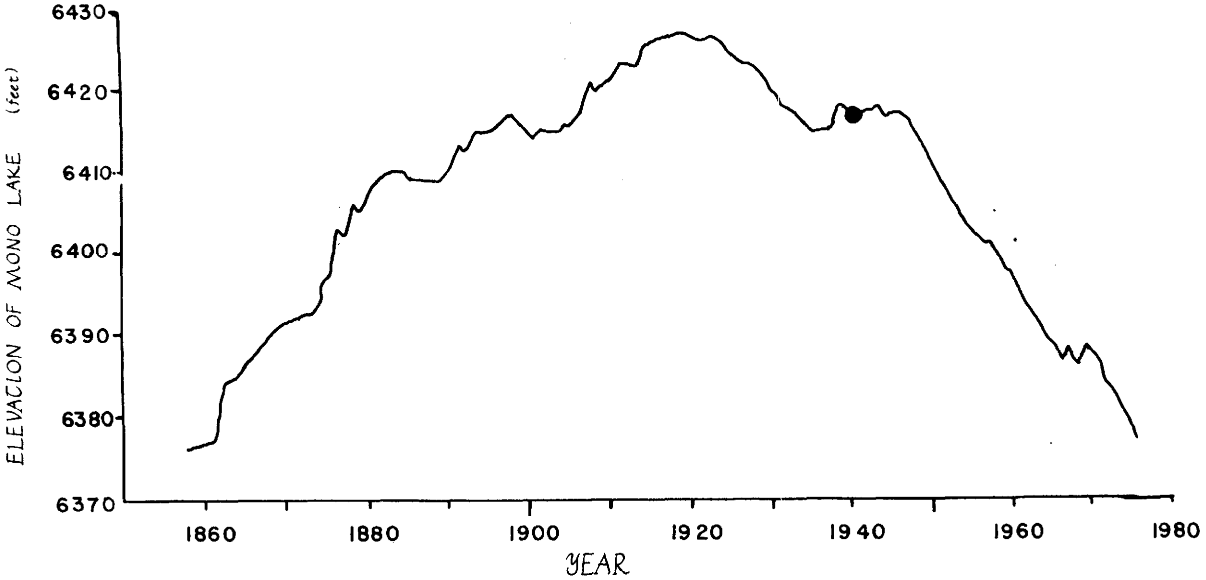


Figure 2-5. THE RECENT FLUCTUATIONS OF MONO LAKE. The dark circle at the year 1940 points out the lake elevation when diversions to Los Angeles began. (Taken from Harding, 1962)

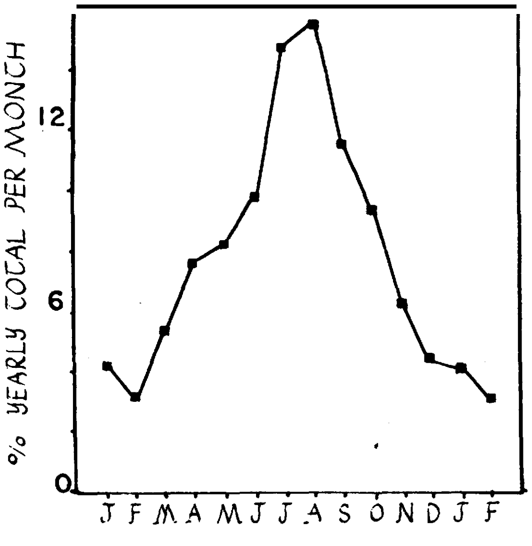


Figure 2-6. MONTHLY EVAPORATION FROM MONO LAKE AS A PERCENT OF THE YEARLY TOTAL. (Taken from Mason, P. 26)

October interval yields 42.1 in, but the (unknown) pan coefficient for a floating pan is higher, since the conditions in the pan are similar to those in the lake itself. If the pan coefficient is .8, yearly evaporation is 42 in/yr.

From October, 1957, through August, 1959, the LADWP took weekly readings on a floating pan anchored near the southwest shore of Mono Lake. On many of the records is the notation, "strong winds and waves since last reading." The result is therefore somewhat unreliable. If it has any accuracy, however, it indicates an evaporation rate greater than 42 in/yr.

Calculation of evaporation on Mono Lake through an energy budget was attempted by Black (1958), Mason (1965) and this study (Appendix 2-l). The method used in this study involves measuring several physical parameters and calculating the theoretical rate of evaporation from them. Conclusions of the Lake Hefner Study (USGS, 1952) indicate that this method can give reliable results if the parameters are accurately monitored for a long period of time. This condition was not met for any of the studies. Black made no measurements, but estimated the parameters. Both Mason and this study made no continuous or routine measurements, but used averages or extrapolations from a few measurements made throughout the summer. In addition, this method has never been successfully demonstrated on a saline lake. The spread of the results reflects the unreliability of the method. Black found 51 in/yr., Mason found 79 in/yr., and the present study found 67 in/yr.

The evaporation rate is probably between 39 and 42 in/yr. For modeling purposes, four different rates were tried, 36, 39, 42, and 45 in/yr. The modeling process itself indicated that the rate is between 39 and 42 in/yr.

Two evaporation conditions were tested with the model. The first assumed no change in evaporation with decreasing lake volume and used the evaporation rates noted above. This gave a stabilization lake level which is too low, because evaporation decreases with a decrease in lake volume and a consequent increase in salinity.

Correcting for changing evaporation with changing volume is complicated. Evaporation takes pure water from the lake and leaves the salts and solids behind. As the lake volume decreases, the amount of salts should stay the same and their concentration should go up proportionally. Evaporation is a function of concentration and specific gravity, and as specific gravity and concentration increase, evaporation decreases. The relationship between specific gravity and evaporation was experimentally determined by Charles Lee in 1934.

Figure 2-7 shows Lee's findings. It also shows the two lines which were used to approximate his curve for modeling purposes. At a specific: gravity less than 1.121, line 1 was used; at greater specific gravities line 2 was used. Lee's determinations were relative to Mono Lake water with a specific gravity of 1.03. Our experiments indicate that this water evaporates at a rate .97 that of fresh water. Lee's results have been adjusted accordingly.

There are two problems with this approach. According to the analysis outlined above, if the volume of the lake decreases to one-half of its former volume, the amount of dissolved solids or salts will remain the same and their concentration will double. This is not necessarily true. It is possible that some of the salts will precipitate out. Lee indicates that this doesn't happen to any great extent until a specific gravity of 1.3 is reached. However, evaporation will concentrate the water in the near-shore shallow areas of the lake slightly above that of the deeper open areas. If this happens, precipitation could occur along the shoreline before it occurs in the open lake. For this reason, the specific gravities calculated by the above procedure should be considered an upper bound. If the predicted specific gravities are too high, the predicted evaporation rate will be too low; thus, the predicted stabilization level of the lake will be too high.

The second problem involves extrapolation of Lee's results. The highest specific gravity used by Lee in his experiment was 1.278. For some combinations of precipitation, evaporation, and streamflow assumptions, the specific gravity predicted by the model exceeds this. For purposes of this study it was assumed that evaporation decreases along Lee's projections at a linear rate (the dashed portion of Figure 2-7).

Another consideration when modeling a shrinking lake is that a smaller lake will heat

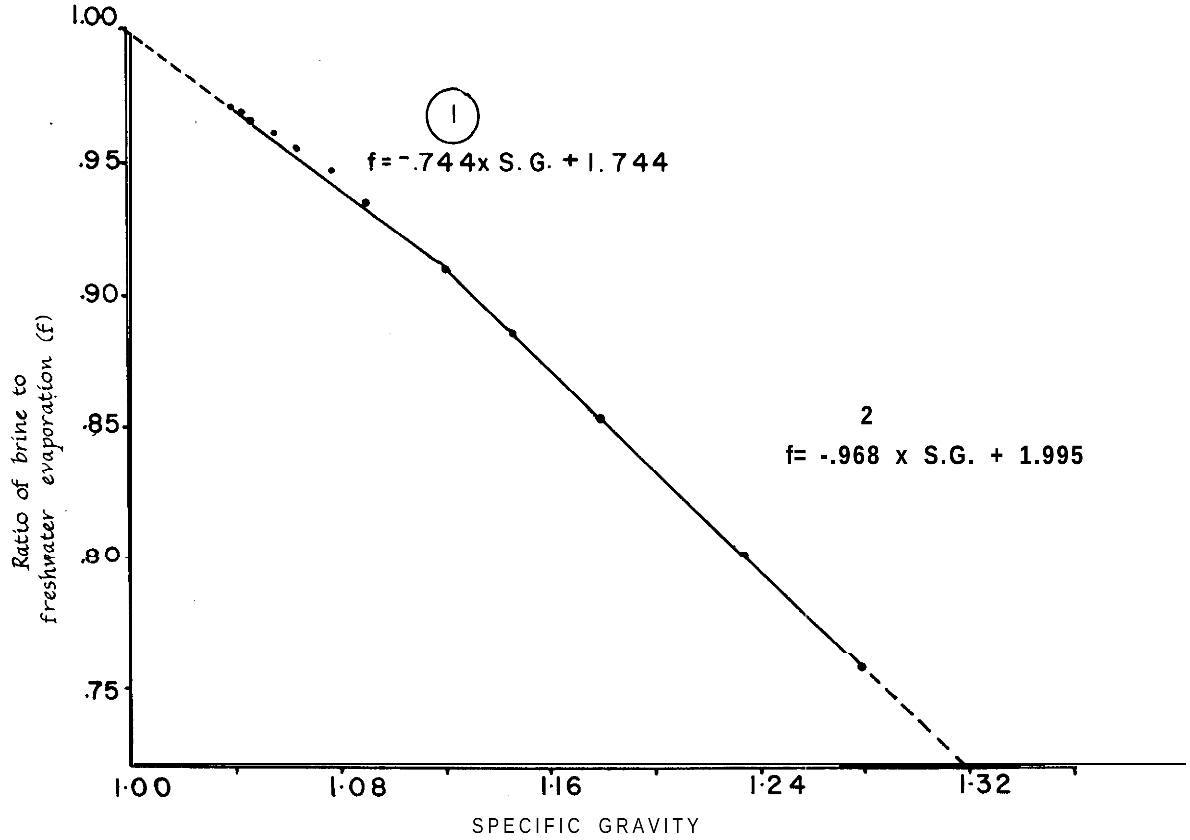


Figure 2-7. CORRECTION TO THE EVAPORATION RATE FOR INCREASING SPECIFIC GRAVITY. (Lee, 1934)

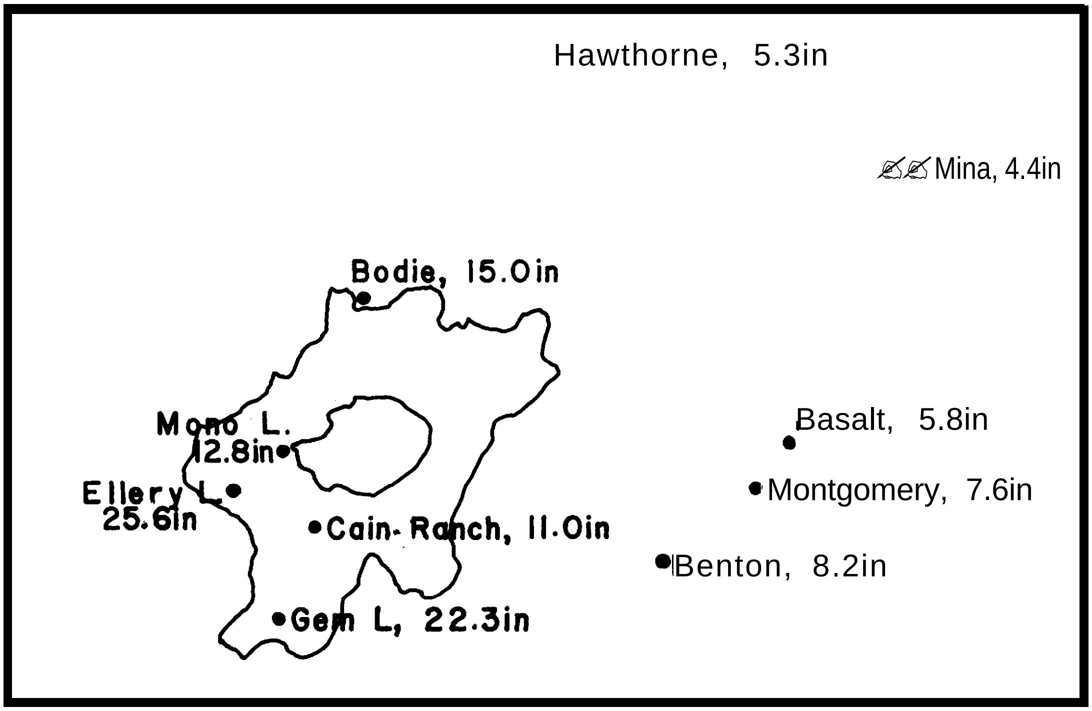


Figure 2-8. MONO BASIN, THE NEARBY WEATHER STATIONS AND THEIR AVERAGE ANNUAL PRECIPITATION IN INCHES.

up faster during the spring and summer. The slightly warmer water would evaporate faster. The change is probably minimal, however, and was ignored.

Inflow

1) Rainfall

Rainfall patterns can be interpreted from records kept at various weather stations in or near Mono Basin. The rainfall shown for each station (Figure 2-8) is the annual average for the various years of record for each station.

An isohyetal map is shown in Figure 2-9. The dashed lines represent rainfall contours (or isohyets). The map is an adaption of ones supplied by Keenan Lee and the LADWP. It is an interpretation of the various weather station averages, allowing for the effects of topography. It is evident that most of the basin falls in the rain shadow of the Sierra Nevada. The far eastern edge of the basin receives less than one-fifth of the rainfall of the western edge.

Stations located in different areas get their precipitation from different storm systems. The western stations - Ellery Lake, Gem Lake, Cain Ranch, and Mono Lake - get most of their precipitation from systems which move from the Pacific Ocean during the winter months (Figure 2-10). Much of the precipitation for these stations falls as snow, which, in the mountain areas, does not melt until spring. The stations east of the basin - Hawthorne, Mina, Basalt, and Montgomery - have a more constant yearly profile but receive a slight majority of their monthly precipitation as summer convective showers. The intermediate stations - Bodie, Mark Twain Camp, and Benton - seem to be affected by both patterns.

The total precipitation on the lake was estimated by an isohyetal method. This involved projecting where the rain contours of 13, 12, 11, 10, 9, 8, 7-1/2 and 7 in/yr fell onto the lake. The lake area between adjacent isohyets was measured and multiplied by the average of the two isohyets. These were then added to obtain total lake precipitation. This made it possible to find the average precipitation on the lake (total precipitation divided by total area). Because this average might change with a decreasing lake level, this process was completed for lake elevations of 6392, 6322, and 6292 feet. The average, however, came to 7.8 inches in each case.

The procedure outlined above gives an estimate of the average yearly precipitation. Lee (1969), using a similar procedure, found 7.3 in/yr for a lake level of approximately 6,400 feet. As the average could not be specified exactly, values of 7.3, 7.8, and 8.3 in/yr were used with the model as future long-term annual averages.

Modeling historic rainfall was more difficult. For this purpose it was necessary to produce a number which indicated the rainfall for a specific year, not just the long-term mean. The idea was to calculate the percent of the long-term annual mean (7.3, 7.8, or 8.3 in/yr) falling during each year. Three different schemes were attempted.

The first rainfall indicator used a weighted average of the percent of the mean precipitation from the western weather bureau stations (Mono Lake and Cain Ranch) and the eastern stations (the Nevada stations). Because the majority of the lake's rainfall comes from the Sierran storm systems, the western stations were weighted by a factor of three:

$$\frac{\dfrac{\text{Mono Lake + Cain Ranch}}{2} \times 3 + (\text{mean for Nevada stations})}{4} = \begin{array}{l}\text{the indicator percent}\\ \text{of the mean precipitation}\end{array}$$

This formula had to be modified slightly for the years when no record for either the Nevada or the Mono Lake stations existed. This combination indicator could be calculated back to 1932.

The second rainfall indicator used certain streamflows as a measure of rainfall on the lake. It was assumed that changes in rainfall would reflect changes in streamflows. The percent of the annual rainfall was assumed to be the percent of the average total streamflows. The LADWP has recorded streamflows of almost all of the major western basin

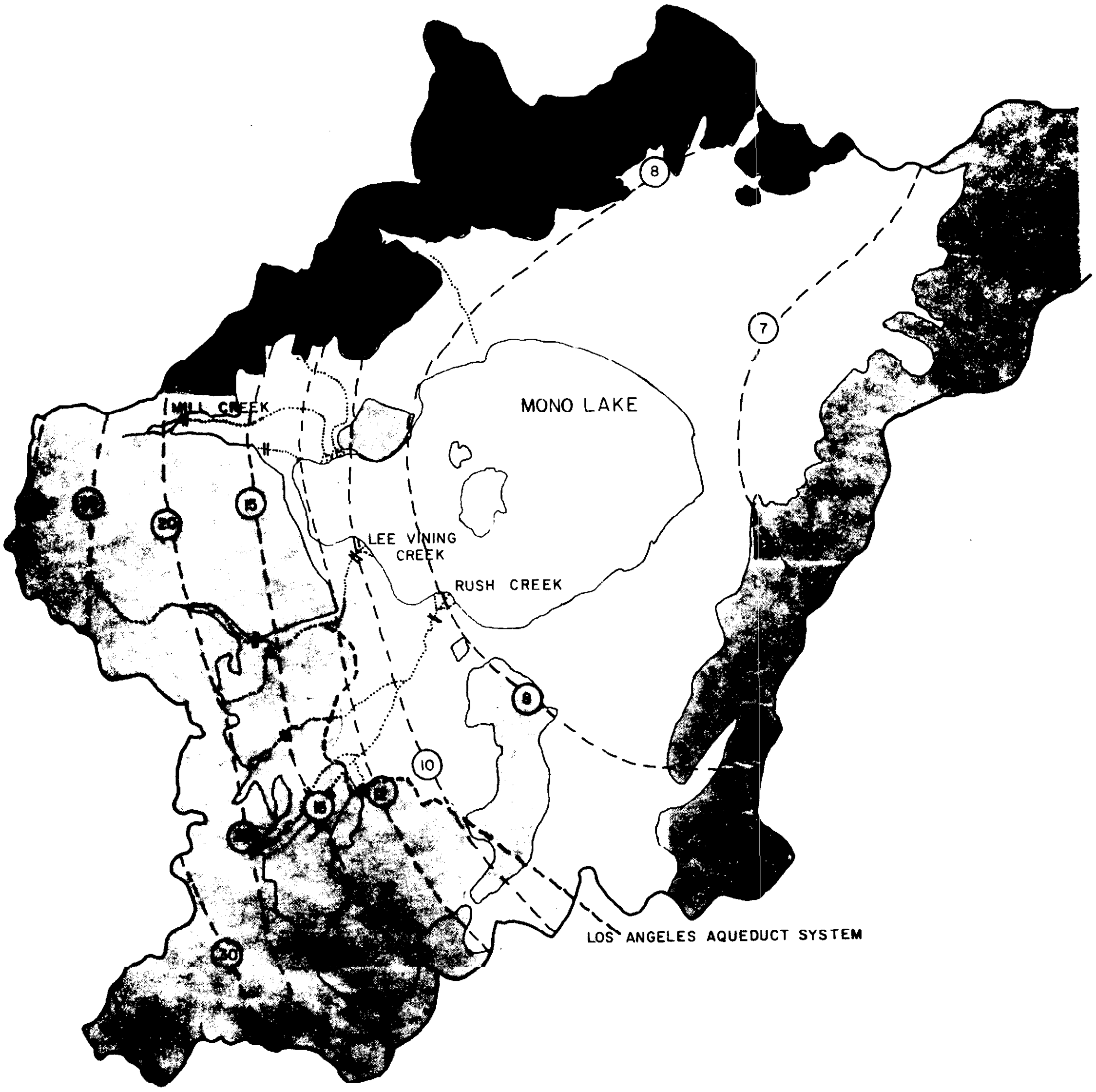


Figure 2-9. THE HYDROLOGY OF MONO BASIN

——⑳——	Rainfall contours showing annual average precipitation in inches. (Taken from isohyetal maps of the LADWP and Keenan Lee)
……………	The major streams of the basin
……╫……	Stream gauging stations
– – – –	The Los Angeles aqueduct system

The light area is the basin floor, the alluvium; the dark areas are the metamorphics, volcanics and till, the potential recharge areas.

streams since the 1930s. The percent of the average total flow of these streams was computed from 1937 on. Pre-1937 calculations were based only on Mill Creek, whose records extend further back.

The third indicator was constructed by S. T. Harding (1962) for the years preceding 1942. He used secondary indications of the precipitation, such as the fluctuations of great basin lakes. All indicators were corrected so that their averages were 100% for the period 1937 - 1975.

2) Streamflow

All streams in the basin drain towards Mono Lake and most of them originate in the Sierra Nevada (Figure 2-9). According to Lee (p. 38):

> The perennial streams all arise in the Sierras and are fed mainly by melt-water from the winter snowpack, with about 2/3 of the total runoff in these streams occurring during May, June, and July.

A few ephemeral streams do flow from other areas, but their contribution to the basin hydrology is minimal. The yearly profile of Lee Vining Creek is shown in Figure 2-10.

The LADWP has kept flow records for Rush, Parker, Walker, Lee Vining, Gibbs, Mill and Dechambeau creeks since the early 1930s (the double hash marks on Figure 1-9 shows the approximate location of the gauging stations.). The pre-1930 total of these flows can be estimated from the relationship of the other creeks to Mill Creek, whose records extend back to 1900. (A linear regression of the total flow with Mill Creek yields a correlation coefficient, r=.87 and a standard error of estimation which is 16% of the mean total flow.) It is worth noting that the measured streams correlate well with each other (i.e. a wet year for one creek is sure to be a wet year for any other).

It is important to realize that the flow measurements were taken not at the lake shore but generally over three miles away. (There were two stations near the lake, at the mouths of Lee Vining and Rush Creeks. These have short periods of records and were not used in the model's calculations.) Downstream from the point where the measurements were made much of the water seeps through the channel bottom into the groundwater system or evaporates. There is nowhere for the groundwater to go, however, but into the lake. The division between groundwater and surface water is not clear-cut. All underground water was surface water at some time in its past, and much of it was surface water where the stream measurements were taken. The stream measurements are, therefore, in part a measure of the surface runoff and in part an implicit measure of the groundwater flow.

3) Groundwater

Mono Lake is the ultimate sink for all groundwater movement in the basin. Discharge occurs as land or underwater shoreline springs or as broad seepages areas. Measurement of the land springs is possible, but any accurate estimate of the total groundwater movement must await more accurate subsurface knowledge, especially aquifer locations and transmissivity. (An aquifer is a rock medium which transmits water.)

Even if a rigorous quantitative understanding of groundwater occurrence is not possible, a qualitative concept of its distribution can be derived from seismic data and knowledge of the general geology of the basin. In particular, the location of the source areas and likely aquifer transmissivities, along with the actual water table levels in the basin, imply certain flow paths.

The simplest interpretation of ground water in the basin would have most of the ground water recharge coming from precipitation on the soft, unconsolidated sediments in the flat, central portion of the basin and little coming from the relatively impermeable hard igneous and metamorphic rocks which form the basin sides. This is most likely NOT the case (Lee, p. 63).

With the exception of the western side of the basin and the area just east of Mono Craters, the fine, impermeable lacustrine sediments are on the surface or at shallow depth. These would tend to prevent the downward percolation of rainwater from reaching the water table. The percolation would be further inhibited by the excessive soil moisture

Figure 2-10. STREAM FLOW AND PRECIPITATION CYCLES AT MONO LAKE. The stream flow is based on 20 years of record from Lee Vining Creek; the precipitation from the 1951-1964 period at the Mono Lake, United States Weather Bureau station. (Taken from Mason, p. 19)

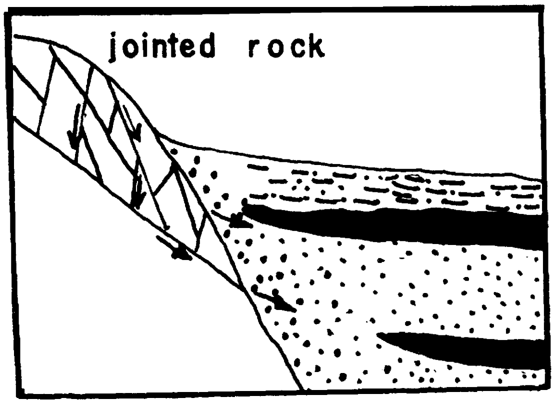


Figure 2-11. HIDDEN RECHARGE. (Taken from Feth, 1964)

deficiency throughout the area. Unless unusually long periods of precipitation occurred, evaporation, not the water table, would claim the water.

Most of the groundwater recharge probably comes from the jointed and fractured igneous rocks surrounding the basin sediments (Figure 2-11). Lee says (p. 63):

> Because there is very little soil developed on much of the tertiary volcanic outcrops, precipitation can infiltrate directly along fractures and joints. Speaking particularly about desert and semi-desert areas (as Mono Basin), Schoeller (1959, p. 17) concludes that when rain falls on bare surfaces of fissured rock, there is no loss to evapotranspiration, and rainwater directly reaches the water table.

Although the Sierra Nevada are not composed of tertiary volcanics, recharge from them probably occurs similarly through joints and fractures, In addition, here the perennial streams lose water through their beds as they travel toward the lake. Occasionally the reverse is true. Along part of the streams' courses to the lake, a high water table forces the groundwater to increase the stream during wet years. The shaded areas of Figure 2-9 show the potential recharge areas.

The distribution of the fracture recharge areas must reflect the distribution of rainfall in the basin. The total rainfall on the hardrock basin rim averages 295,000 acre-ft/yr, but 76% of this falls on the Sierra Nevada (the granites, metamorphics, and tills), and only 24% falls on the remaining north, south and east sides. These results were computed by using the isohyetal method outlined in the section on rainfall. The potential groundwater recharge is certainly greatest along the Sierra Nevada.

Unconfined water in the north, east, and southeast sections of the basin occurs primarily in the fine-grained, low-permeability lacustrine sediment. A flownet calculation by Lee (p. 86) yields only 240 acre-ft/yr contributed to the lake. This is an insignificant portion of the total inflow.

Confined water occurs in the more permeable stream gravels and sands which are generally pressed between layers of lake sediment. Where these sediments are on the surface in the west, they contain unconfined water. The shoreline and underwater springs are the discharges of these aquifers.

4) Seismic Investigations of Groundwater

During 1969, Lee mapped much of the water table using an explosion-triggered seismic refraction technique. In order to provide a knowledge of the depth of the water table for the plant succession investigations and to provide some notion of the distribution of ground water in the basin, this mapping was continued using a similar technique triggered by a sledge hammer. Emphasis was placed upon mapping the near shore water table.

A Bison Seismograph was used. Elevation and location were determined for each shot point and were used to map the water table. At shot points up to 1-1/2 miles from the lake, this data was provided by a surveyor's transit using the lakeshore as a datum. Farther from the lake they were determined either from a standard U.S.G.S. topographic map or by picking shot points near known locations. Transects were usually started near the lake and worked back until the water table became too deep to detect. Transects were picked to represent most of the groundwater conditions occurring around the lake.

A plate on the ground was hit with a sledge hammer. This created a compression wave (essentially a miniature earthquake) in the soil. A geophone placed some distance away recorded the ground's vibrations. From this record, the time it took the wave to get from the impact point to the geophone could be determined. The technique was repeated a number of times for each shot point, progressively moving the hammer further away from the geophone. A compression wave will travel faster through rock saturated with water and after some critical distance between the geophone and the hammer, the wave arrived first by taking the longer route through the 'faster velocity' rock below the water table.

The depth to the water table is given by the equation:

$$\left(\frac{V_2 - V_1}{V_2 + V_1} \right)$$

Where Z represents the depth to the water table, X is the hammer-to-geophone distance at which velocities change, V_2 is the wave velocity in the water saturated rock, and V_1 is the velocity in the surface layer,

Figure 2-12 shows the data from a typical shot point. The time it took for the wave to arrive at the geophone is graphed against the hammer-to-geophone distance. Note that the inverse of the slope of each line is the wave velocity of the ground layer, and that their intersection occurs at X.

The variation of the water table gradient around the basin can be explained by dividing the basin into the five sectors used in the section dealing with geologic processes and shown in Figure 2-2. This suggests to a limited extent, how the water availability around the shoreline will change with the receding lake (Figure 2-13).

Sector one displays a very steep gradient especially where the Sierra Nevada comes down to the lake, reflecting the large flows through the area. Springs are relatively abundant in this area as the mini-aquifers pinch out into the more impermeable sediment, as water rises along imperfections in the confining layer, or as stream valleys intersect the water table. From Mono Park along the shore south to the marina, the water table is at or near the ground surface for the first thousand feet of land and has a rise of about 23 feet. This area is all marsh. As the lake recedes and lowers the piezometeric datum (the lower bound for the groundwater gradient) the outlets for the groundwater move down, too. This succession was recorded by Mason (p. 22) who wrote that the springs in this area have been known to follow the falling lake. This succession is expected to be true for the springs of the Mono Park tufa grove. Since the large groundwater flows must find some outlet, it is reasonable to expect the marsh to move down.

In sector two, the mountains are much farther from the lake and the water must follow a longer course along a shallower gradient to reach the lake from the mountain recharge areas. In addition, a ground water source was eliminated when Los Angeles diverted the Sierran streams. The dry tufa groves reflect the diversions.

Tufa towers are formed by underwater springs. Everywhere a tufa tower now stands there is, or once was, a spring. This can be seen in Mono Park, where many of the towers have water flowing from breaches near their bases. When the towers were beneath the lake, the water undoubtedly flowed from their tops. (Dunn, 1953).

The distribution of tufa towers (Figure l-l) records the distribution of spring flow, and therefore ground water. It is no coincidence that the delta of Lee Vining Creek has an associated tufa grove, for seepage from the creek channel provided the groundwater source. The fact that this and the south tufa grove are now mostly dry probably reflects the Los Angeles water diversions which took away their source.

Partly because of the diversions, sector two is a drier area than sector one. It is likely that the present semi-dry shoreline will move down as the lake recedes.

In the western portion of sector three, east of Mono Craters, the water table gradient was found to be very shallow, because the area is filled with extremely permeable sands from Mono Craters. A well drilled for geothermal exploration near the Craters showed that these sands predominate to the Bishop Tuff 560 feet below ground (Axtell 1972). As the lake recedes, they will probably still predominate and therefore the current water conditions will prevail as the lake falls.

Sector four, the eastern margin of the basin, is dry with a shallow water table gradient. It is interspersed with wet spring areas at Simons Spring and Warm Springs. The largest tufa grove in the basin, now dry, is northeast of Warm Springs. The wet anomalies could either be water rising from an underlying aquifer along a fault or joint or the place where the aquifer itself comes to the surface. The aquifers do not show up in the well drilled on Paoha Island; and near the center of the basin, where the lake has existed for longer and longer periods of time, one would expect the aquifers to thin out.

It is probable that when the lake withdraws, the present wet areas will dry up, as did the one northeast of Warm Springs, and new ones will form.

3) Summary of Inflows

There are three inflows to Mono Lake - rainfall, surface runoff, and groundwater

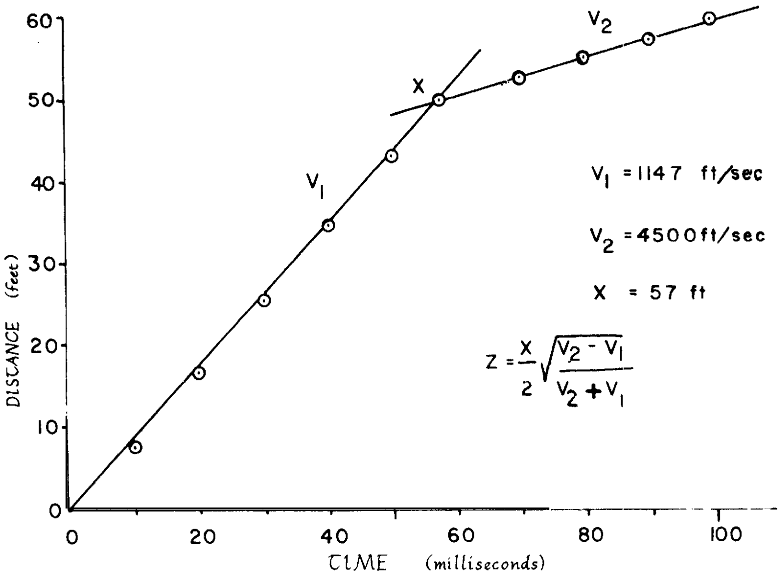


Figure 2-12. ANALYSIS OF SEISMIC DATA

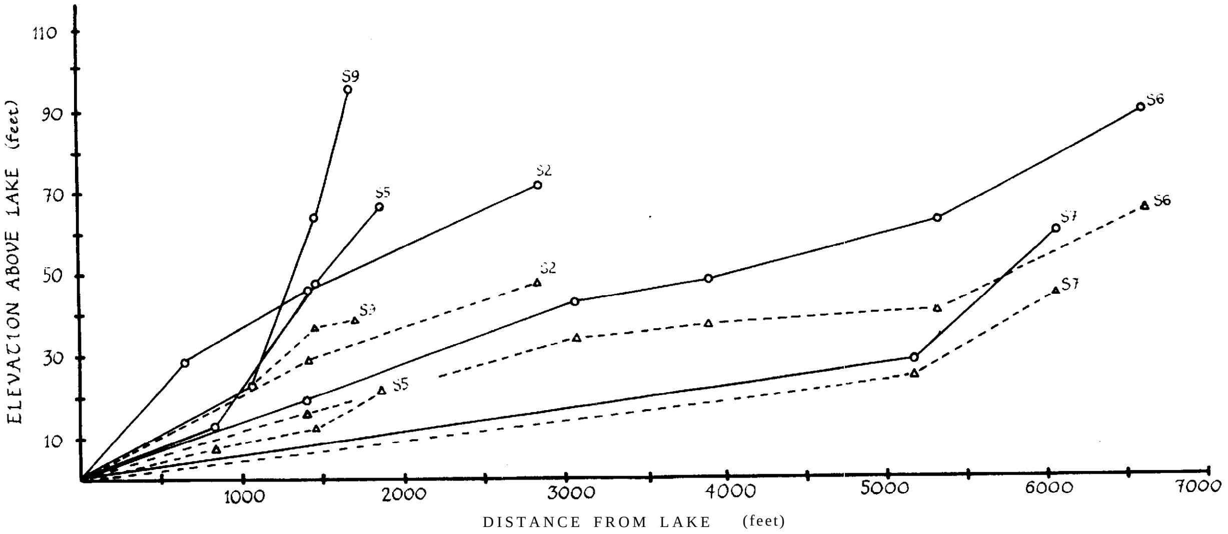


Figure 2-13. GROUNDWATER PROFILES. The solid line displays the profile of the land surface. The dashed line displays that of the water table. The profile numbers represent the transects located in Figure 1-1:

S2 --- The Cemetery } Sector one
S5 --- Sneaker Flat
S9 --- Mono Park
S7 --- Warm Springs Sector four
S6 --- Dechambeau Ranch Sector five

Note that the steepest ground water gradients are S9 and S2 taken in sector one. S5, sneaker flat, is shallower, and was taken on Lee Vining Delta which is possibly made of more permeable material. The shallowest profile is S7 taken in sector four. S6, taken in sector five, displays an intermediate gradient.

flow. The majority of these inflows come from the western portion of the basin, along the Sierra Nevada escarpment.

The historic precipitation on the lake can be approximated by multiplying the long-term average mean precipitation by an indicator representing the percent of the mean for any one year. These indicators were derived in three ways: by using data from the different weather stations, by using the percent of the average measured total streamflow, and by using an indicator derived by S. T. Harding.

Streamflow measurements have been taken by the LADWP on the major western creeks. The recorded flow is a measure of the surface runoff as well as an implicit measure of much of the groundwater flow. It must be adjusted in some way, however, before it represents the true inflow into Mono Lake.

HYDROLOGICAL MODEL

Explanation of the Model: While the hydrological model is conceptually simple, it required millions of computations, and a computer was used to speed the process.

The model was made like a water budget:

(1) (Outflow) - (Inflow) = (Decrease in Lake Volume)

or

(2) (Evaporation)-(Ground Water and Stream Inflow)-(Precipitation) = (Decrease in Lake Volume)

This simple equation describes the lake. If future inflow and outflow can be predicted, the future lake volume (and hence the lake elevation) will follow.

As noted in the last section, the inflow to the lake cannot be measured accurately. The measured streamflow is an approximation of the surface and groundwater inflow, but it must be adjusted in some fashion in order to represent the actual inflow. In the remainder of this discussion, measured streamflow will be denoted as approximate inflow and the actual surface and ground water inflow as real inflow.

The 1921-1975 period was used to determine the relationship between the approximate and the real inflows. For 1937 and subsequent years, the approximate inflow was measured. As previously noted, the pre-1937 approximate inflow was estimated by its relation to the natural flow of Mill Creek. For the years preceding 1921, the predicted approximate inflow bore no relationship to the real inflow. Consequently, only the post-1921 period was used to determine the relationship between the real and approximate inflow. The extrapolation becomes less accurate as the predictions move farther away from the 1937-1975 base period. However, it was unexpected that the extrapolation would break down completely. Possibly the method by which the flows from Mill Creek were measured changed in 1921, although no record of such a change could be found. It should be recognized that the failure of this method of estimating streamflow represents a weakness in the inputs to the model.

Different evaporation, precipitation, and diversion rates were tested with the model in order to understand the effects of the assumptions on the predicted future lake levels. Because the values for the different assumptions are only known within a range (i.e., the average precipitation is between 7.3 and 8.3 in/yr), a range of assumptions must be tried, and the future lake levels can only be specified within a range.

Table 2-14 displays the relevant data for one set of assumptions. An "est" by a value indicates that it was estimated. From this data a theoretical water budget was computed. Column 1 records the year. Column 2 shows the January 1 lake level. (These values are interpolations of the lake level records kept by the LADWP.) Column 3 shows the change in lake level for the year. Column 4 displays the average surface area. It is the average of the January 1 area for the year considered and for the next year. The relation between lake level, area, and volume is interpolated from an area and capacity table prepared by the LADWP. Column 5 is the change in the lake's volume during that year. Negative values denote a decrease in volume, and positive values denote an increase. Column 6 is the precipitation indicator discussed in the section on rainfall. It

TABLE 2-14

HISTORICAL VARIATIONS OF MONO LAKE

Average Rainfall on the lake is 7.8 Inches
Standard Evaporation is 44 In. (uncorrected)
Weather Station Precipitation Indicator

(1) Year	(2) Lake Level Feet	(3) Lake Change Feet	(4) Ave Area Acres	(5) Capty Change Acre-Feet	(6) Precip. %	(7) Total Acre-Ft	(8) Evaporation SP G	(9) Total Acre-Ft	(10) Inflow	(11) Mts	(12) Diversion	(13) Remainder
										-------------Acre	Feet-----------	
1932	6417.59	-0.40	55062.2	-22033.	92.7	33178,	1.04	201307.	146096.	163187. EST		163187. EST
1933	6417.19	-1.12	54840.0	-61440.	91.9	32759.	1.04	200453.	106255.	118857. EST	0.	118857. EST
1934	6416.07	-1.37	54476.2	-74605.	61.2	21671.	1.04	199007.	102737.	87522. EST	0.	87522. EST
1935	6414.70	-0.30	54232.1	-16268.	135.3	47694.	1.04	197970.	134007.	117579. EST		117579. EST
1936	6414.40	0.17	54213.1	9213.	115.7	40771.	1.04	197867.	166309.	167404. EST	0.	167404. EST
1937	6414.57	0.01	54239.4	543.	121.1	42695.	1.04	197982.	155830.	148395. EST	0.	148395. EST
1938	6414.58	3.34	54729.2	182776.	170.9	60796.	1.04	199771.	321751.	260425. EST		260425. EST
1939	6417.92	-1.03	55066.7	-56718.	63.1	22586.	1.04	201357.	122054.	100846. EST	0.	100846. EST
1940	6416.89	-0.33	54867.7	-18089.	111.1	39623.	1.04	200523.	142811.	156170. EST	5774: EST	150396. EST
1941	6416.56	0.26	54857.4	14250.	130.3	46467.	1.04	200451.	168240.	199357. EST	38524.	160833. EST
1942	6416.82	-0.05	54888.1	-2743.	64.3	22940.	1.04	200590.	174907.	193164. EST	7373.	185791. EST
1943	6416.77	0.39	54937.8	21427.	104.2	37209.	1.04	200767.	184985.	192091. EST	10574.	181517. EST
1944	6417.16	-1.20	54819.6	-65795.	81.6	29076.	1.04	200375.	105504.	117374. EST	53366.	64008. EST
1945	6415.96	1.05	54797.6	57523.	142.1	50614.	1.04	200169.	207078.	175011. EST	4226.	170785. EST
1946	6417.01	-0.03	54946.5	-1636.	128.1	45751.	1.04	200824.	153437.	157485. EST	15.	157470. EST
1947	6416.98	-1.67	54698.3	-91327.	24.7	8782.	1.04	199913.	99804.	103067. EST	30697.	72370. EST
1948	6415.31	-2.10	54147.4	-113708.	60.7	21364.	1.04	197725.	62653.	112494. EST	88573. EST	23921. EST
1949	6413.21	-2.12	53530.3	-113504.	77.8	27070.	1.04	195246.	54672.	106665.	83733.	22932.
1950	6411.09	-1.44	53005.0	-76305.	104.8	36107.	1.04	193094.	80682.	128328.	96741.	31587.
1951	6409.65	-2.13	52448.2	-111718.	107.4	36614.	1.04	190901.	42569.	138929.	96970. EST	41959
1952	6407.52	0.81	52236.7	42310.	105.1	35694.	1.05	189878.	196494.	208742.	8969. EST	199773.
1953	6408.33	-1.69	52095.7	-88037.	46.1	15615.	1.05	189463.	85811.	116060.	69691.	46369.
1954	6406.64	-2.17	51477.1	-111699.	83.6	27968.	1.05	187011.	47343.	91356.	43204.	48152.
1955	6404.47	-1.79	50842.5	-91014.	168.1	55545.	1.05	184437.	37878.	107770.	92753. EST	15017. EST
1956	6402.68	-1.02	50392.2	-51400.	68.3	22363.	1.05	182575.	108811.	202607.	86994.	115613.
1957	6401.66	-1.01	50066.7	-50568.	114.9	37400.	1.05	181262.	93293.	121510.	47116.	74394.
1958	6400.65	0.16	49930.3	7973.	104.2	33818.	1.05	180633.	154788.	176080.	32524.	143556.
1959	6400.81	-1.86	49657.9	-92374.	69.7	22485.	1.05	179669.	64809.	92760.	88199.	4561.
1960	6398.95	-2.05	49031.5	-100510.	86.6	27600.	1.05	177150.	49040.	88462.	53806. EST	34656. EST
1961	6396.90	-2.30	48336.2	-111151.	77.0	24180.	1.05	174351.	39019.	78578.	59354. EST	19224. EST
1962	6394.60	-1.50	47730.1	-71620.	118.8	36853.	1.06	171830.	63356.	149388.	97110.	52278.
1963	6393.10	-1.20	47299.4	-57476.	151.3	46509.	1.06	170053.	66068.	159522.	89907.	69615.
1964	6391.90	-2.18	46760.2	-101197.	90.5	27522.	1.06	167926.	39207.	95096.	83229. EST	11867. EST
1965	6389.72	-1.07	46153.8	-49477.	126.4	37920	1.06	165403.	78006.	173492.	88490.	85002.

TABLE 2-14, Cont'd.

(1) Year	(2) Lake Level Feet	(3) Lake Change Feet	(4) Ave Area Acres	(5) Capty Change Acre-Feet	(6) Precip. %	(7) Precip. Total Acre-Ft	(8) Evaporation SP G	(9) Evaporation Total Acre-Ft	(10) Inflow	(11) Mts	(12) Diversion	(13) Remainder
									--------------Acre Feet		-----------	
1966	6388.65	-1.91	45678.2	-87414.	89.1	26454.	1.06	163523.	49654.	111955.	81568.	30387.
1967	6386.74	1.55	45530.7	70841.	116.3	34426.	1.06	162669.	99084.	227228.	11279.	215949.
1968	6388.29	-1.97	45463.7	-89910.	63.5	18769.	1.06	162695.	54016.	97807.	76356.	21451.
1969	6386.32	2.48	45672.5	113382.	153.5	45573.	1.06	163102.	230910.	238231.	20550.	217681.
1970	6388.80	-1.44	45748.4	-66066.	99.2	29510.	1.06	163799.	68223.	132492.	90604.	41888.
1971	6387.36	-1.86	45272.2	-84364.	96.3	28334.	1.06	161853.	49154.	132890.	99276. EST	33614. EST
1972	6385.50	-1.93	44606.3	-86149.	74.9	21720.	1.06	159151.	51281.	108116.	99023.	9093.
1973	6383.57	-1.43	43678.1	-62618.	121.5	34566.	1.07	155817.	58633.	157902.	96086.	61816.
1974	6382.14	-1.94	42875.0	-83165.	93.2	25977.	1.07	152378.	43236.	171240. EST	134559.	36681. EST
1975	6380.20	-1.50	41963.3	-62931.	93.8	25575.	1.07	148781.	60275.	151341. EST	114613.	36728. EST
1976	6378.70											

represents the percent of the mean precipitation which fell on the lake that year. Column 7 is the total precipitation on the lake. This equals the percent of the mean precipitation times the average precipitation times the lake area. (Column 7 = Column 6 x (average precipitation in feet) x Column 4). Column 7, precipitation on the lake in acre-ft is one of the inflow parameters in the water budget equation. Column 8 holds specific gravity (although it is only shown to two significant digits, it is calculated to more). Column 9 is the total evaporation from the lake. This equals the evaporation rate times the lake's area times the specific gravity correction factor. The correction factor was calculated as described in the section explaining the outflow. Column 9 gives the total outflow from the lake.

Column 10 is the calculated (not the measured) stream and groundwater inflow. From the water budget equation equation #2) it is evident that

(3) (Stream and ground water inflow) = (Evaporation) - (Decrease in Lake Volume) -(Precipitation)

Alternatively:

(Column 10) = (Column 9) - (Column 5) - (Column 7)

Column 11 gives the total surface flow measured by the LADWP (or its estimate). Column 12 gives the diversion by the city. This doesn't include the gain through the Mono Craters tunnel, and it is only the outflow from Grant Lake minus the discharge from Mono Gate Number One. Column 13 records what is left after the diversions to flow toward the lake. (Column 13)=(Column 11)-(Column 12).

If the measured streams flowed directly into the lake and included all of the stream and groundwater flow in the basin, column 13 would equal column 10, or the approximate inflow would equal the real inflow. Fortunately, they are linearly related (Figure 2-15). A standard linear regression resulted in a correlation r=.91 through r=.96 depending on the assumptions used. (For a perfect correlation, r=1.00. A coefficient of .9 or .95 denotes a good correspondance between physical data.)

For the data displayed in the figure the regression equation is: Real inflow (Column 10)=876 x Approximate inflow (Column 13) + 20363 (Correlation coefficient r=.958, r^2=.918). The coefficients of the linear regression equation have some physical meaning and will be discussed under the section on testing the model.

To predict with the model, one needs to know some average future measured inflow and the expected annual diversion rate. The average 1921-1975 measured inflow is 137,135 acre-ft/yr. This value is assumed to represent the future. By subtracting the diversion rate from this figure, one obtains the average approximate inflow. Knowing the regression coefficients, one can calculate the average real inflow.

The water budget equation is:

(2) (Evaporation)-(Ground Water and Stream Inflow)-(Precipitation)= (Decrease in Lake Volume)

The following equations are also true:

(4) (Precipitation)=(Precipitation Rate) x (the Lake's Surface Area)

(5) (Evaporation)=(Evaporation Rate) x (the Lake's Surface Area)

The water budget equation can therefore be rewritten:

(6) (Evaporation Rate)-(Precipitation Rate) x (Lake Area) - (Real Inflow)= (Decrease in Lake Volume)

Equation number six is not as straightforward as it appears. The lake area represented in the equation is really the average lake area for that time period. This is the beginning and end lake area divided by two. Since the end lake area isn't known until the decrease in lake volume is computed, there are actually two unknowns in the equation and it must be solved by an iterative technique.

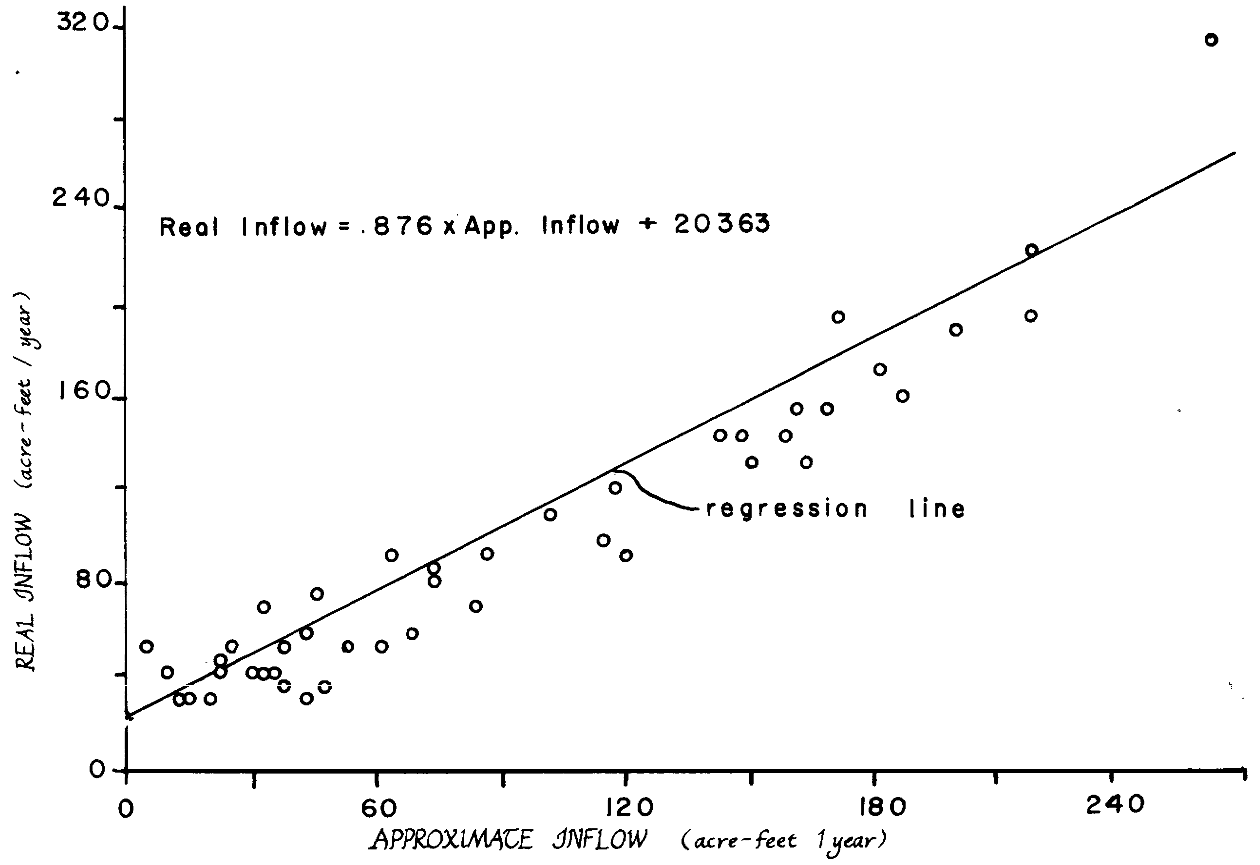


Figure 2-15. APPROXIMATE INFLOW vs. REAL INFLOW

With each successive year, the lake area will be decreasing; consequently the lake volume will decrease less and less each year. Therefore the lake will drop quickly at first, but then the rate of decline will slow down. Eventually the lake will stabilize (decrease in volume = 0). When this is the case (from equation number six):

$$(7)\quad \text{(Lake Area)} = \frac{\text{(Real Inflow)}}{\text{(Evaporation rate - Precipitation rate)}}$$

The stabilization area of the lake can be calculated directly, knowing an average real inflow (acre-ft/yr), an average precipitation rate (ft/yr) and an average evaporation rate (ft/yr).

The above process is conceptually identical but mathematically more complicated if the evaporation rate is not a constant, but is a function of the specific gravity. For the equation calculating the decrease in lake volume there should be an additional iteration to calculate the average specific gravity which can only be known by finding the new lake volume from the calculated decrease in lake volume. However, since specific gravity changes only slowly with lake volume, it was calculated before each set of iterations and assumed to remain constant during the iteration process. This avoided a repetitious calculation. However, the iteration could not be avoided for the equation calculating the area of the lake at stabilization.

The model, then, consists of two parts. The first part used the historical record as a basis for the linear regression between the post-diversion streamflows in the southwest section of the basin and the real inflow as calculated from the water budget equation. The second part used this relationship to find an average inflow from which the yearly decrease in lake volume and the lake volume at stabilization were calculated.

Several assumptions were tested with this model. Average precipitation rates of 7.3, 7.8, and 8.3 in/yr were used. Three different rainfall indicators, discussed in the section explaining rainfall, were examined. Evaporation rates of 36, 39, 42, and 45 in/yr were used. In addition, as noted previously, these evaporation rates were employed with and without a correction for increasing specific gravity (decreasing evaporation). When specific gravity corrections were used, evaporation rates were picked so that the corrected rates turned out to be 36, 39, 42, and 45 in/yr in 1976. This made the results from the two methods comparable. As a final condition, different diversion rates were tested. There are 72 different assumptions for each diversion rate.

The different precipitation rates all give approximately the same results. This is because precipitation contributes only a small amount toward the total inflow to the lake. Since 7.8 in/yr was found to be the most likely rate during this study, it will be the one discussed. In addition, only the 39 and 42 in/yr evaporation rates will be discussed (Appendix 2-2).

Testing the Model: The most effective way to test the model is to let it start its predicting process not in 1975 but in 1940 and compare the 1940-1975 predictions with the historical record. The year 1940 was picked so that there would be a previous record with which to calibrate the model.

Figure 2-16 displays the results using the precipitation indicator derived from streamflows, average precipitation of 7.8 in/yr, and an evaporation rate of 42 in/yr with no correction for increasing salinity. For comparison, the actual streamflow, diversion, and precipitation measurements for each year were used, instead of averages, which must be used for predicting future rates. Note that the prediction starts 1/2 foot high in 1941 and ends 3-1/2 feet high in 1975. During this 35 year period, the lake dropped over 36 feet. This is a slightly greater drop than will occur in the next 35 years. The linear regression correlation coefficient relating the approximate inflow to the real inflow was only .78 for the 1921-1940 calibration period. If a longer period of record is used for calibration, the derived relation between the real and approximate inflow becomes more accurate and the resulting prediction becomes more precise. If the same calibration period is used, but evaporation is set to 39 in/yr instead of 42, the 1975 prediction is slightly less than 3 feet higher than actual. Specific gravity corrections are minor until the lake volume decreases significantly past its 1976 value. Consequently, the test was not run with this condition,

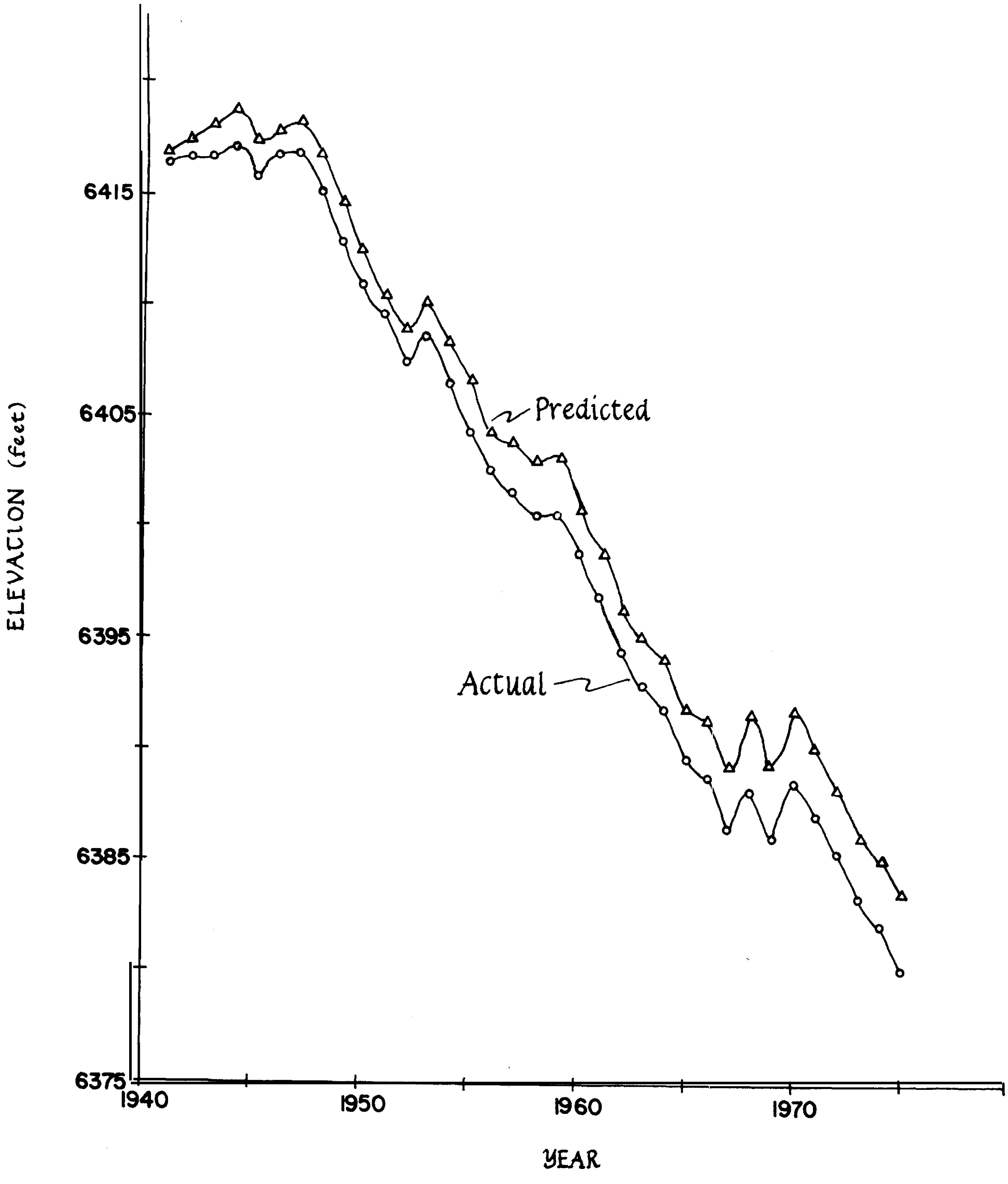


Figure 2-16. PREDICTED AND ACTUAL LAKE ELEVATIONS

Average precipitation = 7.8 in/yr
Evaporation = 42 in/yr
Stream flow precipitation indicator

The weather station precipitation indicator was also run for the different assumptions. It was necessary to use a different calibration period, however. The streamflow indicator can be calculated back to 1921, but the weather station data begins in 1932. As a result, the calibration period had to extend to 1950 in order to derive a meaningful correlation. For an evaporation rate of 42 in/yr, the model is 1-1/2 feet high. The fact that the deviations of the predicted lake levels from the actual levels are small builds confidence in the model's predicting ability.

The model can be tested in another way. The constants in the regression equation have some physical significance and form a sort of test for the model. The equation relating the approximate inflow to the real inflow takes the form:

(8) (Real Inflow) = 3 x (Approximate Inflow) + A

where B and A are the regression equation constants. B represents the fraction of the approximate inflow which reaches the lake. For example, if B equals .8, then 80% (or .8) of the approximate inflow reaches the lake and 20% evaporates or is lost in some other way. Unfortunately, it is impossible to estimate B from other information, but if any water is lost in the passage from the stream gauge to the lake, B should be less than 1.00. B was calculated to be slightly greater than .8 for all assumption combinations.

Coefficient A represents the amount of stream and ground water inflow from areas other than those where the measurements were taken. This can be seen if one considers what would happen if, for some reason, there were no measured streamflow left after the diversion. In that case the approximate inflow would equal zero. The rest of the basin would still contribute something to the inflow total, however. A must represent that contribution.

There is very little streamflow which doesn't come from the measured creeks. The A should therefore represent mostly groundwater flow. Lee (p. 49) estimates the groundwater flow to the lake to be 39,500 acre-ft/yr. The calculated A should be somewhat less than this, for the approximate inflow includes some implicit measure of groundwater flow.

The calculated A value is greater than 20,000 acre-ft/yr for evaporation rates of 39 in/yr or greater, For evaporation rates greater than 42 in/yr, the calculated A values are greater than 40,000 acre ft/yr. The "correct" evaporation rate, then, appears to be between 39 and 42 in/yr (See Table 2-17.). Note that the B values for the precipitation indicator derived by S. T. Harding seem too high (.95) and the A values seem too low. The correlation coefficient (r) is also the lowest of the three indicators. This indicator has the shortest period of record for calibration (1921-1941) and it is to be expected that its results are the least accurate,

<u>Predictions</u>: Different diversion rates have different effects on the lake. While this chapter of the report deals only with the lake, it should be remembered that the effects are far-reaching. Because future diversion rates will result from political and management decisions, knowledge of the effects of the diversions on the ecosystem, and on the lake in particular, should be available,

Different assumptions give somewhat different stabilization levels for the lake. For constant evaporation, these predicted levels are shown in Figure 2-18. Three diversion rates are given. A number of conclusions are evident. Changing the assumed precipitation falling on the lake produces an insignificant change in the stabilization level, because the contribution of rainfall to the total inflow is minimal. Also, the weather station precipitation indicator (denoted by R in the figure) consistently gives a stabilization level five to ten feet lower than the indicator derived from streamflows (denoted by S).

Increasing the assumed evaporation increases the equilibrium lake level. This seemingly unexpected result is produced by the nature of the relationship between the approximate and the real inflow. The real inflow was calculated from the water budget equation. Increasing the assumed evaporation is equivalent to increasing the outflow from the lake. To maintain the historic decreases in lake volume, the calculated inflow must go up. The measured streamflows are known for each year. If the calculated inflow goes up, the amount of inflow coming from other portions of the basin must be higher. (This is equivalent to saying that the A values increase in the regression equation. (Equation 7).) Diverting the measured streamflow is then diverting a smaller fraction of

TABLE 2-17

Evaporation (in/yr)		Weather Station Indicator No Evaporation Correction	Weather Station Indicator with Evaporation Correction	Streamflow derived Indicator No Evaporation Correction	Streamflow derived Indicator with Evaporation Correction	Indicator derived by Harding No Evaporation Correction
36	r=	.9572	.9580	.9064	.9066	.8163
	A=	-3773	403	3828	8353	-9999
	B=	.863	.873	.809	.821	.967
39	r=	.9578	.9582	.9067	.9064	.8152
	A=	8295	13341	16080	21513	-1952
	B=	.869	.881	.816	.829	.965
42	r=	.9581	.9581	.9068	.9059	.8141
	A=	20362	25495	28331	33876	12110
	B=	.876	.888	.823	.837	.963
45	r=	.9583	.9578	.9067	.9051	.8129
	A=	32429	38041	40583	46637	26169
	B=	.882	.895	.830	.845	.962

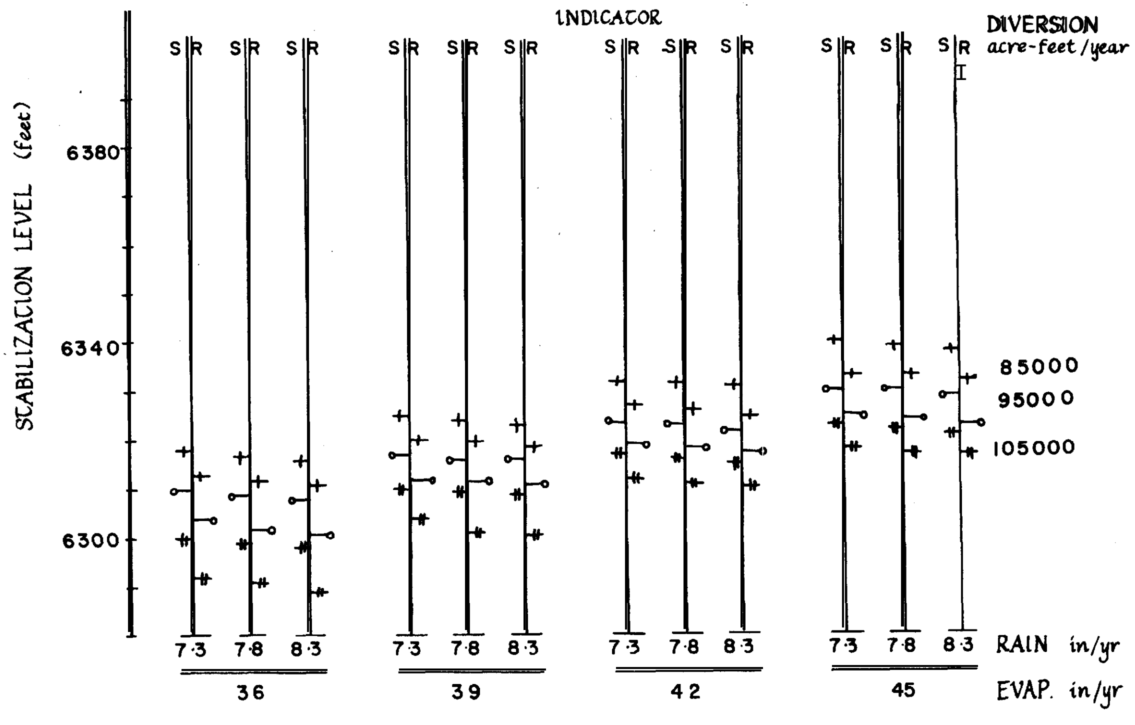


Figure 2-18. STABILIZATION LAKE ELEVATIONS - NO SALINITY CORRECTION ON EVAPORATION

85,000 acre-ft/yr diversion
95,000 acre-ft/yr diversion
105,000 acre-ft/yr diversion

the total inflow, and the result is a higher lake level at stabilization.

For the diversions shown (Figure 2-18), 85,000 to 105,000 acre-ft/yr, the level calculated for the "correct evaporation" (between 39 and 42 in/yr) is between 6,300 and 6,330 feet. If the evaporation correction is included in this picture, the results change dramatically. Figure 2-19 shows these results (using an average precipitation of 7.8 in/yr). The difference in stabilization level, with and without the evaporation correction, is often over 15 feet.

The calculated stabilization level with no correction for increases in salinity should be considered a lower bound for the equilibrium lake level, and the corrected condition the upper bound. Between these two lies the true value. For example, for a diversion of 95,000 acre-ft/yr the final lake levels range from 6,318 to 6,383 feet. As the evaporation is probably neither 39 nor 42 in/yr but somewhere in between, and the evaporation corrections give a stabilization level which is too high, while the uncorrected conditions give one that is too low, it is unlikely that the lake will stabilize in the extremes of the 6,318-6,338 range. The correct level for a diversion of 95,000 acre-ft/yr is probably 6,328 feet.

There is one other item of interest in Figure 2-18. If there are no diversions, all the assumptions produce stabilization levels near 6,400 feet, This is the natural equilibrium of the lake in response to the 1921-1975 climatic conditions.

By varying the diversion rates used with the model, one can obtain a more general relationship between the diversion and the stabilization lake level (Figure 2-20). For simplicity, the results using corrected evaporation rates of 39 in/yr are not shown. However, they are parallel to the 42 in/yr solution but are 5 to 7 feet lower. Taking the true evaporation rate as being between 39 and 42 in/yr, the corrected evaporation rate as an upper bound and the uncorrected evaporation rate as a lower bound to the stabilization level, one can construct an average, or most probable relationship between the diversions and the equilibrium lake level (Figure 2-21). It is noteworthy that the accuracy of Figure 2-21 increases with decreasing diversions. In other words, the different assumptions suggest a broader and broader range as the diversions increase.

It is evident from the figure that if Los Angeles continues the present diversion of approximately 100,000 acre-ft/yr, the lake will stabilize at 6,323 ft. This is 55 percent of the present (1976) surface area and 29 percent of the volume. The outlines of this lake level are shown in Figure 2-22. At this level neither Paoha nor Negit are islands; both are connected to the shore.

Depth soundings made during the course of this study indicate that the lake must remain above 6,359 feet (18 feet below the 1976 level) in order to keep Paoha separated from the shore. Running the model for 200 years after equilibrium was reached indicates that fluctuations of about 5 feet can be expected for the 1921-1975 climate conditions. Therefore the lake must remain above 6,364 feet to maintain Paoha as an island. To do this, diversions would have to be cut back to approximately 55,000 acre-ft/yr. To maintain Negit Island with a 5 foot buffer zone, the lake would have to be raised to 6,380 feet. This corresponds to diversions of about 25,000 acre-ft/yr.

The foregoing analysis makes no mention of the lake's approach to equilibrium. The approach was calculated for each of the assumptions discussed above. From the expanded water budget equation (Equation 6), it is evident that the decrease in lake volume is a function of area. Since the area is constantly decreasing, the lake will fall quickly at first (approximately 1.5 feet/yr as at present) and more slowly as the lake nears its equilibrium point. A representative example appears in Figure 2-23. Although not shown in the figure, a diversion of 100,000 acre-ft/yr means that Paoha will be connected to the shore before the year 2010. For all assumption possibilities, Negit will be connected some time within the next two years.

Where would the lake be if Los Angeles had never diverted any water? When this condition was run with the model, the result was the top line in Figure 2-23. The 1975 lake elevation would have been 6,410 feet, and the lake would still be falling toward its equilibrium level of 6,400 feet. This shows that the post-1940 lake decline (below 6,400 ft.) was not caused by climatic conditions as the pre-1940 decline was, but was caused by the diversion of water to Los Angeles.

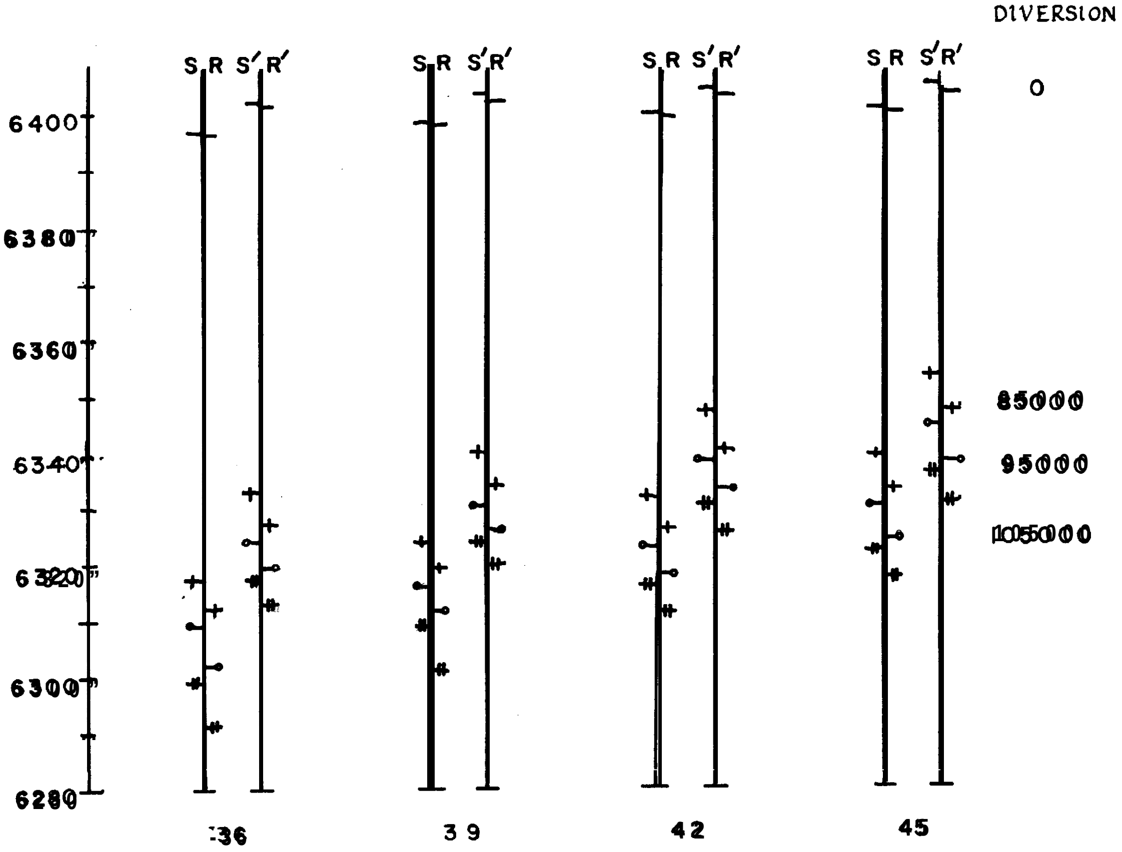


Figure 2-19. STABILIZATION LAKE ELEVATION INCLUDING SALINITY CORRECTION ON EVAPORATION

85,000 acre-ft/yr diversion

95,000 acre-ft/yr diversion

105,000 acre-ft/yr diversion

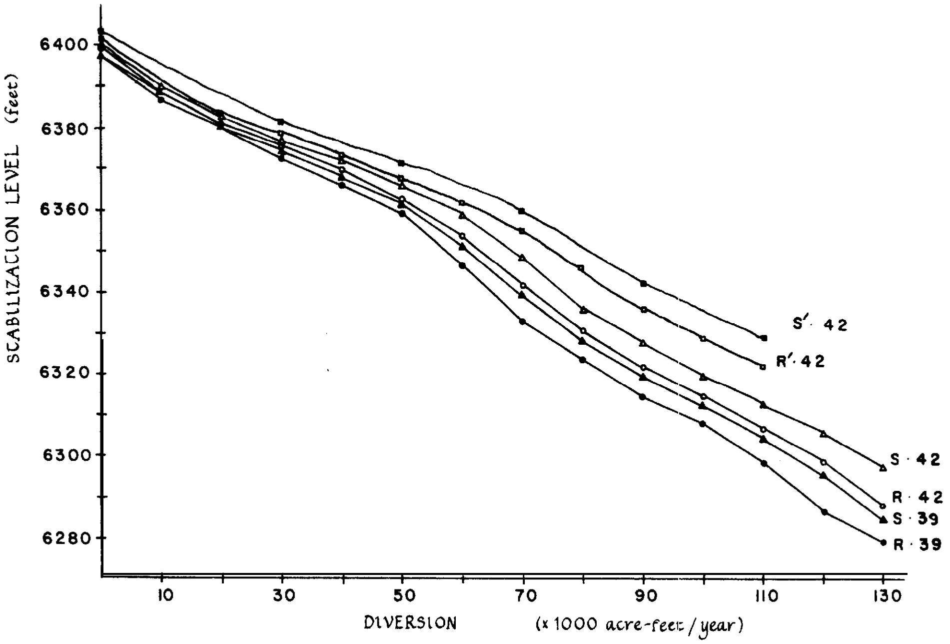


Figure 2-20. DIVERSION vs EQUILIBRIUM LAKE ELEVATION

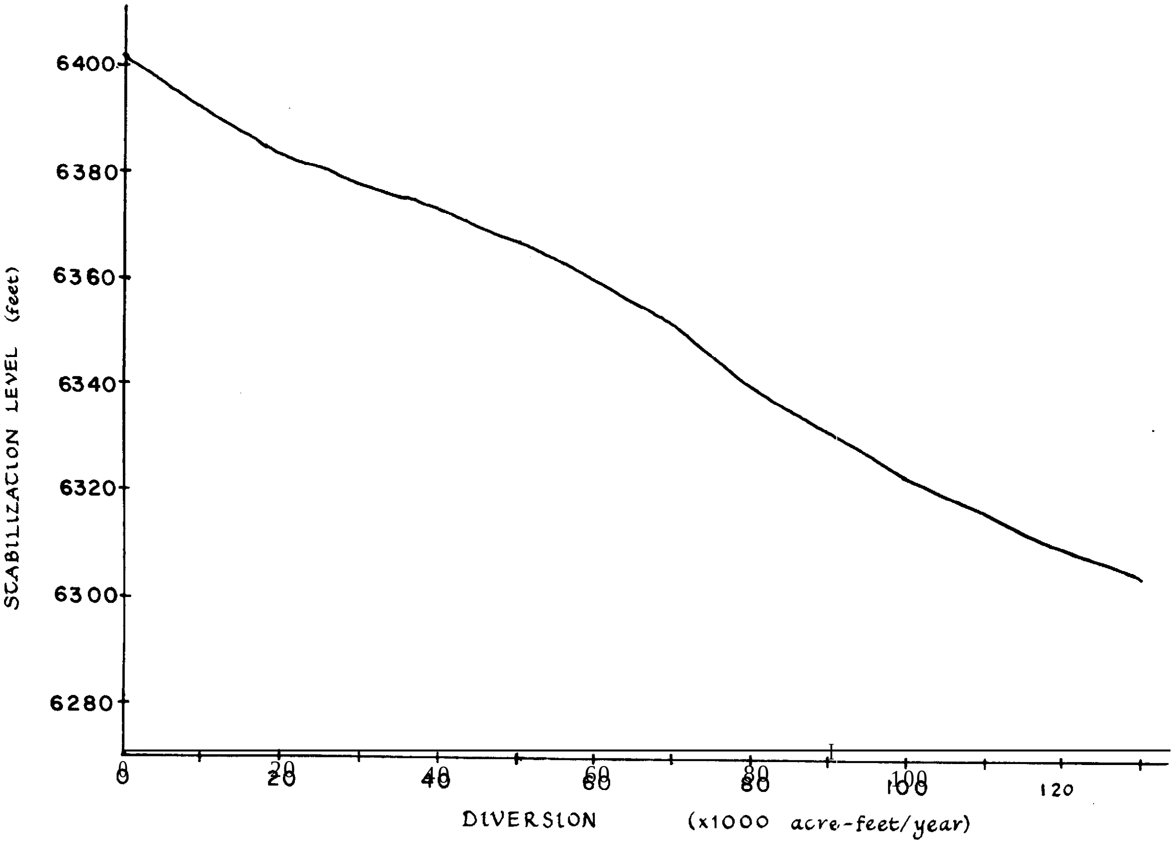


Figure 2-21. DIVERSION vs EQUILIBRIUM LAKE ELEVATION

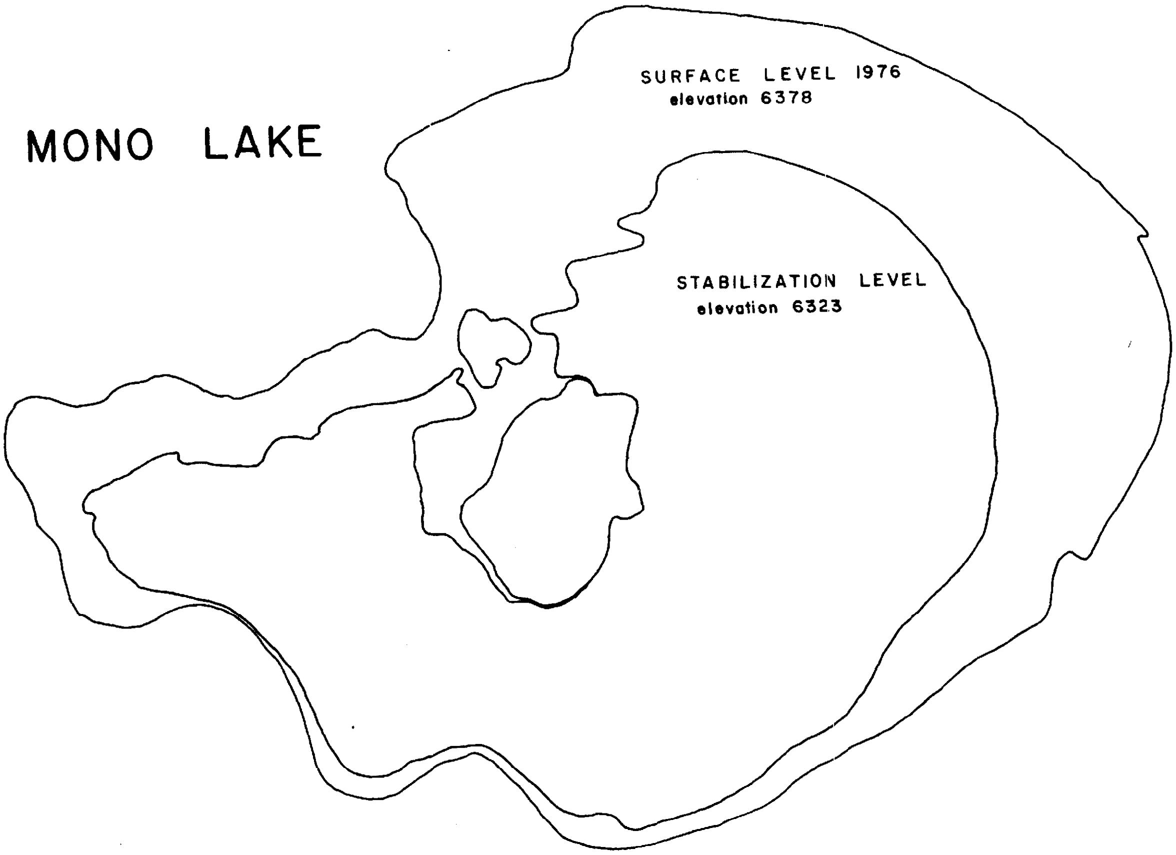


Figure 2-22. THE OUTLINE OF THE 1976, AND THE EQUILIBRIUM LAKE

Diversion is assumed to be 100,000 acre-ft/yr

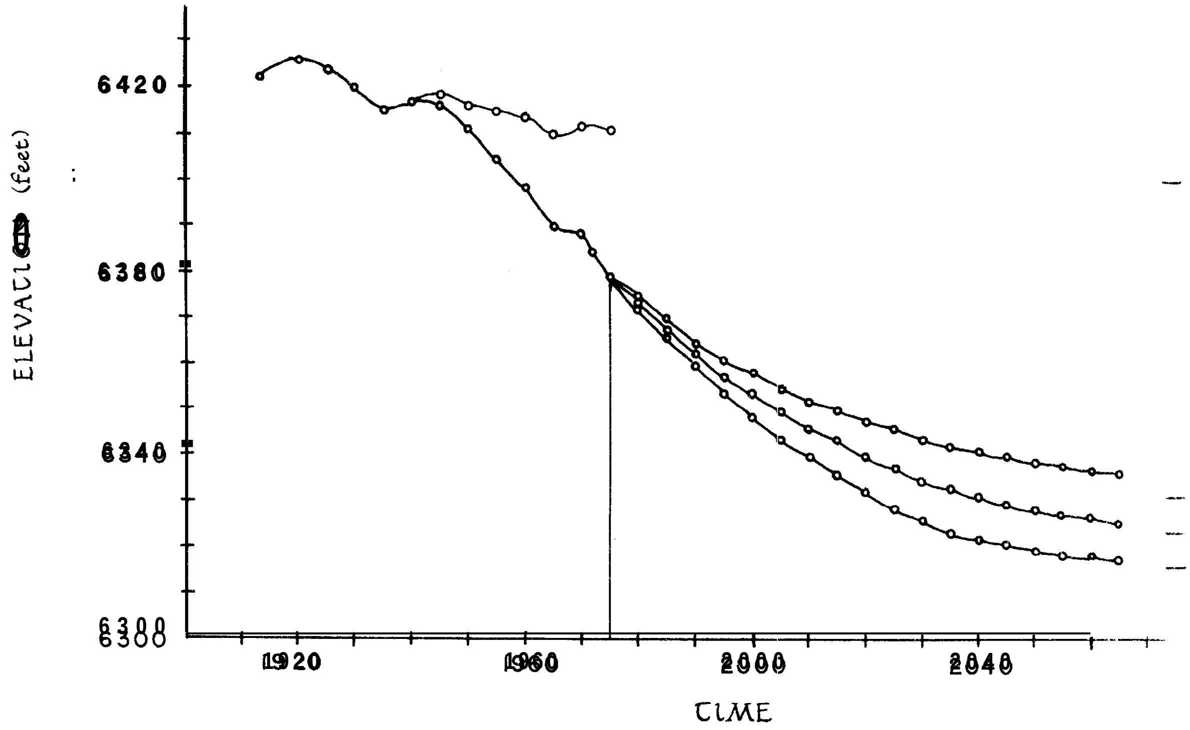


Figure 2-23. THE PREDICTED FUTURE ELEVATIONS OF MONO LAKE

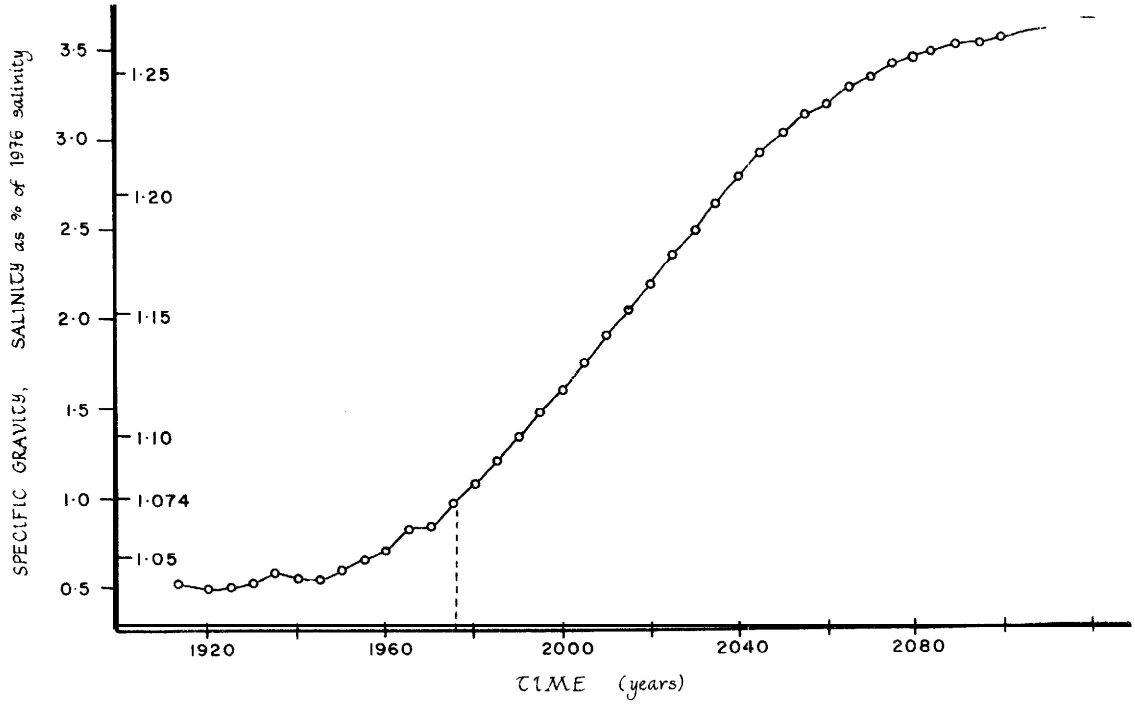


Figure 2-24. THE PREDICTED UPPER BOUND FOR THE SALINITY OF MONO LAKE

The discussion has only dealt with the lake's elevation, but many important parameters are associated with the lake's decline. An upper bound for the salinity or specific gravity can easily be calculated from the new lake volume. (This was discussed in the section dealing with outflow from the lake.) Mono Lake's future salinity is predicted in Figure 2-24 for diversions of 100,000 acre-ft/yr. Note that at equilibrium the lake could be up to 3.67 times as salty as it is now (or seven times as salty as the ocean!).

As noted in the section discussing the geologic processes, the newly exposed soil is an important parameter in the dust problem in the basin. Since the lake's high water mark in 1919, 15,300 acres of new shoreline have been exposed. As the lake recedes to 6,323 feet, 46% of its present area, or 19,100 additional acres will be exposed. The dust problem is going to increase.

The average depth of the lake and the amount of soil exposed can be determined for any lake elevation from Figure 2-25. This graph displays the cumulative percent of surface area for any depth interval. It was drawn from the bathymetric chart of Mono Lake determined by Scholl (1967) relative to the 1965 lake elevation of 6,390 feet. Despite its rather forbidding appearance, it is relatively straight-forward.

Taking a lake elevation of 6,325 feet, one can see that this is 65 feet below the 6,390 foot surface for which the graph was drawn. It corresponds to 49% of the surface area of the 1965 lake. The surface area of the lake in 1965 was 46,154 acres, so the surface area of the 6,325 foot lake is 49% of it, or .49 times 46,154. This means that 22,728 acres would be exposed by the receding lake,

Making the lake shallower will affect its heating and cooling. The section of the report on physical limnology (Chapter 3.1) explains the lake's thermal structure, but it is appropriate to mention here that a shallower lake might heat up more efficiently during the spring, and the thermocline might be driven to the lake bottom in many areas. If this happens, the lake will be well mixed throughout most of the summer instead of thermally stratified as it is now.

In conclusion, the predictions described here are the changes wrought in one part of the system, the lake. It is important to see the lake as part of its larger geological and biological context. This chapter attempts to predict the lake's response to man-made changes; it attempts a preview of a scene that will take decades to arrive.

SUMMARY

Mono Lake is the remnant of the much larger Pleistocene Lake Russell. It is a relatively old lake, having existed continuously for at least 500,000 years. Since the last glacial epoch, 12,000 years ago, the lake has maintained approximately its present level, fluctuating between 6,365 and 6,480 feet (Lajoie, 1968).

In 1940, the City of Los Angeles began diverting streamflow from the southwest section of the basin. These diversions were increased until the early 1970's, when they reached 100,000 acre-ft/yr. Since the early 1920's the lake has been shrinking, at first in response to a drier climatic cycle, but, since 1940, because of the diversion of water to Los Angeles.

If the present climatic cycle and the present diversion rate of 100,000 acre-ft/yr continue, Mono Lake will drop 53 feet to an elevation of 6,323 feet (Figure 2-22). It will then contain 54% of its present (1976) surface area and 29% of its volume. Negit Island will become connected to the shore some time during the next two years; Paoha, before 2010. The lake will be within one foot of its equilibrium level just after the middle of the next century (Figure 2-23). If Los Angeles had never diverted any water, the 1975 lake level would have been 6,410 feet, 30 feet above the present level. It would be falling toward 6,400 feet, where the lake would stabilize in response to the present climate.

If the lake does decrease to an elevation of 6,323 feet, nearly 20,000 acres of new soil will be exposed. The current dust storms in the basin take much of their material from the newly-exposed soil.

The future levels of Mono Lake depend on how much water is diverted by Los Angeles (Figure 2-21). To maintain Paoha as an island with a five-foot margin of safety, no more than 55,000 acre-feet of water could be exported from the basin each year. To maintain Negit with a five foot buffer zone, no more than 25,000 acre-feet could be taken; this would result in the stabilization of the lake above its present level.

Chapter 3

LIMNOLOGY

INTRODUCTION

Limnology is devoted to the study of lake ecology. Most lakes are freshwater (i.e., not salty or saline) and have both inflows and outflows. In contrast, Mono Lake is located in a closed basin and, like the sea, has no outflows except evaporation. Thus anything dissolved in the water entering the lake remains and accumulates. Three times as salty as the ocean, Mono Lake has as its principle dissolved constituents sodium, chloride, carbonate, and sulphate ions. Additionally, the carbonate ions impart a highly alkaline or caustic character to the water (pH=9.7). These extreme conditions can only be tolerated by the few organisms adapted for survival in highly saline-alkaline waters. This makes Mono Lake an ecologically "open" environment, free to be colonized by those organisms who are sturdy enough to survive and reproduce. Consequently, the plants and animals able to exist in the lake (low diversity) have few competitors and can thus support great numbers of individuals (high productivity). The nutrient-rich waters allow prolific autotrophic growth (organisms appropriating energy from the sun and/or simple carbon compounds). In addition, specific mechanisms for obtaining food exist among the secondary consumers. Hence, the food chain or web of Mono Lake is simple, efficient, and highly productive. A non-competitive partitioning of food occurs between the filter-feeding bring shrimp and the substrate-scraping brine fly larvae, The low diversity of the community combined with the specific, non-overlapping pathways for energy flow in the food web are indicative of an unstable arrangement in the ecosystem. Any disruption of this fragile balance through fluctuations in environmental conditions or species composition could lead to the elimination of species presently found in the lake.

Previous work on the biological limnology of Mono Lake was done by Mason (1967). To predict the effects of habitat alteration on Mono Lake's biotic communities, more descriptive and laboratory work was needed. Three areas were investigated: (1) physical and chemical limnology, (2) the primary producer level, and (3) the secondary producer level. In the first section, only those physical and chemical parameters were measured which related directly to plant and animal distribution and metabolism. The primary producer section contains determinations of primary production, chlorophyll, phaeopigment and ATP. These provide an indication of algal biomass and photosynthetic capacity and rate. Species composition and distribution of algae were determined through identification and enumeration of samples and cultures. Bioassay experiments were conducted to assess what nutrients were limiting in the algae. Other experiments were designed to investigate the physiological stress (i.e., photosynthetic efficiency) caused by salinity increase. The section on secondary producers focuses on the distribution and abundance of *Artemia salina* and *Ephydra hians*. Finally, an experimental section describes the LC_{50} bioassay, solute regulation and respiration experiments conducted to examine salt stress in *Artemia* and *Ephydra*.

SUMMARY

Physical and Chemical Aspects

1. Physical and chemical parameters considered important to the planktonic organisms of Mono were measured.

2. A 20% increase in chloride since 1974 indicates that Mono Lake is rapidly becoming concentrated in its salt content.

Primary Producer Level

1. Characteristic of Mono Lake's primary producer level this summer were substantial levels of primary production, chlorophyll, ATP biomass and phytoplankton cells in the hypolimnion relative to the content of the surface waters.

2. Bioassay experiments suggest pronounced micronutrient limitation, particularly manganese.

3. The results of short term salinity tolerance experiments indicate a significant reduction of photosynthetic rates with a 25% increase in salinity.

Secondary Producer Level

1. Productivity of the open-water planktonic brine shrimp and the benthic brine fly larvae of the littoral region was high during the summer months.

2. Environmental factors regulating the distribution of these secondary producers are considered.

3. Characteristics of the biology, behavior and life histories of these animals are described.

Salinity Tolerance in the larval brine fly (Ephydra hians) and brine shrimp (Artemia Salina)

1. High mortality occurs among brine shrimp exposed to salinities higher than 1.2 M NaCl (210 g 1 total salinity). Brine fly larvae have low mortality at these high salinities. This situation is probably related to changing oxygen consumption and salt regulation.

2. The evidence examined here indicates that the present populations of larval brine fly and brine shrimp will not maintain their present high levels of production with the increased salinities expected for Mono Lake, and may be subject to extinction.

3.1 PHYSICAL AND CHEMICAL LIMNOLOGY

Gayle Dana, David B. Herbst, Connie Lovejoy, Bob Loeffler, Keith Otsuki

INTRODUCTION

Because the Mono Basin is an arid semi-desert open to the wind, Mono Lake receives a large amount of wind and heat energy. One of the most important physical aspects of the lake, its thermal structure, is directly dependent on these massive wind and heat inputs. Mono Lake undergoes a seasonal cycle, thermally stratifying in late spring and summer, and remaining almost isothermal in the fall and winter. The surface water temperatures of Mono range from 23°C to 2°C during this cycle (Lee 1969, p. 43). Because very little mixing occurs across the thermocline in the summer, this thermal-density discontinuity plays a crucial role in restricting the distribution of planktonic organisms as well as in determining the distribution and concentrations of various chemical constituents.

Mono is a closed basin saline lake, its salts totaling almost three times those of the ocean. Its pH is held a constant 9.7 by the action of the bicarbonate-carbonate buffering system. With the possible exception of manganese, nutrient limitation is not a regulating factor in primary production.

During the summer of 1976, we measured selected physical and chemical parameters of Mono Lake (see Table 3-l-l).

MATERIALS AND METHODS

Water temperatures were measured directly by mercury thermometer from a three liter Van Dorn water bottle brought up from various depths at the deep water and shallow water stations (see Figure l-l) on the lake. Secchi depth measurements were also recorded at the deep water and shallow water stations at approximately 0900 and 1000 hours respectively. Dates of secchi measurements correspond to dates of in situ primary production experiments (see section 3-Z).

One set of chloride analyses were made May 30, 1976, by the Argentometric method (APHA 1971). Dissolved oxygen was determined on September 9 by the Miller method (Walker et al. 1970). Alkalinity measurements as determined by potentiometric titration (APHA 1971) with 1N HCl, were taken at regular intervals throughout **the** duration of the study. Dissolved inorganic carbon was also determined by volume measurements of CO2 released upon acidification.

Table 3-1-1

CHEMICAL CONSTITUENTS OF MONO LAKE

MAJOR	$g.\ l^{-1}$
Na	29.5(29)
CO_3	18.9(16)
Cl	17.6(29)
HCO_3	11.2(15)
SO_4	10.3(29)
K	1.5(29)

MINOR	$mg.\ l^{-1}$
B	331(29)
*Sr	120
PO_4	74.5(29)
F	48(29)
*Br	40
Mg	33.4(29)
NO_3- N	26.4(29)(5.2-66)
SiO_2	24(29)
As	15.5(29)
*Li	10
*I	7
Ca	4.07(29)
*W	4
*NO_2-N	.02
*NH_4-N	1(2)(1.01-1.09)

MICRO	$ug.\ l^{-1}$
Fe	420(29)
**Al	40
**Ti	30
**Mn	20
**Cu	10
**V	7
**Ni	2
**Mo	1
**Co	.7
**Ge	.3

- all unmarked ions are averages of Los Angeles Department of Water and Power 1974 analyses.
- * from Mason 1967 (1957 USGS analyses)
- ** from Mason 1967 (1964 USGS analyses)
- numbers in parentheses indicate the number of values averaged, followed in some cases by the range of values.

Molarities of selected ions:

1976	Cl	.615	molar
1974	Na	1.28	"
1974	K	.039	"
1974	CO_3	.315	"
1974	HCO_3	.184	"

RESULTS

A depth-time diagram of isotherms at the deep water station (Figure 3-2-l) shows the thermocline moving from 12 m in mid-summer to 16 m in late summer. The September 1 measurement shows a situation of multiple thermal discontinuity.

Secchi depth measurements at the deep water station shown in Figure 3-l-1, indicate a relatively high light penetration in the mid-depths, with the greatest reading of 8.5 m on July 4. Light penetration of the surface waters receded on August 24 and September 3, when the secchi depth reached only 2 m.

Little variation was found in chloride concentrations, the values averaging 21.83 g 1^{-1}. The dissolved oxygen measurements at the deep and shallow water stations in Figure 3-l-2 show a clinograde type profile.

Alkalinity values remained constant throughout the summer, all depths having the same dissolved inorganic carbon concentration of 4.3 g 1^{-1}.

DISCUSSION

Wind action in the Mono Basin is partly accountable for the thermal stratification regime and the secchi depth trends for the summer. Winds were infrequent until mid-August when strong winds and cooler ambient temperatures were common. The result of this is the thermal stratification seen on August 24 (Figure 3-2-l). The upper 10 m are nearly isothermal, with a sharp decline in temperature at 16 m. By early September winds had calmed and air temperatures had risen, causing a restratification in the surface layers. The secchi depth measurements show a similar situation. The high winds caused the water to become turbid, as indicated by the shallow secchi depths on August 23 and 24 and September 3 and 12.

The clinograde oxygen profiles are indicative of productive waters after thermal stratification in the spring. Although hypolimnetic waters are relatively poor in dissolved oxygen, they are not entirely anaerobic. The low dissolved oxygen content of the hypolimnion could be attributed mainly to bacterial decomposition and also to plant respiration.

The alkalinity values are important because they illustrate the large amount of carbon available for photosynthetic purposes, Similar values of dissolved inorganic carbon were found by Mason (1967).

Chloride concentrations have increased almost 20% since 1974 (see Table 3-l-l). If an assumption is made that the increase in salinity (as total dissolved solids) is proportional to the increase in chloride concentration since 1974, then a value of 105.4 g 1^{-1} salinity for 1976 is produced. This assumption is erroneous, given such factors as different solubilities of the various salts, but it gives an idea of how salinity has increased in the last two years. From records of the last thirty years, a graph was constructed illustrating the increase in salinity from 1940 to the present (Fig. 3-l-3).

When the lake reaches its stabilization level, the average depth will be only 10 m. Given the strong winds of the Mono Basin, the lake will remain well mixed thermally and chemically. The salt content will be concentrated, with some salts at saturation. A side effect of increased salt content is the reduced amount of dissolved oxygen the water may hold. Therefore, although the water will be well mixed, there will be less dissolved oxygen. As following sections indicate, the chemical and physical structure of the lake when stabilization is reached will determine the fate of the biotic community.

3.2 PRIMARY PRODUCER LEVEL

Connie Lovejoy, Gayle Dana

INTRODUCTION

Soda Lakes are characteristically productive waters. High dissolved inorganic nitrogen and phosphorus concentrations, in combination with high pH buffering capacity and large reserves of total carbon dioxide, result in conditions in which algal production is

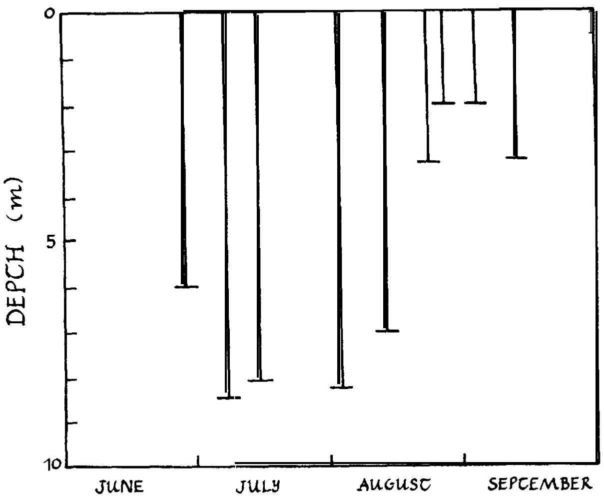


Figure 3-1-1 SECCHI DEPTH MEASUREMENTS (m) AT THE DEEP STATION.

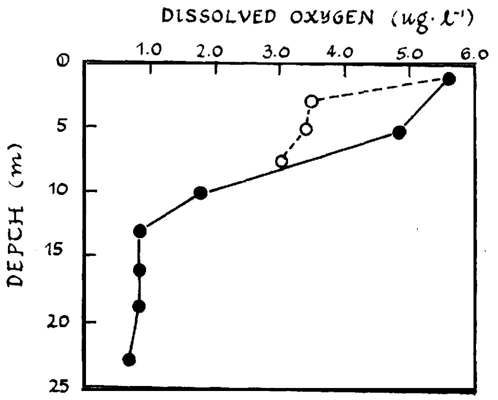


Figure 3-1-2. DISSOLVED OXYGEN DEPTH PROFILES AT THE DEEP (CLOSED CIRCLES) AND SHALLOW (OPEN CIRCLES) STATIONS ON SEPTEMBER 9

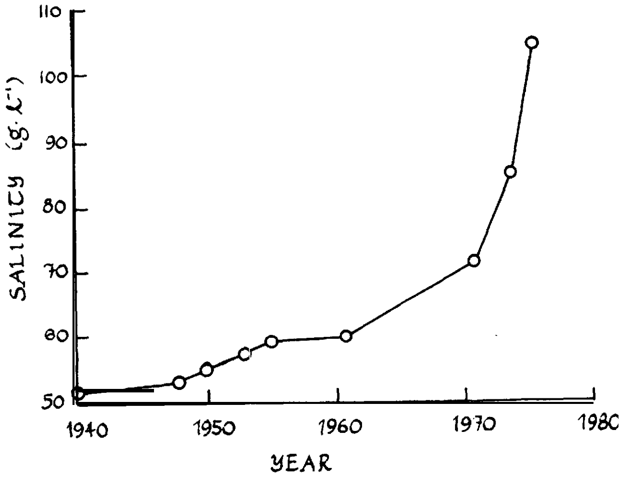


Figure 3-1-3. SALINITY INCREASES OF MONO LAKE SINCE 1940. (1976 figure extrapolated from 1974 chloride analyses.)

limited only by light, temperature, and the photosynthetic capacity of the organisms. In tropical soda lakes where irradiation and temperature are also high, the theoretical upper limit of phytoplankton productivity is approached (Talling et. al. 1973).

The athalassic waters of Mono Lake support high levels of secondary and tertiary production. This suggests a concomittently large phytoplankton component. This component has been comparatively neglected in past studies, despite the probable role of the primary producers in driving-overall lake metabolism.

This study followed primary production throughout the summer of 1976 through estimates of in situ photosynthetic rates, standing crop, and algal species composition. In addition, inorganic nutrient limitation of algal production was investigated and preliminary results were obtained concerning the possible effects of future increases in lake salinity on phytoplankton metabolism.

METHODS

Sampling Procedure

Water was collected by three liter Van Dorn bottle at two stations: an inshore shallow ($z = 8.5$ m) water station (SWS) on the western side of the lake, and a deep ($z = 22$ m) water station (DWS), between Paoha Island and the southwest shoreline (Figure 1-1). Temperature was measured immediately by mercury thermometer. Both stations were monitored at regular intervals between July 7 and September 12, 1976. In addition, on August 30, 1976 a single series of samples down the water column was taken 200 meters east of Paoha Island for cellular carbon and chlorophyll determinations. This station was 37 meters deep and was close to the deepest point in the lake.

Photosynthetic Rates

In situ photosynthesis was determined by the Goldman (1963) modification of the ^{14}C technique of Steelmann Nielson (1952). Water was dispensed into 125 ml pyrex bottles which were injected with 0.5 mls of 22.3uCi ml^{-1} ^{14}C-HC03 and suspended at the depths of collection. Two light bottles and one dark bottle were used at each depth. Bottles were retrieved after four hours' incubation, generally at 0800 to 1200 hours at the deep station and at 0930 to 1330 hours at the shallow station, and were transported packed in ice to the laboratory. Particulate material was then filtered under low vacuum pressure onto 0.45 um millipore membrane filters. Inorganic carbon precipitate was removed from filters by fuming them for twenty-four hours over concentrated hydrochloric acid. Filters were air dried and then counted by a gas flow Nuclear-Chicago Geiger-Muller machine to 10,000 counts or 30 minutes. Dissolved inorganic carbon was determined by volume measurements of CO2 released following acidification. This gave a concentration of 4.3 g C 1^{-1} , which compared reasonably well with the estimate by Mason (1967) of 4.08 g C 1^{-1} . The carbon content of the water did not change throughout the period of study, as determined by pH and alkalinity measurements performed in conjunction with each set of primary production measurements.

Chlorophyll Determinations

Chlorophyll and phaeopigments were assayed by the spectrophotometric method of Strickland and Parsons (1968). Particulate material was filtered from 400 to 1400 ml samples of lake water on Whatman GF/C filters, coated with $MgCO_3$, and stored at -20° C until analysis. The filters were homogenized with a glass tissue grinder in 90% acetone, and following centrifugation, extracted pigments were measured in a Beckman DB-G spectrophotometer.

Phytoplankton Species Enumeration

Samples of 10 to 50 mls of lake water were filtered through 0.45 um millipore membranes which were then mounted on slides and cleared by the gluteraldehyde technique of Dozier and Richerson (1975). Cells were enumerated under 1250X magnification phase contrast with a Zeiss compound microscope, to a total of at least 100 cells and generally 400 cells per filter.

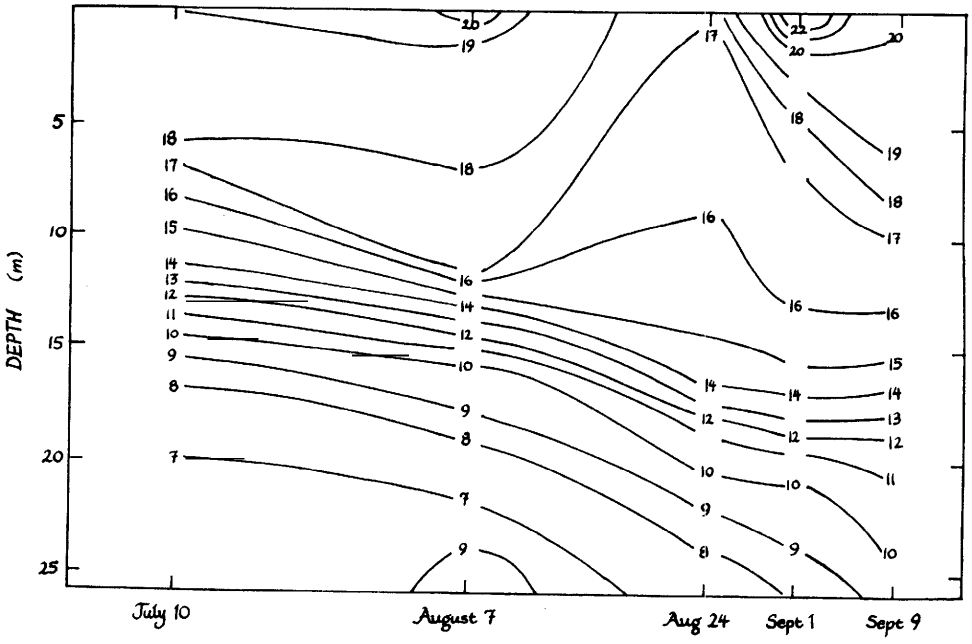


Figure 3-2-1. TEMPERATURE (°C) ISOPLETH DIAGRAM OF THE DEEP WATER STATION.

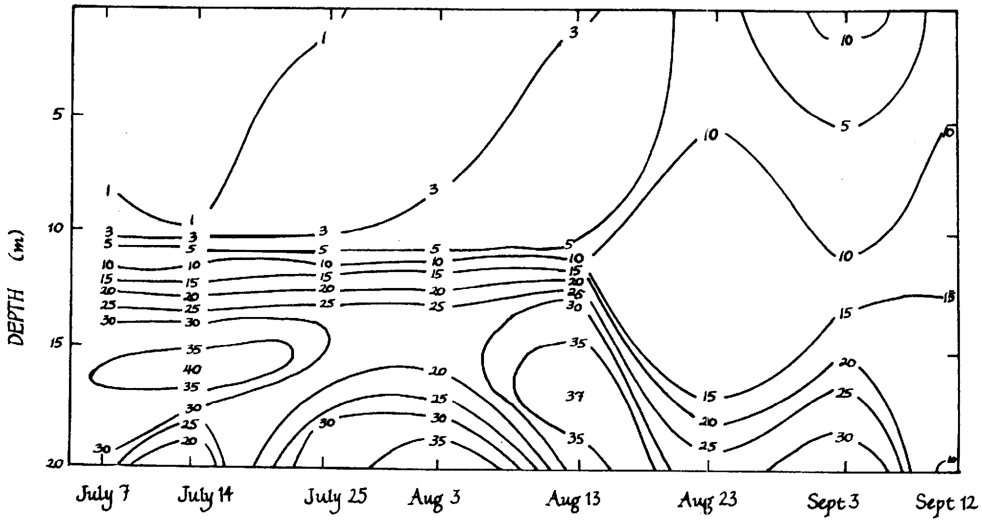


Figure 3-2-2. CHLOROPHYLL a (mgC•m^{-3}) ISOPLETH DIAGRAM FOR THE DEEP WATER STATION.

Cellular Carbon Estimates

Cell biomass was determined by the ATP method of Holm-Hanson and Booth (1966). 150 ml to 400 ml aliquots of lake water were filtered through Whatman GF/C filters which were plunged into 5 ml of boiling tris buffer (pH 7.5) and extracted for seven minutes. Samples were stored frozen until analysis by the luciferase mediated assay, using JRB-ATP photometer with integrating counter. ATP values were converted to cellular carbon by the ratio of 250 carbon to 1 ATP (Holm-Hanson 1970).

Nutrient Limitation

Nutrient limitation was determined by a modification of the photosynthetic approach of Goldman (1963). Following addition of nutrient spikes to 16 meter lake water, cultures were incubated in translucent two-liter polyethene bottles at 10^o C, 2000 lux daylight fluorescent light in a 16 hour light-8 hour dark cycle. At days zero, two, and five the cultures were subsampled into 125 ml pyrex light and dark bottles, injected with $^{14}C\text{-}HCO_3$ and the photosynthetic rates were determined as outlined above.

The following nutrient additions were made in combinations as shown in Table 3-2-3 as micromolar concentrations:

Nutrients	Element	Final concentration
Macronutrients:		(uM)
NaNO3	N	10.00
MSO_4	S, Mg	2.00
$MgCl_2$	MG	2.00
$CaCl_2$	Ca	1.00
K_2HPO_4	P	1.00
Micronutrients:		
$FeC1_3$	Fe	0.2
H_3BO_3	B	1.0
$MnC1_2$	Mn	0.7
$ZnC1_2$	Zn	0.08
$CoC1_2$	co	0.002
$CuC1_2$	Cu	0.00002
Na_2 EDTA		2.0

Salinity Tolerance

Filtered lake water was concentrated by evaporation to one-half the original volume. Various dilutions of this with GF/C filtered unconcentrated water were inoculated with unfiltered 16 m water. Photosynthetic rates were followed as in the nutrient limitation experiments at days zero, two, and five,

As a further approach to test the ability of phytoplankton to grow under hypersaline conditions, 15 meter water was filtered through a 0.45 um millipore membrane and the membrane incubated in ASM media (Gorham, et al 1964) made up in distilled water, GF/C filtered lake water, 120% lake water and 200% lake water (concentrated by evaporation). Cultures were incubated under the conditions specified above for 30 days and then examined for species composition.

RESULTS

Photosynthetic Rates

Primary production rates are presented for the deep water station in Figure 3-2-3 and the shallow water station in Figure 3-2-4. Areal rates of photo-assimilation of inorganic carbon as determined by trapezoidal integration of the primary production curves are presented in Table 3-2-l.

Areal production was at a maximum at the beginning of the period of study, when photosynthesis was most intense in the hypolimnion (see Figure 3-2-l for temperature data). As productivity decreased throughout the course of the summer, the zone of maximum

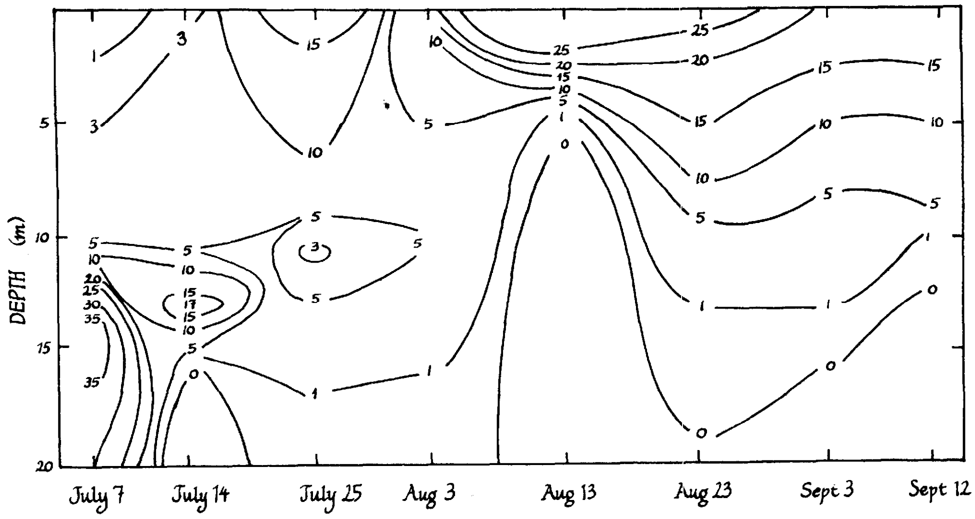
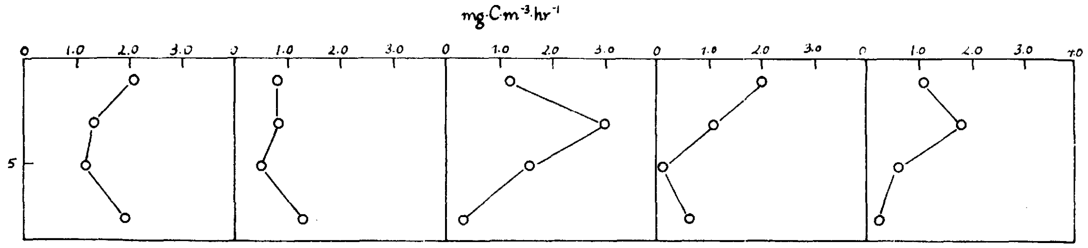
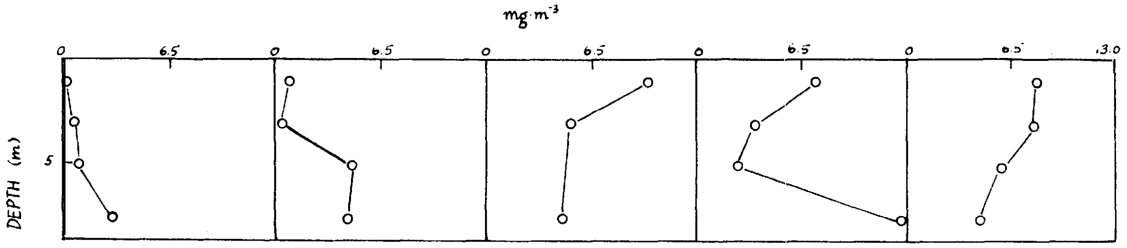


Figure 3-2-3. PRIMARY PRODUCTIVITY (mgC m^{-3} hr^{-1}) ISOPLETH DIAGRAM FOR THE DEEP WATER STATION.





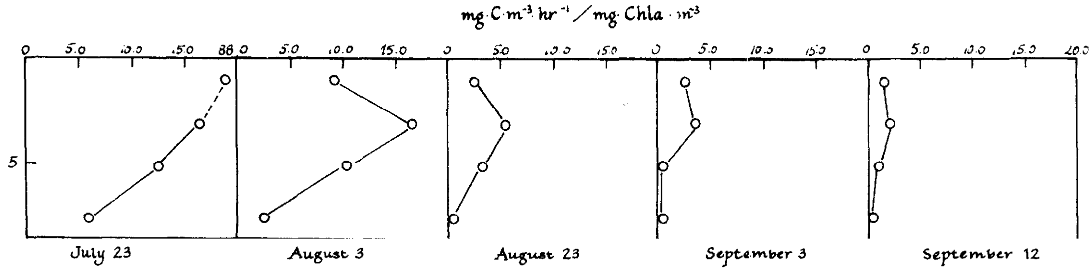


Figure 3-2-4. PRIMARY PRODUCTIVITY (mgC m^{-3} hr^{-1}) DEPTH PROFILES AT THE SHALLOW WATER STATION.

Figure 3-2-5. CHLOROPHYLL a (mg m^{-3}) DEPTH PROFILES AT THE SHALLOW WATER STATION.

Figure 3-2-6. PRIMARY PRODUCTIVITY PER UNIT OF CHLOROPHYLL a DEPTH PROFILES AT THE SHALLOW WATER STATION.

Table 3-2-1

AREAL CHLOROPHYLL CONTENT AND PHOTOSYNTHETIC RATES AT THE DEEP WATER STATION THROUGHOUT THE SUMMER

Date	SWS	DWS			SWS	DWS		
		upper 10 m	lower 12 m	Total		upper 10 m	lower 12 m	Total
7 July		5.7	464.3	470.0		29.1	208.6	309.7
14 July		8.8	286.5	295.3		33.6	55.2	88.8
25 July	11.5	13.4	302.4	315.8	141.8	112.2	30.5	142.7
3 August	23.8	22.2	299.6	321.8	96.3	67.0	31.5	98.5
13 August		32.7	358.9	391.0		85.1	0	85.1
23 August	52.8	103.2	185.4	288.6	159.9	142.2	7.2	149.2
3 September	57.1	66.9	259.0	325.9	80.4	108.3	8.5	116.8
12 September	56.5	111.4	161.2	272.6	81.5	117.6	11.5	129.1

Integral chlorophyll a mg m^{-2})	Integral photosynthesis (mgC M^{-2} hr^{-1})

Values obtained by trapezoidal integration of chlorophyll and primary production profiles.

productivity moved higher up the water column, On August 13 algal photosynthesis was limited to the top five meters of the water column. On this day high winds caused abnormally rough surface conditions throughout the period of incubation.

For the shallow water station no consistent trends in photosynthetic depth distribution are obvious; however, integral photosynthesis follows a trend similar to that of the deep water station, with productivity peaking July 25 and August 23.

Chlorophyll

A net decrease in total chlorophyll down the water column was recorded at the deep water station over the summer, following a similar trend in primary productivity measurements (Figure 3-2-2 and Table 3-2-l). In July and early August chlorophyll was at a maximum in the hypolimnion, with very low epilimnetic values; less than 5 mg 1^{-1} . Towards the end of August, as the main thermocline was depressed, substantial increases in chlorophyll content of the epilimnion were recorded, This chlorophyll distribution throughout the season is reflected in secchi depth measurements (see Figure 3-l-l). Water clarity was high in July and early August and declined to low values by the end of August.

The shallow water station differed substantially from the deep water station's water column, with a net increase in area1 chlorophyll content by the end of the summer; however, the shallow water station did follow very closely the chlorophyll dynamics of the deep water station epilimnion (Figure 3-2-5 and Table 3-2-l).

Photosynthetic capacity

As a measure of physiological efficiency, the productivity per unit chlorophyll was calculated. These ratios are presented in Figures 3-2-6 and 3-2-7 and follow classic photosynthesis chlorophyll curves (c.f., Yentsch 1963) with a maximum at or near the surface. This maximum is sometimes beneath a zone of surface inhibition which is particularly marked in most of the shallow water station profiles. Surface maxima rose to extremely high values on July 25 at both the shallow water station and the deep water station.

There were two possible explanations of the low productivity per unit chlorophyll of the hypolimnetic waters. Either the large numbers of algae in this zone were physiologically unhealthyand represented a senescing population from a burst of growth earlier in the season, or the cells in this zone simply may have been light limited. To test this, on August 24, water was collected from 19 meters and incubated with ^{14}C-HCO3 at various depths down the water column. The high productivity of this water under high light conditions in the epilimnion indicates that these cells were physiologically active (Figure 3-2-8). The carbon-to-chlorophyll uptake rations, however, were low throughout the water column.

Biomass distributions

Cellular carbon profiles as determined by ATP analysis are presented in Figures 3-2-9 and 3-2-10. These point to the substantial hypolimnetic biomass relative to epilimnetic values. Production per unit biomass of plankton declines rapidly with depth while chlorophyll per unit biomass increases, with a maximum at 19 meters. At the 37 meter station a similar distribution was found (Figure 3-2-l0), with very little biomass in the surface waters relative to the biomass of the hypolimnion. In this station phaeopigment increased substantially with depth, indicating that senescence of phytoplankton populations increased with the depth.

Phytoplankton species composition

Throughout the period of the study the Mono Lake phytoplankton community was dominated by two species; a pennate diatom *Nitzschia communi* and a minute (2-4 um) coccoid species which reproduced by binary fission in a lateral plane and hence was tentatively identified as a green alga of the genus *Coccomyxa*. A third species present in significant numbers in July and August was a 2 um diameter Chlamydomonas In addition *Chrysosphaerella* sp. increased in abundance throughout the summer but never reached significant numbers. Another rare constituent was a 17 um diameter punctiform centrate diatom closely resembling the fossil genus *Actinodiscus* (Grev. 1863). A phytoplankton species list for Mono Lake is presented in Table 3-2-2.

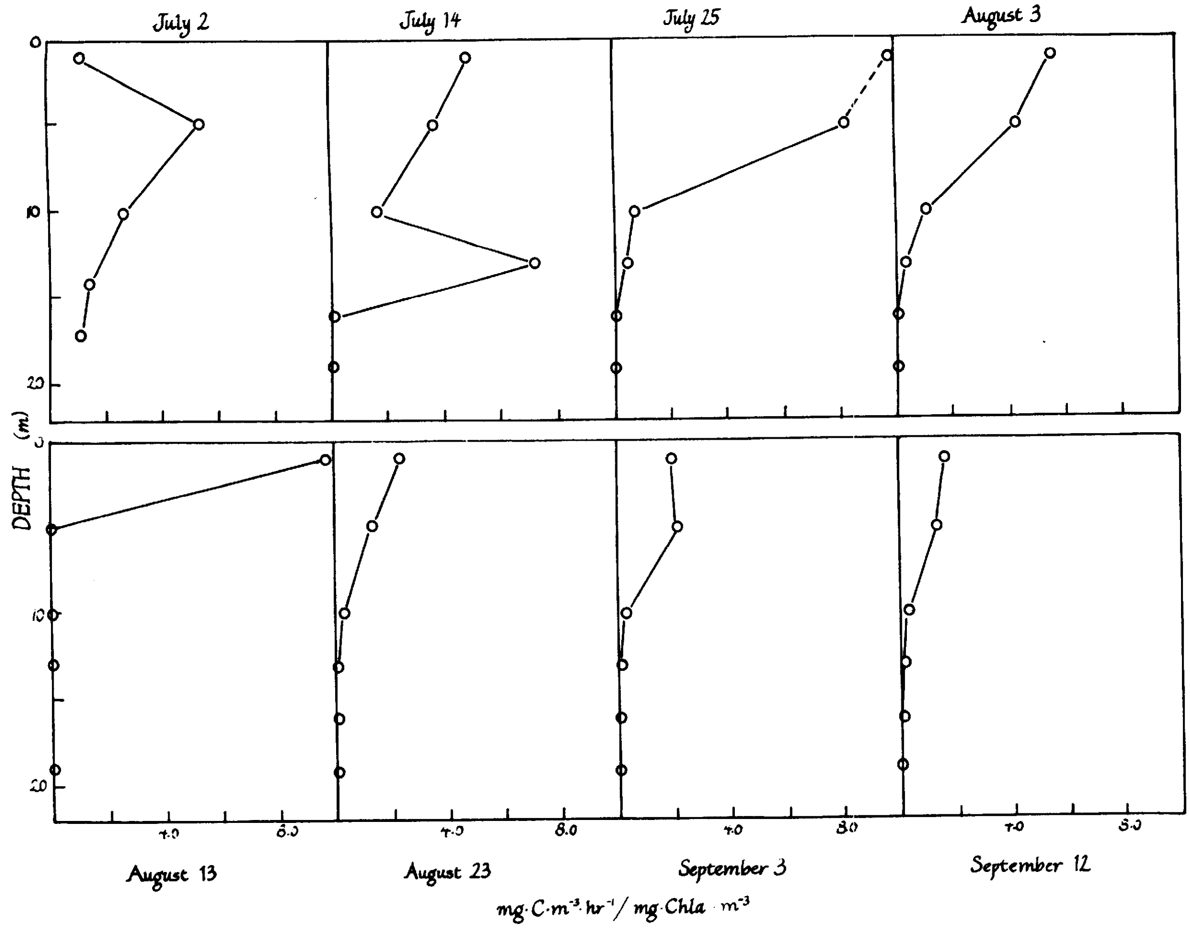


Figure 3-2-7. PRIMARY PRODUCTIVITY (mgC m^{-3} hr^{-1}) PER UNIT CHLOROPHYLL a AT THE DEEP WATER STATION.

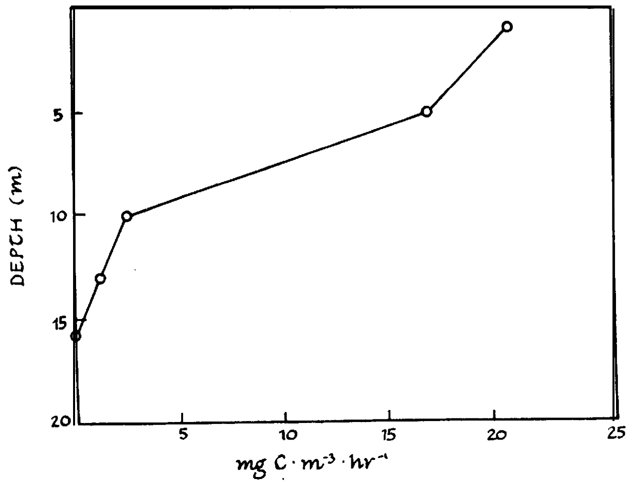


Figure 3-2-8. PRIMARY PRODUCTIVITY (mgC m^{-3} hr^{-1}) DEPTH PROFILE FOR WATER COLLECTED FROM 19 m AND INCUBATED AT VARIOUS DEPTHS THROUGHOUT THE WATER COLUMN. (Chlorophyll a = 23.9 mg m^{-3})

Table 3-2-2

PHYTOPLANKTON SPECIES PRESENT IN MONO LAKE FROM JUNE TO SEPTEMBER 1976

Cyanophyceae:

- *Coccomyxa* sp.
- *Cyanarcus haemiformis*
- *Dactylococcopsis acicularis*
- *Dactylococcopsis luradiformis*
- *Microcystis litoralis*
- *Merismopaedia* sp.
- *Anabaena* spp.

Chlorophyceae:

- *Chlamydomonas* sp.

Chrysophyceae:

- *Chrysosphaerella* sp.

Bacillariophyceae:

- *Amphora coffeaformis*
- *Cyclotella stelligera*
- *Navicula radiosa*
- *Nitzschia communis*
- *Nitzschia palea*
- *Synura spp*.

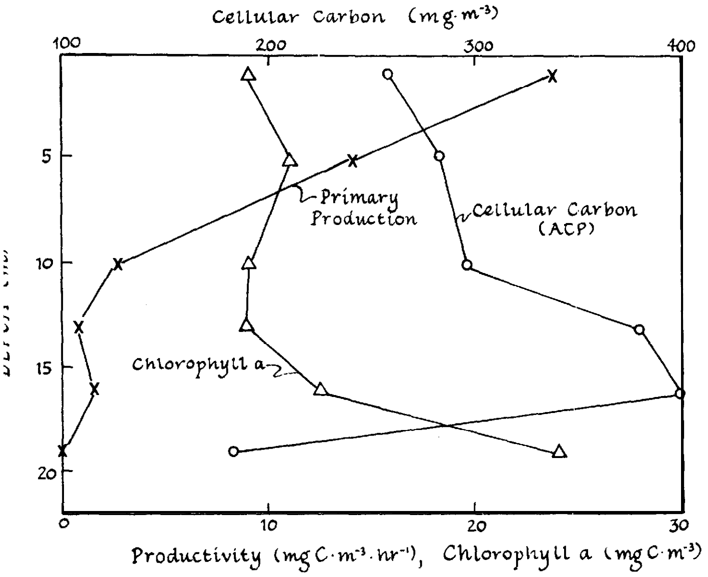


Figure 3-2-9. CELLULAR CARBON (mg m^{-3}) ESTIMATED BY ATP MEASUREMENTS, PRIMARY PRODUCTIVITY (mg m^{-3} hr^{-1}) AND CHLOROPHYLL a (mg m^{-3}) DEPTH PROFILES AT THE DEEP WATER STATION ON AUGUST 24, 1976.

chlorophyll a

ATP biomass (cellular carbon)

primary productivity

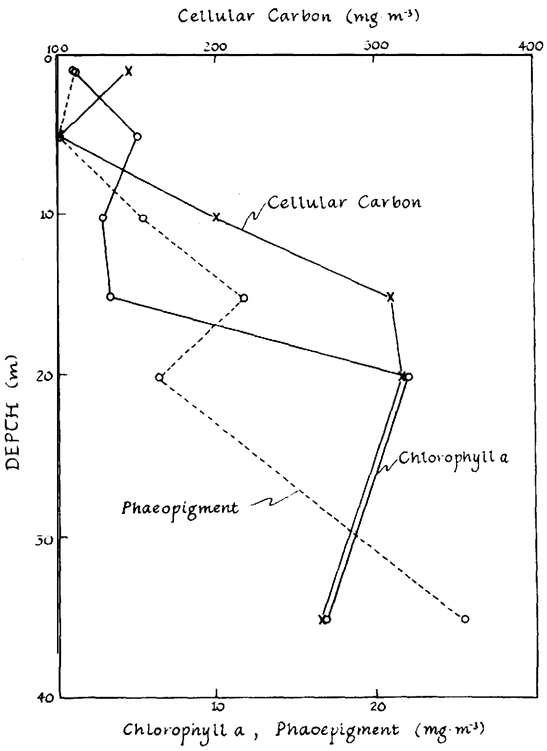


Figure 3-2-10. CELLULAR CARBON (mg m^{-3}) ESTIMATED BY ATP MEASUREMENTS, CHLOROPHYLL a (mg m^{-3}) AND PHAOPIGMENT (mg m^{-3}) DEPTH PROFILES TO 35 m IN THE VICINITY OF PAOHA ISLAND ON AUGUST 23, 1976.

phaeopigment

chlorophyll a

ATP biomass (cellular carbon)

The three phytoplankton dominants at the beginning of summer attained maximum population densities in the hypolimnion (Figure 3-2-11). This was particularly striking for both Chlamydomonas and Coccomyxa sp. which both had hypolimnetic maxima two orders of magnitude higher than epilimnetic densities. This depth distribution was less pronounced by early August, and by late August both the coccoid cells and Nitzschia communis were distributed more-or-less homogeneously throughout the water column.

In addition to the phytoplankton examined on the gluteraldehyde cleared filters, numerous fungal hyphae, gemmae, and arthrospores were observed throughout summer. Several other Nitzchia sp. frustules were detected which exhibited various degrees of parasitism by Chytridomycetes.

Nutrient Limitation

In the first experiment conducted August 6 through August 11, a macronutrient mixture resulted in no obvious stimulation, whereas the micronutrient mixture addition produced a significant increase in photosynthesis (Table 3-2-3). This effect was not due to the chelator added to maintain micronutrients in solution, since EDTA on its own produced no effect. The second experiment, conducted August 14 through August 19, showed Mn to have a significant stimulatory effect on photosynthesis. In both experiments the effects of nutrient addition were obvious only after five days.

Salinity Tolerance

A 25% increase in salinity resulted in immediate depression of photosynthetic rates. A 12.5% increase produced no statistically significant effect on photosynthesis from the control at the beginning or end of the incubation period (Table 3-2-4.)

In the long-term growth experiment, all algal species inoculated on millipore membrane into ASM media made up with filtered, unconcentrated Mono Lake water grew well. However, in the non-saline, distilled water ASM culture only the coccoid, Coccomyxa sp., grew well; while in the hypersaline ASM (200% Mono) Nitzchia palea and the dominant Nitzchia communis of the lake grew up to the exclusion of all other algae. At 120% Nitzchia communis dominated.

DISCUSSION

The most striking aspect of the summer phytoplankton dynamics was the enormous level of primary production, chlorophyll, ATP biomass and phytoplankton cells in the hypolimnion relative to the content of the surface waters, particularly in July and August. Several hypotheses can be presented to explain this:

(i) Surface waters were inhibitory to phytoplankton metabolism. This must be rejected, since productivity per unit chlorophyll was highest near the surface, in fact, as high as the highest values recorded for eutrophic lakes (Parsons and Takahashi 1973). Furthermore, cells from near the bottom of the hypolimnion incubated throughout the water column performed best under the high light and temperature regime of the surface.

(ii) Surface waters were heavily grazed by brine shrimp and therefore the primary producers were herbivore limited. Reliable depth-time distribution of brine shrimp is not available; however, brine shrimp were never found in substantial densities in the hypolimnion. It is therefore possible that the thermocline represents a barrier to vertical migration of the zooplankton, thereby isolating hypolimnetic phytoplankton from grazing.

(iii) The deep water maximum represents an accumulation of cells which sedimented following massive growth prior to summer. Trapped beneath the thermocline once stratification set in, these cells grew at extremely slow rates under the low light and temperature conditions of this zone of the water column. As epilimnetic phytoplankton levels built up and increased shading reduced light penetration, photosynthesis became increasingly difficult. The high phaeopigment content of the hypolimnion, the net decrease in hypolimnetic integral chlorophyll content throughout summer, and the low photosynthesis per unit chlorophyll of algae from the hypolimnion under optimal euphotic light levels all tend to favor this hypothesis.

Two factors responsible for the low 02 tensions at the bottom of the hypolimnion are

Table 3-2-3

NUTRIENT LIMITATION IN MONO LAKE

Experiment 1.

Incubation Time (days)	Control (no addition)	Macronutrients	Micronutrients + EDTA	EDTA only
2	26	21	19	18
5	16	72	86	13

Analysis of Variance

F = 51.74; df = 7.8; $p < 0.01$
Day 5 - Micronutrient vs Control
-significant- $p < 0.01$
All other differences between
treatments at each day
-not significant-

Experiment 2.

Incubation Time (days)	Control (no addition)	Manganese + EDTA	Iron + EDTA	Cobalt + EDTA
0	16	18	19	14
2	19	17	18	16
5	30	50	36	34

Analysis of Variance

F = 3.94; df = 11, 12; $p < 0.05$
Day 5 - Mn vs Control
-significant- $p < 0.01$
All other differences between
treatments at each day
-not significant-

Each value represents the mean photosynthetic rate (mgC m^{-3} hr^{-1}) of two replicates minus dark uptake. Controls averaged over four hours of incubation at 10°C and 2000 lux daylight fluorescent light. Water subsampled from cultures incubated up to 5 days with nutrient additions. Experiment 1 begun August 6; experiment 2, August 14, with water collected both days from 16 m.

Table 3-Z-4

SALINITY TOLERANCE

	Salinity		
Day	0%	12.5%	25%
0	83	65	16
5	87	76	6.5

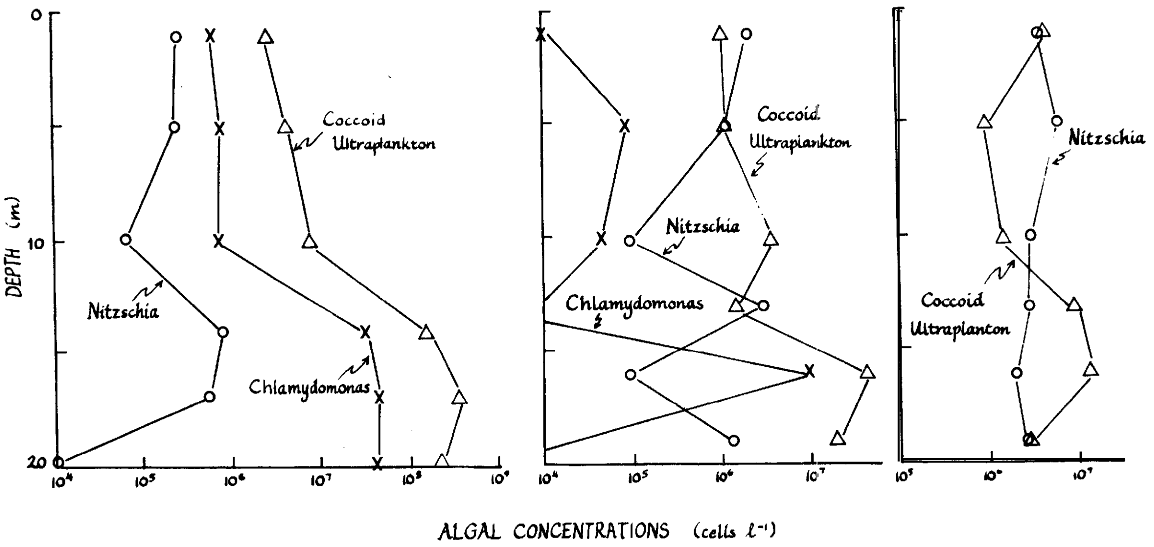
Analysis of Varience

0% Day 1 and Day 5 pooled for analysis

F = 10.31; df = 4, 5; $p< 0.05$
0% vs Day 1 12.5% - not significant
0% vs Day 1 25.0% - significant $p<0.01$
0% vs Day 5 12.5% - not significant
0% vs Day 5 25.0% - significant $p<0.01$

Filtered lake water concentrated by evaporation inoculated with 16 m unfiltered water Subsampled immediately and at day 5 for photosynthetic rate measurements at 10°C and 2000 lux. Each value represents the mean carbon assimilation rate (mg m^{-3} hr^{-1}) minus dark uptake of two replicates* averaged over a 2 hour incubation. Salinities are expressed as % increase over the original Mono Lake concentration. Experiment begun July 11.

* except 0% where single values for day 1 and 5



A. July 7, 1976

B August 3, 1976

C. August 23, 1976

Figure 3-2-11. DEPTH PROFILE DISTRIBUTIONS (CELLS 1^{-1}) OF THE THREE PHYTOPLANKTON DOMINANTS.

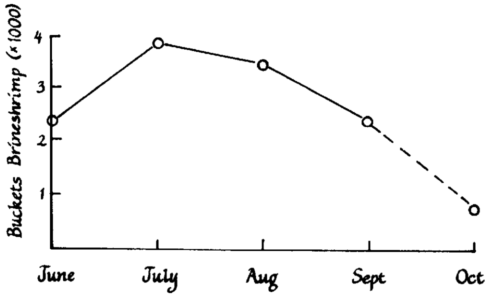


Figure 3-3-1. MONTHLY TOTAL FOR FACTORY BRINE SHRIMP CATCHES AT MONO LAKE FOR 1976. o---o extrapolated from 1 week's catch in October

the high respiratory oxygen demand of these deep populations and decomposition of dying cells (Figure 3-1-2).

The low phytoplankton diversity of this lake does not seem unusual in view of its eutrophic state. However, the diversity does seem to be higher than that recorded by Mason (1967). This may represent a difference in methodology rather than a shift in lake species composition, since enumeration in this study used a filtration technique which retains all microorganisms, whereas Mason used the Utermohl sedimentation technique with settling times well short of those for complete sedimentation of ultraplanktonic species. *Dunaliella* was reported by Mason as one of the three lake dominants. This alga was not detected in this study, perhaps due to the seasonality of the organism. Similarly *Nitzschia palea* was rarely detected, and then, in the main, only as empty frustules.

While both the nutrient limitation and salinity tolerance experiments produced what appear to be clear-cut results, it must be remembered that the tests were performed at only one time of the year using water from 16 meters where, as seen by the productivity and enumeration data, the phytoplankton community is both physiologically and taxonomically very distinct from that of the epilimnion. Therefore these results must be treated only as preliminary.

We could not confirm Mason's (1967) contention that Mg was the primary limiting nutrient in Mono Lake. In this study micronutrient limitation was pronounced. Manganese limitation does not seem unusual in view of the high pH of the lake, since Mn is readily lost from solution as hydrated oxides which may further strip Mn^{++} from water by adsorption reactions (Stumm and Morgan 1970).

It is clear that Mono Lake contains phytoplankton species of widely varying salinity tolerance with a coccoid species capable of growing at very low salinity and a diatom thriving under hypersaline conditions, up to twice the salinity of present Mono Lake concentrations. We might reasonably assume, therefore, that any future change in lake level and hence salinity will produce distinct changes in algal species composition. These species which differ physiologically also vary greatly in size and morphology and hence grazability. Ingestion rates for *Artemia* are known to be dependent upon cell size (Reeve 1963), and cell morphology has a major effect on feeding rates of many zooplankton (Wetzel 1976). Therefore, these effects on algal species composition may be translated throughout all trophic levels.

3.3 SECONDARY PRODUCER LEVEL

Gayle Dana, David B. Herbst

INTRODUCTION

This portion of the limnology section is an account of the natural history and biology of *Artemia* (brine shrimp) and *Ephydra* (larval brine fly). It covers life histories, population numbers, and distribution patterns.

Artemia salina

The most important and abundant zooplankton in the summer months is the brine shrimp, *Artemia salina*. In the winter season when Artemia is absent, two rotifers predominate, *Brachionus plicatus* and *Hexarthra jenkinae* 1967). Protozoans also occur year round. The emphasis in this study was given to *Artemia*, because of its important trophic relationships with the bird populations of Mono and because the rotifers were uncommon during the period of investigation.

Life History:

Artemia salina is a common inhabitant of saline lakes, occurring in tremendous numbers in littoral and open waters. It is of particular importance in Mono Lake as a food source for the birds and as one of the few populations of Artemia which is commercially harvested for tropical fish food. The Mono Lake population may-merit additional distinction as being a different physiological race, if not a separate species (Bowen 1964).

Artemia overwinter as cysts, hatch out in the spring as nauplii and reach the adult stage after fourteen successive molts. The Mono Lake population is bisexual, whereas other populations are reported as being parthenogenetic (Gilchrist 1960). The two sexes differ in that females possess two large egg sacs and males two large prehensile or secondary antennae modified for clasping the females during copulation. The females copulate after every molt (4-6 days) and release nauplii or fertilized eggs from the egg sac. This cycle continues throughout the summer; the overwintering cysts are produced in the fall and are followed by the die-off of the adults. A very small number of adults may remain in the lake over the winter months, but the majority of the next year's crop of brine shrimp comes from the overwintering cysts.

At Mono Lake in summer, 1976, the first adults appeared in June and the population reached its peak in July (Figure 3-3-1). The numbers slowly dropped in September. Most brine shrimp were gone by November. (John Gebel, pers. comm.).

Artemia is a filter feeder, subsisting mainly on phytoplankton, bacteria and, possibly, detritus. The process of filter-feeding is aided by the regular fringe of filter setae situated on the eleven pair of phyllopodia or leaf-like appendages that occur on the trunk of Artemia. The phyllopods are made of six components, three of which are directed backwards, thus forming valvular flaps closing off the space between their own limb and the limb behind. A current of water flows towards the animal impelled by an alternating expansion and contraction process of the interlimb spaces. Food particles are passed between the two walls of the filter setae to the food groove on the ventral midline of the trunk and then swept forward to the mouth. Food is digested in the midgut; dissolved oxygen is taken up through the gut epithelium, where it enters the haemolymph to be used for respiratory processes (Lockhead 1950).

Since Artemia inhabits extremely saline lakes, it must have a way to keep its internal salt concentrations below toxic levels. The mechanism of osmotic and ionic regulation has been studied by Croghan (1958 b,c,d.). Artemia takes its external media into the gut by a rapid swallowing. Salts in solution enter the haemolymph across the gut epithelium, leaving fresh water in the gut. The salts are then excreted by means of an active transport system in the branchiae. Thus, by maintaining its salt and water balances, Artemia can remain hypotonic in a hypertonic media.

Sampling Methods:

Two locations on Mono Lake were monitored from late June to early September of 1976. The first, a typical shallow water habitat, was 8.5 m deep while the second, a deep water habitat, was 22 m deep. Both of these correspond to the shallow and deep stations in Figure 1-1.

A 12 cm diameter zooplankton net was towed vertically through the water column to measure the overall density and sex ratio of the brine shrimp. Vertical distribution profiles were obtained with a three liter Van Dorn water sampler. These collections were all made at approximately 0900 hours at the deep station and 1000 hours at the shallow station. Samples were processed in the laboratory by direct count. Adult, immature and naupliar stages were included in total density counts, Densities were averaged over the summer period. Collection dates in most cases correspond to dates of in situ primary production experiments (see section 3.2). Temperature readings were taken within three days of brine shrimp collection dates.

Fresh water sublacustrine springs and plumes in the lake (areas of high densities of brine shrimp) were sampled by a vertical tow with the zooplankton net. Most of sublacustrine springs sampled were in the area of Gull Bath Creek and Danburg Beach on the northwest shore (see Figure 1-1). Sites of plume sampling were near the west shore of Paoha Island.

Population Densities:

We could discern four major distribution types of the brine shrimp: shallow water, deep water, plumes, and fresh water sublacustrine springs. Table 3-3-1 presents density ranges and averages for these habitats. There was little difference in brine shrimp densities between the shallow and deep water stations, the latter showing greater fluctuations in number throughout the summer. This may be due to the effects of an offshore wind moving brine shrimp away from shore, or to currents associated with the shallow water habitat. These areas were observed to be patchy; marked differences were found in samples taken only a few meters apart (see also Mason, 1967). Densities for plume and spring areas were high. Plume densities were of the highest numbers recorded during the Summer.

The brine shrimp plumes are a curious formation. They occur only in littoral areas, above rock and tufa, and can be as large as several meters in size. A hypothesis set forth by Mason (1966) points to the warming of littoral waters by solar radiation in combination with a photo- and rheotaxic-response by the brine shrimp as the cause of these formations. The heated bottom water rises, often along an easy upward path such as tufa and rock. The brine shrimp experience a negative photo-kinetic response and swim downward, also causing an apparent positive rheotaxis.

Brine shrimp gather in great numbers at upwelling sites in the lake. The origin of this vertical water motion is either freshwater springs or methane gas released from bacterial decomposition in the bottom sediments. These upwellings, present in both shallow and deep water, apparently contain a uniform density distribution of brine shrimp, at least in the epilimnetic waters, and provide ideal surface feeding sites for birds. Several hypotheses may account for these gatherings: (1) bring shrimp accumulate in a circulating cell of water formed by the upwelling current (similar to a Langmuir circulation spiral), (2) the upwelling may supply nutrients occurring in the hypolimnion or in spring water to the epilimnion, stimulating algal growth or increasing numbers of suspended bacteria in the water column and thus attracting the filter feeding brine shrimp, (3) brine shrimp may have a preference for lower salinity in the spring upwellings, or (4) brine shrimp may have a preference for the generally lower temperatures of the upwellings. As the brine shrimp show neither a preference for freshwater spring source over methane gas sources, nor an alignment with any low temperature depth strata, explanations (3) and (4) are unlikely. Therefore, it seems probable that brine shrimp are initially attracted to these productive waters for feeding and held in the larger upwellings by the pattern of water circulation.

Although Artemia reproduces throughout the summer, there was a disproportionately greater number of nauplii and immature animals in early September. It is possible that in response to a cooling trend at the summer's end, adult Artemia produce more nauplii which can reach maturity before the fall die-off and therefore produce more of the overwintering cysts. This would ensure a large population to start next spring's crop of brine shrimp. The large increase in immature animals may also be an indication of a two-generation cycle in Mono Lake-- the first generation derived from the overwintering cysts, and the second generation comprised of the September boom of young animals.

The average sex ratio for the brine shrimp was two males to one female. A one-to-one ratio would be expected for this species; it is most likely that there is a differential death rate which causes the females to be less abundant than the males (Garth Redfield, pers. comm.).

Vertical Distribution Profiles:

Vertical distribution profiles for the deep station show a high density of animals at the surface from early July to early August (Figure 3-3-2, a-d) and an absence of animals at the surface from late August to early September (Figure 3-3-2, e-g.). A clumped aggregation low in the water column is found in late summer, and a more evenly spread vertical distribution in midsummer. The shallow station distribution did not show such a marked change through the sampling period (Figure 3-3-3, a-e). There, Artemia generally stayed away from the surface waters, aggregating more at the mid-depths (3-7 m).

Factors such as phytoplankton-zooplankton and bacterial-zooplankton interactions (i.e., feeding), temperature, dissolved oxygen, currents, and amount of incident light may explain the nature of these distribution patterns. Succession of phytoplankton species from a predominately blue-green alga to a predominately diatom alga through the summer may influence the distribution, but the relationship of Artemia to these successive faunas is unclear. Previous investigations by Mason (1967) have shown high concentrations of young brine shrimp at the thermocline, and he speculates that this is the result of feeding by the animals at the top of the phytoplankton concentrations of the hypolimnion. Evidence for bacterial feeding might be shown in Figure 3-3-4 where there is a definite layer of brine shrimp at 10 m, one half meter above the bottom. This may be due to a high density algal layer rather than to a bacterial layer. Temperature determines the depth to which Artemia may go; 10-11°C seems to be the lowest temperature it can tolerate (Figure 3-3-2). One measurement of dissolved oxygen on September 9 shows a good correlation between a decrease in brine shrimp numbers and a dramatic drop in dissolved oxygen (Figure 3-3-2, g). Currents and responses to light may have some determining effect, Mason (1966) reports a negative photokinetic response of Artemia, which hints of a possibility for diurnal

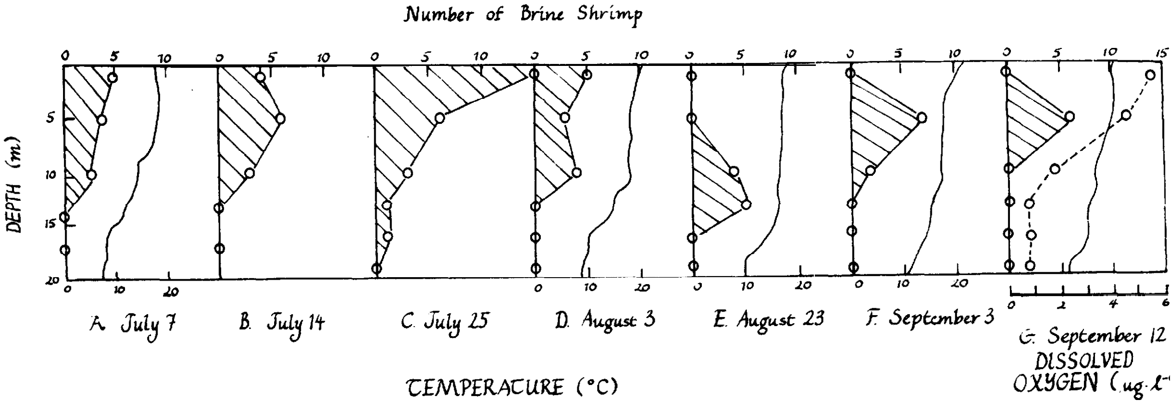


Figure 3-3-2. BRINE SHRIMP DENSITY DEPTH PROFILES AT THE DEEP STATION. Temperature and oxygen data were included for some dates.

——— temperature (°C)

o---o dissolved oxygen (µg 1^{-1})

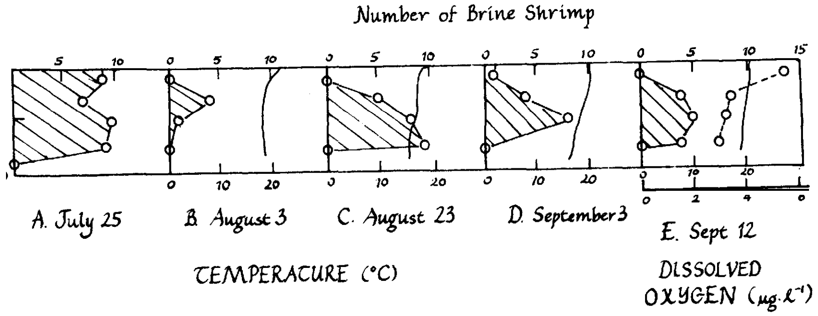


Figure 3-3-3. BRINE SHRIMP DENSITY DEPTH PROFILES AT THE SHALLOW STATION. Temperature and oxygen data was included for some dates.

——— temperature (°C)

o---o dissolved oxygen (µg 1^{-1})

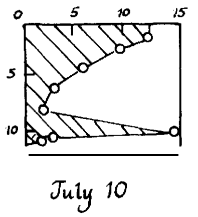


Figure 3-3-4. A BRINE SHRIMP DENSITY DEPTH PROFILE THAT GIVES EVIDENCE OF BACTERIAL FEEDING BY THE SHRIMP.

vertical migration. However, this has not been established for *Artemia* in its natural environment.

Implications and Predictions:

Mono Lake houses a large population of *Artemia*, as shown by density measurements taken during the summer of 1976. A further indication of high biomass is the amount of brine shrimp harvested by the commercial brine shrimp factory at Mono Lake. The factory's summer harvest usually totals 500,000 pounds of brine shrimp (John Gebel, pers. comm.). Because the factory harvests from only two of the many springs in the lake, this is a small proportion of the total brine shrimp population.

The importance of grazing pressure by *Artemia* on the phytoplankton populations of the lake has been mentioned by Mason (1967). This is also discussed by Stephans and Gillespie (1976) as important in the Great Salt Lake, Utah, where Artemia is abundant. It is agreed in this study that grazing by such high numbers of Artemia must restrict phytoplankton productivity to some degree. Conversely, density-dependent population controls operate so that *Artemia* numbers are dictated by phytoplankton biomass. The excretory products of *Artemia* also affect phytoplankton productivity by providing a source of nutrients that would be otherwise unavailable at certain times of the summer.

These large numbers of *Artemia* are 'the most important food source for the California Gull and may be important as well to the Eared Grebe and other birds (see Chapter 5). Large aggregations of Gulls during the summer and Grebes in the fall feed at the fresh water sublacustrine springs. This suggests that these areas, with their great densities of Artemia are of particular value to these birds.

If the lake level decreases as predicted, Mono Lake will become much more saline and have a shallower average depth (probably around 10 m as compared to approximately 20 m today). As a result, dissolved oxygen concentrations and water temperature will remain relatively mixed throughout the water column. The total amount of dissolved oxygen, however, will be greatly reduced because of the increase in salt concentrations and water temperatures. These changes will probably have a dramatic effect on *Artemia* populations. With higher specific gravity and less dissolved oxygen in the lake's water, the oxygen requirements and the increased bouyancy of the brine shrimp will necessitate a surface existence. This result was suggested by laboratory experiments with increased water salinities, in which *Artemia* was restricted to the surface waters and rarely descended to any depth. If their effective habitat is confined to the surface waters, *Artemia's* biomass will be greatly reduced. Because *Artemia's* food source is usually concentrated not at the surface, but lower down in the water column (see Fig. 3-2-11), *Artemia* may be faced with food as well as space limitations. This interpretation assumes *Artemia* will survive salt stress caused by the increasing salt concentration of Mono Lake water (see Section 3.4).

Table 3-3-1

BRINE SHRIMP DENSITIES, AVERAGE DEPTH,

AND DIAMETER OF FOUR DISTRIBUTION TYPES.

Distribution Type	Average Depth (M)	Diameter of Spring or Plume (M)	Density ($\#/M^3$) (Range)	Average Density ($\#/M^3$)
Shallow Station	8.5	---	452 1,941	1,296
Deep Station	23	---	1,131 1,706	1,392
Plume	2.2	.a 1.5	145,542 306,666	201,847
Spring	6.6	2.0 7.0	2,288 37,761	37,761

Larval Brine Fly

The subgenus *Hydropyrus* (to which the Mono Lake fly *Ephydra hians* belongs) shows more tolerance for highly saline or alkaline waters than any other member of the *Ephydra* genus. Distribution of the subgenus in North America is primarily in the western and northern United States and in the Great Basin. Eggs, larvae, and pupae of this species develop aquatically, submerged in the waters of Mono Lake.

Development of the larvae occurs through growth stages called instars. There are probably three or four instar periods, each separated by a molt. The later instars of *E. hians* can be recognized by their larger size and by the presence of a black dorsal stripe. Although it is difficult to assess the seasonality of population change for the Mono Lake brine fly (since the present study was conducted during the summer season only) it is likely that adults lay eggs throughout spring and summer, developing from egg through larval instars and pupa to adult in a period of about three weeks. This long oviposition period indicates that there will be many generations in a year and that the population will be relatively constant and productive during the summer. When for one reason or another most adult flies disappear from the lake in late fall, the larvae or eggs sustain the population over a period of dormancy, overwintering until environmental conditions are once again favorable.

The distribution of brine fly larvae is limited to the shallow waters near the lake shore (littoral zone) among fragments of the hard tufa rock substrate. The larvae are seldom found in open water, on soft substrate, or below a depth of a few meters. Both the larvae and the pupae can usually be found on the undersides of these rock fragments. This location is probably chosen mainly to serve as protection from turbulent wave action. The larvae crawl about the rocks with the aid of clawed prolegs, feeding on detritus and scraping algae off the tufa. Submerged at all times, larvae have adapted for aquatic respiration. Many species of aquatic fly larvae respire directly with the atmosphere by means of exposing spiracles (breathing holes) at the surface. In *Ephydra hians* the spiracles at the end of the tail-like anal respiratory tube which originally served this purpose are now vestigial structures, no longer functional. The respiratory tube has evolved into a tracheal gill, taking dissolved oxygen directly out of the water.

The requirement of the larvae for a solid attachment site as they undergo pupation is probably the primary character of their biology which determines the pattern of distribution. The last pair of prolegs (beneath the anal tube) are larger than the others with claws that are longer and curved in the direction opposite to the preceding claws. This enables the larva to grasp the rough-surfaced tufa fragments:; there the larva clamps rigidly as the cuticle hardens, forming the puparium. The emergence of the adult fly from the puparium is temperature dependent, the time of development varying from about 26 hours at 15°C to about 6 hours at 30°C, females having a slightly shorter pupation period than males (Nick Collins, pers. comm.). Upon emergence the adult fly is enclosed in a bubble of air created by the space left within the puparium by the developing pupa. This bouyant air bubble carries the young fly to the water surface where the wings then develop fully.

The aquatic component of the brine fly population of Mono Lake (i.e., the larvae and pupae) is highly productive. In times past the abundant pupae, known as "Koot-saw-bay", were gathered from windrows along the shore by the Mono Indians and were used as an important source of food. Neither the larvae nor the pupae are fed on to any significant extent at higher trophic levels. This factor further contributes to their high and stable productivity. Present densities, usually about 15-30 individuals per square inch on the undersides of tufa, represent a healthy population. Because of the difficulty in estimating total habitat space available over the lake and limitations on the estimation of absolute numbers and generations, secondary productivity of the larval brine fly remains unknown.

Larvae and pupae of a previously unreported species of the biting midge family *Ceratopogonidae*, were discovered in Mono Lake during this study. Tentative identification of these blood-sucking no-see-urns is *Culicoides varipennis*, a known halobiont (salt-inhabitant) (Wirth, 1952). The larvae of C. *varipennis* are found along the shallow, rocky margins of the lake. The slender, 6-7 mm long larvae swim with rapid, eel-like movements along the edges of tufa, feeding on attached algae. The few pupae collected were found in open surface waters.

3.4 SALINITY TOLERANCE IN EPHYDRA AND ARTEMIA

David B. Herbst, Gayle Dana

INTRODUCTION

During the summer of 1976 experiments were initiated to determine the effects of increasing salinity on the physiology of the brine shrimp Artemia salina and the larval brine fly Ephydra (Hydropyrus) hians. Oxygen uptake (respiration), regulation of tissue water and solutes, and mortality as measured in an LC_{50} bioassay (lethal concentration at which half an experimental group is dead after a certain length of time) were obtained for increasing salinities of Mono Lake water. This information bears on the ability of these populations of secondary producers to survive and reproduce in an environment subject to changes in salinity.

Croghan (1958a) and Conte (1972) have shown that both the adult and naupliar stages of Artemia are effective hyposmotic regulators over a wide range of salinities. Croghan (1958 b) has been able to adapt brine shrimp to a crystallizing sea water brine in the laboratory, and field collections have been made in the salt-saturated waters of the Great Salt Lake. The nauplii, however, appear to be less tolerant of salinity increase, as mortality increases sharply above 2.0 M NaCl.

Among the changes in Artemia induced by salinity increase are failure of emergence from the cyst above 2.0 M NaCl external concentration (Clegg 1964) decreased protein biosynthesis (Conte 1973), and an activation of the salt-regulating Na-K ATPase pump (Augenfeld 1969). Energy, in the form of ATP, is required to operate the enzyme pumps removing salt from the tissues. The demand for ATP in a salt-stressed shrimp would be expected to be reflected in an increased respiration rate. However, Gilchrist (1958) has reported no change for females; males appear to consume more oxygen at low salinity than at high salinity because of morphological differences.

Of particular interest is the work of Bowen (1964) showing the reproductive isolation by habitat of the Mono Lake variety of Artemia. Upon being transferred to the media in which the other populations of brine shrimp under study were cultured, Mono brine shrimp died. Conversely, the other groups of brine shrimp died upon transference to Mono Lake water. This work suggests that both the lake and the organism represent a unique situation.

Though no studies have been made on Ephydra hians, the osmotic regulation of two related halobiont species (E. cinerea and E. riparia) has been examined (Nemenz, 1960 and Sutcliffe, 1960). Larvae of E. cinerea from the Great Salt Lake are markedly hypotonic to the concentrated lake water. -Although their haemolymph is dilute relative to the external environment, their internal osmotic pressure of 20.4 atmospheres is the highest known among insects.

METHODS

Animals were collected the same day they were used in an experiment, brine shrimp from an average 3 m depth off the west shore and larval brine flies from shallow-lying fragments of tufa gathered from the western shores. Specimens were kept cool and out of direct sunlight during transit to lab facilities. Adult brine shrimp (average wet weight: males=8 mg; females=12 mg, with egg sacs; average length=8 mm) and late larval instar brine flies (average wet weight=7 mg; average length=12 mm, dorsal stripe well developed) were selected for the studies. Only active individuals were chosen. All experiments were run at a water temperature of ca. 20°C.

(1) LC_{50} Salinity Tolerance Bioassay:

Groups of 20-30 male brine shrimp, female brine shrimp, and brine fly larvae were placed in 250 ml volume of the test salinity. If the 105 g/liter salinity (from chlorinity) of present Mono Lake Water (MLW) is taken as 100% relative salinity, then bioassays were run at 120, 140, 160, 180, 200, 250 and 300% MLW. The water used in all experiments was obtained by filtering and evaporating (by boiling) lake water to a specific gravity corresponding to the desired percent of present salinity. Control groups (in 100% MLW, filtered and brought just to boiling point to ensure uniformity) were run concurrently, two experimental replicate groups at each salinity being tested. In addition, animals surviving one salinity test were transferred to the next highest salinity in an effort to determine the influence of acclimation or preadaptation on salinity stress. Duration of these bioassays was 48-72 hours, and aeration with a bubbling stone for 10 seconds was undertaken every 12 hours. The criterion for death in Artemia was cessation of the rhythmic phyllopod swimming motion and in Ephydra was lack of response to tactile stimulation.

Bioassay data was processed statistically by analysis of variance ($p >.01$). Mortality after 45 hours provided a useful plot as this time corresponded to a stabilization level of mortality in all groups tested.

(2) Oxygen Uptake:

Animals used in respiration experiments were acclimated in the salinity to be tested for 24 hours before the experiment. Air was continuously bubbled through the water to keep it as saturated with oxygen as possible. Approximately 20 animals from each experimental group (male Artemia, female Artemia, and Ephydra larvae) were placed in 300 ml BOD bottles for a five-hour period at salinities of 100, 120, 160, 200, 250 and 300% MLW. Dissolved oxygen content was measured by the Miller method (Walker, et. al. 1970) at the beginning and end of each experiment. A control bottle was run along with the experimental groups. BOD bottles were stored in the dark during this five hours and inverted to ensure mixing at the beginning, middle and end of each experiment. Tissue wet weight was measured at the end of the experiment to ± 5 mg. Animals not surviving the five hour period were not included in this weight (they never amounted to more than 10% of the original number). Oxygen uptake was calculated as ul O_2/min/gram wet tissue.

(3) Water and Solute Regulation:

To determine the regulation of water and solute content of the tissues, large numbers of brine shrimp (sexes combined) and brine fly larvae were acclimated for 24 hours in salinities of 100, 150, 200, 250 and 300 % MLW. After they were rinsed with distilled water and blot-dried on filter paper, the wet weight of their tissues (of both dead and living animals) to ± 5 mg was determined. Dry weight of the tissues was determined after 8 hours of oven drying, and the tissues were homogenized and centrifuged. Aliquots of the supernatant were titrated for chloride content. The data, reported as mM NaCl in total body water (TBW) probably reflects accurately the haemolymph osmolarity; Croghan (1958a) has shown that NaCl is the principal osmotic solute and that the haemolymph volume accounts for most of the total body water and remains relatively constant over a wide range of salinities.

RESULTS

Results of the LC_{50} salinity bioassay, plotted as mortality after 45 hours vs. salinity, are given in Figure 3-4-1. Mortality among the larval brine flies was not corrected for instances of pupation which by the criterion qualify this state as death. However, since this influence would be to further decrease the rate of actual mortality from a level which already shows no statistically significant differences between salinities tested, its effect would be nil. It is interesting to note, however, that while pupation of 5-10 percent occurs in controls (controls are in 100% MLW), not a single instance of pupation occurs among the larvae exposed to salinities higher than 200 % MLW (1.2 NaCl). Mortality among the brine shrimp increases sharply between 180 and 200 % MLW. While the increase in death rate was significantly higher among females than males for salinities below 200 %, the opposite was the case above 200 % MLW. In all cases the acclimated or preadapted groups did not differ markedly from experimental groups. This data is more variable and difficult to assess, as the sample size was often quite low.

Oxygen uptake vs. salinity is plotted in Figure 3-4-Z. Respiration rate among male Artemia shows increase and stabilization for salinities up to 200 % MLW and a rapid decrease in respiration rate above 200 % MLW. While the data for females are more variable, no changes in the level of oxygen consumption appear until 300 % MLW where (as with the male brine shrimp) respiration drops to a very low level. Oxygen uptake by the brine fly larvae decreases consistently with increasing salinity until at 300% MLW virtually no respiration is occurring. This physiological response to the increase in salinity is accompanied by decreased motion, coiling of individuals on themselves, and clumping at the water surface.

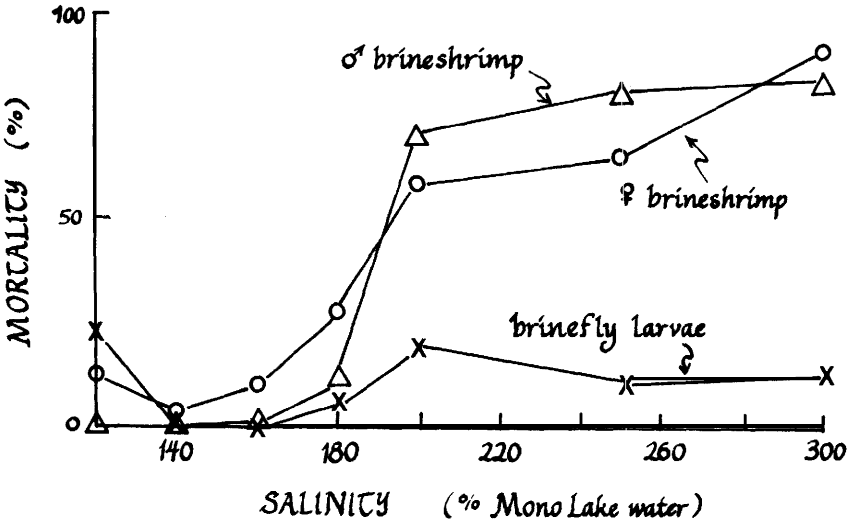


Figure 3-4-1. MORTALITY vs SALINITY IN MALE AND FEMALE ARTEMIA AND EPHYDRA AFTER A 45 HOUR PERIOD. Data points are the mean of two replicates corrected for control values.

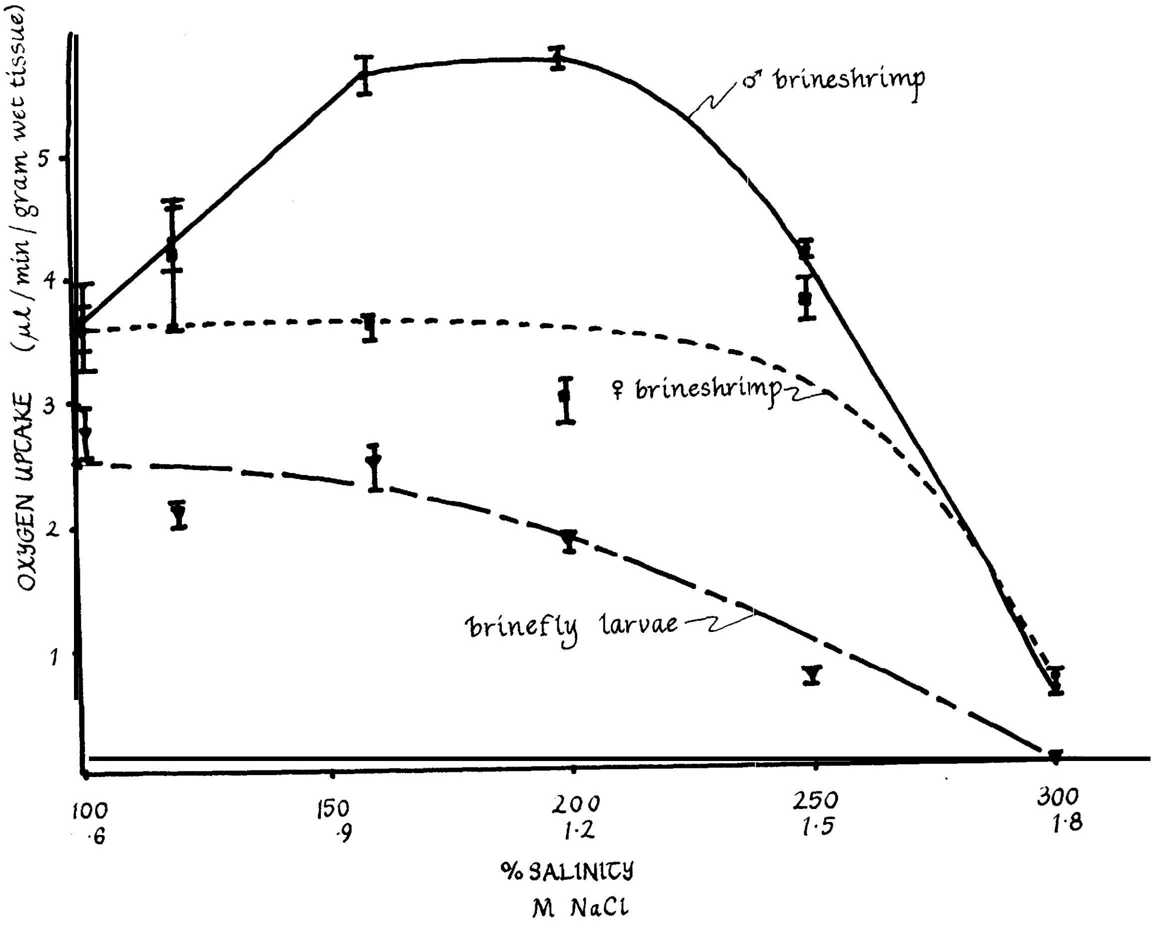


Figure 3-4-2. OXYGEN CONSUMPTION vs SALINITY IN ARTEMIA AND EPHYDRA IN µl/min/g WET WEIGHT TISSUE. Error bars indicate variability in 2-5 replicates for that experimental oxygen titration.

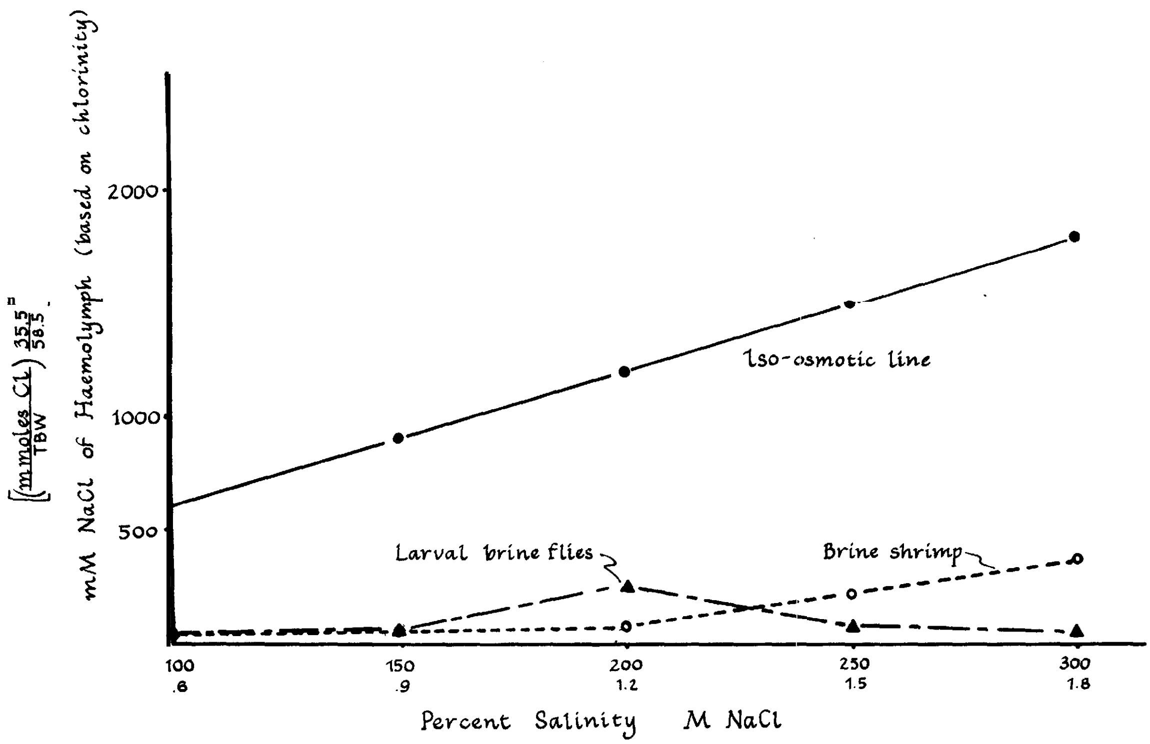


Figure 3-4-3. INTERNAL SALT CONCENTRATION vs EXTERNAL SALT CONCENTRATION IN ARTEMIA AND EPHYDRA. Data points represent one experimental series only (i.e. one replicate).

The changes in osmotic solute and water content of the tissues with salinity are expressed in Figure 3-4-3 and Table 3-4-1. Figure 3-4-3 depicts the hyposmotic condition of the haemolymph of both Artemia and Ephydra relative to the isosmotic line (where internal concentration is equal to external concentration). Artemia is not a strong regulator of its internal solutes, as can be seen by the 20-fold increase in osmotic concentration of NaCl for an external increase of 100 % to 300 % MLW. Table 3-4-1 shows that this is due both to steadily decreasing total body water and to increasing chloride content of the tissue. While the brine fly larvae also show this decreasing proportion of total body water, the data on chloride content of the tissue is more variable. This variability may be attributed either to the small sample quantity of tissue used to initiate the experiments or to the true physiological state of the larvae.

DISCUSSION

Artemia salina and the larvae of a species of brine fly (Ephydra cinerea) occur naturally in the salt-saturated waters of the Great Salt Lake. Moreover, laboratory studies indicate that brine shrimp can be adapted to "crystallizing sea water brines." In contrast, the present LC_{50} bioassay shows that Mono Lake brine shrimp do not survive well in lake water concentrated above 1.2 M NaCl (well below saturation). These conflicting results might be attributed to the limitations of our direct transfer method, in that the factor of acclimation to these conditions over time (as would occur naturally in a receding Mono Lake) is not considered. Although mortality might be partly attributed to sudden osmotic shock, this bioassay nevertheless gives an indication of the salinity tolerance of the varieties of Artemia and Ephydra presently found in Mono Lake. Furthermore, the only other carefully controlled LC_{50} salinity bioassay (done on the adults of a related species of Australian brine shrimp) reported in the 'literature (Geddes 1975)

Table 3-4-1

WATER AND SOLUTE REGULATION IN <u>ARTEMIA</u> AND <u>EPHYDRA</u>

	Brine Shrimp			Larval Brine Fly		
Salinity	mM NaCl in TBW (SD)	TBW as % Orig. wt.	mmoles Cl' per mg dry tissue	mM NaCl in TBW (SD)	TBW as % Orig. wt.	mmoles Cl' per mg dry tissue
100	18.8 (.007)	84.72	,173	40.9 (.01)	79.75	.263
150	64.1 (.01)	84.71	.584	61.6 (025)	71.70	.253
200	93.9 (.01)	81.75	.690	259.9 (.03)	70.45	1.01
250	218.4 (.02)	79.15	1.36	88.5 (.016)	68.23	,311
300	389.2 (0)	75.39	1.95	54.9 (.02)	64.93	.167

Table 1 includes mM NaCl in total body water (TBW), total body water as % original weight and chloride per mg dry tissue for salinities of 100, 150, 200, 250, and 300% Mono Lake water. The data represents one experimental series only (i.e. one replicate per point); the standard deviation (S.D.) values are calculated for 3 to 5 chloride titration replicates per salinity group.

uses the same direct transfer method as employed in this study. Mono Lake Artemia have a lower LC_{50} value (1.2 M at 45 hours) than that found for the Australian Paratemia (3.4 M at 54 hours; though collected from Australian lakes having a salinity higher than this). This suggests that the Mono variety is more sensitive (less tolerant) to salt stress than Paratemia, though the LC_{50} value may indicate a somewhat lower tolerance than that actually observed in the field. In the light of Bowen's work (1964) indicating that the Mono Lake brine shrimp population is genetically isolated because of the unique characteristics of Mono Lake water, and because all physiology studies done in the past have used sea water or a laboratory-prepared medium, the experiments done here should be regarded exclusive of other research. This being the case, the high mortality rate above 1.2 M NaCl can be attributed to salt regulation stress and/or the decreased oxygen content of the more concentrated water.

Another important physical change which has not been considered is an increase in the ambient temperature of the lake water. In addition to further decreasing the solubility of oxygen, increased temperature acts synergistically with increased salinity to lower the lethal limit of salt tolerance in Parartemia (Geddes 1975).

The response of oxygen uptake to increased salinity should reflect energy required to maintain homeostasis. Most of this energy will probably be channeled into power for the operation of salt regulating enzyme pumps. Indeed, the work of Reeves (1963) indicates that the optimum growth efficiency in Artemia occurs at salinities below those considered presently. Decreased growth efficiency at higher salinities may be due to an "increased proportion of assimilated food being appropriated for osmotic work". Over the lower range of salinity tested (100-200 % MLW) the male brine shrimp increase their rate of oxygen uptake while the females remain essentially the same, Since the male brine shrimp are able to obtain more energy (through oxidative metabolism), they should be able to cope better at these salinities than the unchanging females. This is, in fact, borne out by significantly lower mortality among males than females over this range. As Gilchrist (1958) has pointed out, the ability of the males to consume oxygen at a greater rate than that of the females is probably related to the presence of the large, flattened prehensile antennae which give the males a greater relative surface area over which respiratory gas exchange can occur. At the highest salinity tested, oxygen consumption in Artemia is reduced to low levels, probably reflecting both the decreased availability of dissolved oxygen and the inability to respire effectively.

Although Artemia is a hyposmotic regulator it is clear from Table 3-4-l that the Mono Lake shrimp are not strong regulators and that their body fluids are becoming saltier as the external concentration of solutes increases. The highest salt concentrations may contribute to death not only by osmotic stress but also by actual protein denaturation with increased ionic strength. The increased salt content of the tissue may, in addition, contribute to increased salt load in the birds feeding on brine shrimp.

The ability of the brine fly larvae to maintain a low level of mortality at high salinities may be due to the state of lowered metabolic activity indicated by decreasing oxygen uptake. In addition to this physiological condition, the larvae exhibit a slowing of movement. During the bioassays, individuals would coil tightly and clump in groups at the water's surface. This behavior is characteristic of other invertebrates preparing to protect themselves from dessication by exposing less surface area (Crowe and Cooper 1971). For the brine fly larvae this may reflect an evolved trait enabling survival in habitats which are naturally subjected to exposure or decreased water availability (i.e., aquatic habitats in arid regions which may evaporate during certain periods). During this period of inactivity it is possible that a minimum amount of energy is devoted to supporting the integrity of life. This needed energy may be supplied by anaerobic metabolism or through direct respiratory gas exchange with the atmosphere (though this is unlikely, since the larvae are no longer adapted for this option).

The data on water regulation (Table 3-4-l) implies that with a 15 percent decrease in total body water over the range of salinities tested, the larvae may be under osmotic stress. However, if the decreasing chloride content of the tissues for salinities above 200 % MLW is accurate (see results section), then it would seem that following an increase in internal osmotic concentration (to 200 % MLW) the haemolymph osmolarity returns to normal at higher salinities. It is likely that in this quiescent state a larva is not taking any of the medium into the gut, and, since the external cuticle is probably impermeable to chloride and sodium ions, an osmotic loss of water from the body tissues without accumulation of osmotically active solutes would be expected.

The cessation of physiological and behavioral activity reported here for the larval brine fly has far-reaching implications. Though this condition permits survival, it eliminates further growth, as the energy required for protein and enzyme biosynthesis (during the crucial developmental stages of larval molt and pupation) cannot be provided. The absence of pupation among groups of larvae at salinities above 200 % MLW indicates that this is so. This situation would in effect "freeze" the population in the larval stage, and if they are like other animals with this type of protective mechanism this state may be prolonged for years. Since the larvae probably overwinter, this inactive condition may not be unusual to them.

In conclusion, although the possibility exists that the brine shrimp and fly larvae of Mono Lake may be able to adapt themselves physiologically to a slowly increasing salinity or to evolve a genetic tolerance enabling survival, the weight of evidence examined here indicates that the present populations of these animals will not be able to withstand the increasing salinity predicted for Mono Lake.

Chapter 4

ENTOMOLOGY

David B. Herbst

AQUATIC AND SHORE INSECTS OF THE MONO BASIN: INTRODUCTION

The purpose of this study is to survey the distribution, abundance and diversity of the aquatic invertebrate and shore fauna (insects in particular) of the basin with respect to habitat type and geographic location. This is done so that comparative information is available for use in the interpretation of the distribution of other lake basin animals (birds) and plants. Aquatic environments are emphasized because of their productivity and because they are the habitats most immediately affected by water diversion.

An attempt will be made to identify the environmental factors which control the occurrence or restrict the distribution of a particular insect or association of insects. Characterization of trophic relations (food web) for different habitats will be made. Predictions for successional changes in the aquatic invertebrate populations of the ecosystem and considerations of present and future stability will be made.

The insects inhabiting the lake are covered in the Secondary Production Level of the Limnology section (Chapter 3-3).

SAMPLING

During July and August springs, streams, ponds, marshes and mud flats were sampled qualitatively and/or quantitatively. Several environmental factors were measured at these sample sites (see Aquatic Survey List). With the aquatic list is a set of microhabitat descriptions for each sample site. Alcoholic specimens from these samples were identified to lowest taxon possible and ranked on a 1-3 index for frequency of occurrence and size in qualitative samples. In quantitative samples they are reported as number occurring in sample area. Productivity is recorded as number and biomass per square foot (in QN samples) while diversity is calculated by the equation of Margalef (Southwood, 1966). Comparison of these values is valid only within the context of sampling method (QL or QN). Some unsubdivided groups (e.g.,chironomidae for example) are probably composed of several distinct species, some of which show externally different characters; but because of the uncertainty of existing keys to the larvae they are not separated here. Comparative analysis of aquatic sample sites was made by calculation of similarity quotients (Southwood, 1966) between each site based on taxon composition.

Qualitative sampling was accomplished by unaided collection while quantitative sampling was done either with a square-foot surber sampler or ring sampler (.893 ft.^{2}). This sampling equipment enables estimation of benthic (bottom dwelling) productivity. The surber sampler gives a somewhat biased estimate, as it collects aquatic insect drift as well as benthic fauna during the sample period while the ring sampler does not (as it isolates the sample area).

Lake or stream shore insect densities were estimated by counting an average number within a one or six square inch frame of reference. Densities too low to estimate accurately are denoted by a + sign. A set of environmental factors was measured at each sample site (see Shore Survey List).

Drift nets were set for 6-10 minute periods in some of the major streams of the basin to determine the biomass of aquatic insect drift entering the lake during a daylight period. The main purpose was to ascertain if this drift might have some significance in terms of food source to birds which gather preferentially at the stream inlets to the lake.

The typical transition in vegetation and substrate type which characterizes the (spring source) flow of stream to lake follows. Above or around the spring source there are usually marshes and marsh ponds formed from overflow and seepage. Below the spring source, flowing downward towards the lake is the stream bed itself. Marginal and aquatic vegetation is usually abundant along the upper stream region where the stream substrate *is* composed of rubble, gravels and coarse sands. This upper region is in marked contrast to the lower stream substrate, composed primarily of fine sands, silt, and clay. There, a more-or-less distinct transition into a non-vegetated zone has occurred. This plant succession, described in greater detail in the plant section of this report, is the basis for designating stream habitat types in this section as vegetated (upper region) and non-vegetated (low region).

The typical microhabitat separation of the shore is on the basis of water availability and substrate. The three microhabitats found generally form parallel bands of a combined width of 5 to 10 meters. The detrital mud flats immediately adjacent to the water's edge are the newly-emerged lake bottom detritus, usually associated with a water film or small puddles. Next to the detrital mud flats is a more-or-less sandy zone containing interstitially adsorbed water and occasional white alkali deposits on the surface. Finally, there are alkali sand flats which are relatively dry and overlain by alkali dust. This is only a general description of the shore, and varied substrate types are found in different locations.

AQUATIC SURVEY

Benthic (bottom dwelling) productivity in a lotic (flowing) environment is expected to be high when the stream substrate is predominantly rubble, current is riffling, and vegetation (marginal and aquatic) is present. Each of the high productivity sampling sites is characterized by the above conditions, and all belong to the vegetated stream zone habitat type. However, these conditions and this habitat do not always harbor high productivity. Diversity also tends to be higher in the vegetated zone habitat and at sites where the substrate contains rocks, rubble, and coarser material allowing a greater number of niches to be available for colonization. Pond sites show a high diversity presumably because of the wide and varied food base, although productivity varies. The non-vegetated stream zone, having a finer particulate substrate, has a generally lower productivity and diversity. Lowest diversity (as indicated by Margalef's equation) occurs at sites in which one species dominates in great numbers over other types.

Figure 4-l shows the distribution obtained when similarity quotients are grouped according to closest relations between sample sites (in a manner analogous to the plexus diagram construction used in the plant study, Chapter 6). Their similarity quotients are indicative of the proportion of species common to the sites being compared. Six more-or-less distinct associations are present, falling into groups **which** have either habitat type and/or location in common. (1) West side complex (subdivided as Dechambeau group and Gull Bath group), the core composed of stream vegetated zone habitats with the pond and non-vegetated stream habitat sites on the periphery, (2) East sidle complex (composed of ponds, vegetated and non-vegetated stream habitat types at Simon springs and Warm springs), (3) East Paoha marsh spring stream, (4) "Sneaker flat" spring stream, (5) all ponds (east and west side) and (6) mud flats. The one site defying description (site 5) also failed to fit into any of these groups. This statistically derived pattern indicates that the distribution of certain insects and insect associations is restricted primarily by geographic location within the lake basin (in particular East-West) with the influence of habitat type superimposed on this. The map of zoogeographic regions in Cole and Schlinger (1969) indicates that the east and west sides of Mono Lake are in separate zones.

The only environmental factor which is different from east to west is pH, which is slightly higher (7.5-8) for the east side complex (except in the acidic causeway pond) than for the west side complex (pH 5.5-6.5). This factor may contribute to the observed differences in fauna.

Although cyclic changes in both numerical and developmental composition of populations could not be observed during the single summer season spent at Mono Lake, some observations were made on the biology of a few aquatic insects.

Chironomids (midges) are the most ubiquitous aquatic insect in the basin. Found in every habitat except the detrital mud flats of the lake shore, the specimens grouped under this taxon are undoubtedly composed of several different species, though one type dominates. The larvae have been found free living, in gelatinous cases, in sand-fiber tubes, attached to rocks, among filamentous algae and in the detrital sediment of ponds.

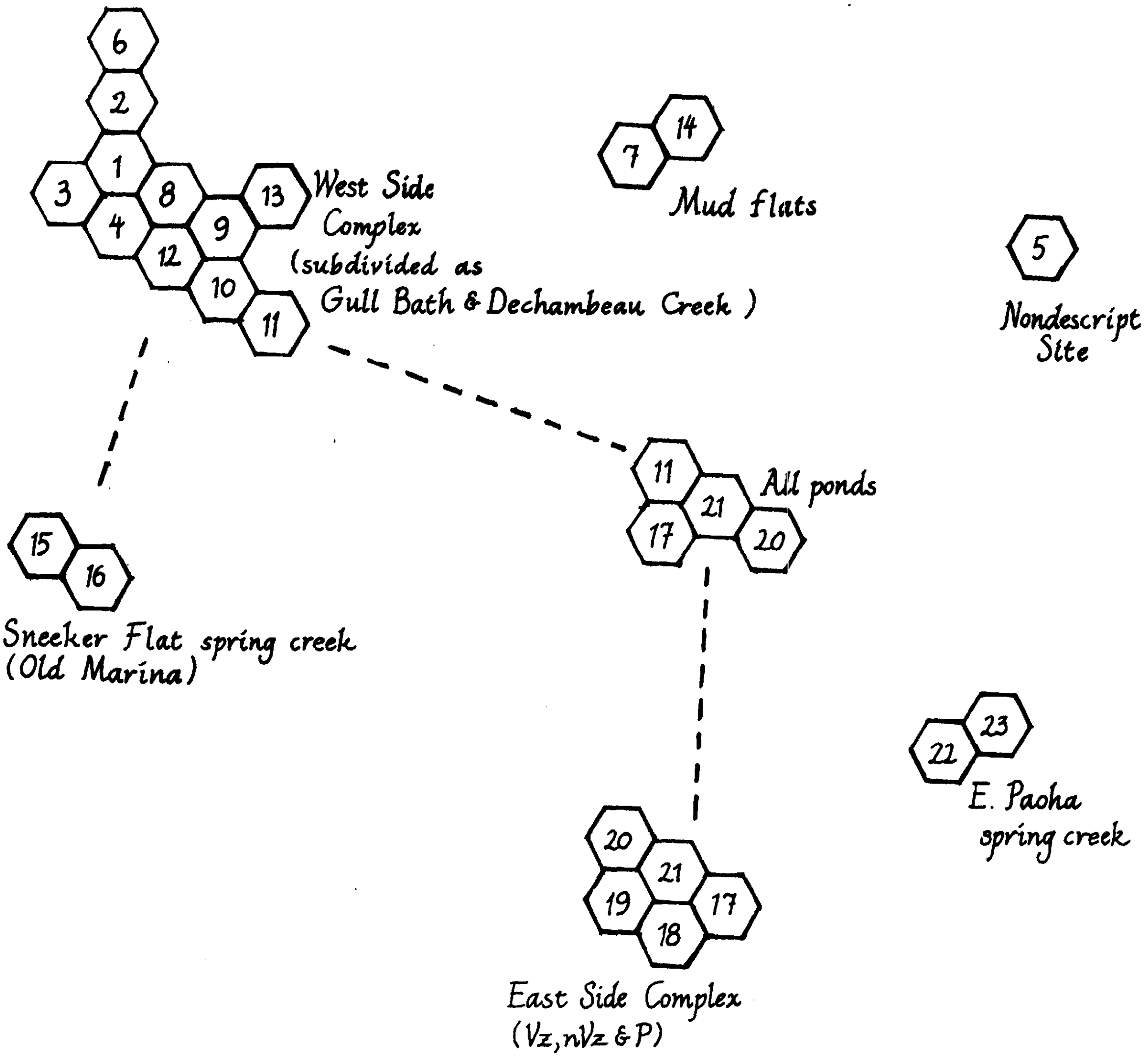


Figure 4-1. STATISTICAL DISTRIBUTION OF SAMPLE SITES BY SORENSEN'S QUOTIENT OF SIMILARITY = $\frac{2j}{a+b}$ where j = no. of joint occurrences of species
a = total no. taxons in site a
b = total no. taxons in site b
For methods explanation of this cluster diagram see plant section discussion of plexus diagram. Note peripheral location of pond, marsh and nVz habitat types around the Vz habitats of the West Side Complex. Overlap indicated by dashed lines and/or repeated site number.

Simuliid (black fly) larvae are also common, though restricted to the swift-flowing streams of the west side. Throughout the summer, only larval forms had been collected until late August when the first pupae were collected. This may represent the time of developmental transition since no adult simuliids were collected over the summer sampling period.

Specimens of the damselfly nymph Amphiagrion abbreviatum from marsh water (site 5) were infested with a parasitic water mite larvae. These mites (usually of the genus Arrenurus) are found on late instars only. The mites are known to crawl from the nymph to the adult during emergence, remaining with and feeding on the adult's body fluids until they have obtained sufficient nutriment to drop off and develop into adults.

Usinger (1956, p. 190) notes that the water boatman Corisella decolor "shows a preference, or at least tolerance, for saline waters." He also notes that Corisella is commonly found together with the halobiont Trichocorixa, the dominant insect of the Salton Sea. As Trichocorixa is absent from all sites sampled (including the lake) it may be assumed that the extreme conditions of the lake are intolerable to even this saline-adapted species and that the ponds inhabited by Corisella are unacceptable to Trichocorixa because of their low salinity. The presence of Corisella indicates that the species may have lived in Mono Lake when the salinity was lower and that it has since retreated to the more tolerable pond habitats.

The water striders Gerris and Trepobates are surface insects, feeding on organic material in the surface film, scavenging floating dead plant and animal tissue, and skating about on standing or flowing water. Although this ability should allow them to have a wide range, they cannot take advantage of the resources of the lake because the surface tension is not great enough to support their weight (i.e., their cuticular surface is wettable due to surfactants present in the lake water; Herbst, unpublished data).

Figures 4-2, 4-3 and 4-4 depict the probable trophic structure of each aquatic 'habitat type organized by feeding source, mechanism and level. This general information is derived largely from Cummins (1973). Stream trophic structure covers both vegetated and non-vegetated zone, though the food base will be shifted from the algae and aquatic plants of the productive vegetated zone into detrital sediment feeding in the non-vegetated zone. The mud flats and pond habitats also depend on the detrital component for primary production. The detritus substrate of these habitats provides an abundant food source to the predominant surface or sediment feeding detritovores.

Without the aid of information on the past faunal composition of the aquatic environment it is difficult to say how community succession is or will be proceeding except to say that succession in the aquatic habitat changes with time and receding lake level in a sequence towards those animals representative of marsh pond and marsh.

The mechanisms that promote the geographic and habitat isolation of insect types and associations noted in this study also promote speciation and adaptation to the particular environmental conditions encountered (specialization). This results in an increased diversity which is a good yardstick for community stability. Furthermore, the general pattern of the habitat trophic structures, with higher diversity on the consumer than the producer level indicates a further stabilizing effect (Watt, 1973; p. 85). However, environmental stability is also a requisite for biotic stability, and while it is true that probably no net loss in spring source aquatic environments is likely to occur in the future (i.e., though old springs will dry up, new ones will form),, local changes in environmental conditions could be disruptive to the community stability of these areas.

Table 4-3 shows the biomass and numbers of stream insects drifting into the lake during a twelve hour day period (calculations based on six or ten minute sampling period). These insects represent an available food source to the birds gathering at the stream inlets to the lake. The Gull Bath Beach stream, which is frequently visited by the California Gull, has the greatest amount of potential food and may thus serve as a feeding site in addition to its use as a source of fresh drinking water. It is likely that the now dry Rush and Lee Vining Creeks once supported a similar productivity.

SHORE SURVEY

The composition of shore insect populations is reported in Table 4-2, the shore survey list. This list indicates that there are three insects which dominate the shore habitat; (1) the brine fly: Ephydra hians, (2) the chloropid fly, and (3) the shore bug: Saldula

Table 4-1

AQUATIC SURVEY LIST

(Abundance)

	Sample Site and Location																						
	Q - 1							Q - 5							Q - 2		Q - 3				Q - 4	Q - 6	
Organism	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Gastropoda	5	2m	1m	1				7		2s	3s	1					3m	7	98				
Mollusca	2																						
Turbellaria																							
Planeriidae	2									1s		5											
Oligochaeta	6	2x	4	6				7															
Amphipoda																							
Hyallela azteca				7						3s	3s	40											
Hydracarina					2mi						3mi			1s			1mi		2s		2s		
Chladocera							3mi			3mi	3mi			3mi			3mi		3mi	3mi	3mi		
Diptera																							
Chironomidae	6L		11L 1A	5L				120L 10P	2s (L)	3s (L)	3m (LP)	80L 25P	13L		1L	1s (L)		2L	15L 2P	12L	1L	3s (LP)	3s (L)
Simuliidae																							
Species A	2L		2s (L)	25L				15L	1s (L)	3s (L)		40L 7P	2L		9L	1L							
Species B	1L																						
Tabanidae																							
Chrysops		1m (L)																	1m (L)				
Dolichopodidae																			1s (L)	1L			
Empididae																							
Species A								2L															
Species B								1s (L)															
Dixidae																							
Dixa																							
Anthomyidae																							
Limnophora								6L				1L											
Stratiomyidae																							

Table 4-1, Cont'd.

Organism	Sample Site and Location																					
	Q - 1						Q - 5							Q - 2		Q - 3				Q - 4	Q - 6	
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Eulalia			1L				18L									2x (L)	1x (L)	2L		6L		
Stratiomys																			1x (LP)			
Rhagionidae																						
Atherix variegata			1L																			
Psychodidae																		1L	1L			
Culicidae										1s (P)												
Culex tasalis																2m (L)		1s (L)	1s (L)	2L	3m (L)	2m (L)
Ceratopogonidae						1s (P)																
Palpomyia-Bezzia																	2L	4L	1P	2P		
Culicoides						1s (P)																
Ephydridae																						
Ochtera mantis				21 (A)																		
Notophilinae																	1P			1P		
Scatellini sp.A(?)																		5P	2P			
Scatellini sp.B(?)						2m (LP)							1m (LP)				15P	7P	4P	9P		
Ephydra hains																		1L	1m (P)			
Ephydra (?)						2m (LP)												13L 2P				
Chloropidae		2A																				
Tipulidae																						2m (L)
Syrphidae		1L																				
Trichoptera																						
Limnephiloidea	1x (P)				1m (P)			1x (P)														
Hydropsychidae		2x (L)								1x (L)												

Table 4-1, Cont'd.

Sample Site and Location

		Q - 1						Q - 5							Q - 2		Q - 3				Q - 4	Q - 6	
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Lepidostomatidae																							
Lepidostoma															380L 1P	11L							
Hydroptilidae								85L	2s (L)	2s (L)		3P											
Glossosomatidae									1x (L)			1x (L)											
Odonata																							
Hyponeura lugens															1N								
Coenagrionidae																							
Argia vivida															2x (N)	1x (N)							
Amphiagrian abbreviatum					2x (N)					1x (N)	2x (N)												
Ephemeroptern																							
Baetidae																							
Baetis	2N		2m (N)	4N				6N	1m (N)	3m (N)		3N			18N	1m (N)							
Ephemerellidae								1m (N)															
Coleoptera																							
Hydrophilidae								1L										15L	37L		6L		
Paracymus ellipsis					2s (A)		1s (A)		1s (A)				1s (A)	1s (A)			3s (A)	2s (A)	3A	1s (A)	3A		
Enochrus								1L	1m (A)								1x (A)				1x (A)		
Tropisternus					2m (L)														1x (AL)				
Dytiscidae																							
Hygrotus									1s (L)	2s (AL)	1m (AL)								2A	1s (L)	17A 33L		
Rhantus atricolor											1x (AL)						1x (A)						
Elmidae								1L														1m (L)	
Staphylinidae																					1A		
Hemiptera																							
Gerridae																							

Table 4-1, Cont'd.

	Sample Site and Location																						
	Q - 1							Q - 5							Q - 2		Q - 3				Q - 4	Q - 6	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Gerris gilletei											3x (AN)						3x (AN)	1x (A)	1A		3x (A)		
Trepobates becki											3m (AN)								2m (N)		2N		
Corixidae																							
Corisella decolor										1s (AN)	2s (AN)						2m (A)		7A 5N	2m (AN)	1A 6N		
Saldidae																							
Saldula arenicola																			1s (A)				
Plecoptera																							
Perlodidae																							
Arcynopteryx								2x (N)															
Collembolla																							
Poduridae																2mi					3mi	3mi	3mi
Homoptera																							
Aphididae			1A																				
Hymenoptera																							
Ichneumonidae			1A																				
Unidentified Eggs	3s		3s	2s				3s															
Sampling Method	S	QL	S	R	QL	R	QL	R	QL	QL	QL	R	R	QL	R	R	QL	2R	R	R	R	QL	QL
Standing Crop (no./ft^2)	27	1.5	21	56	2.0	0	1.7	314	1.2	2,2	2.4	229	17	1,8	460	13	2.1	24	229	24	103	2.5	2.5
Productivity (mg/ft^2)	400	-	45	257	-	0	-	1120	-	-	-	582	5	-	550	50	-	134	1690	34	247	-	-
Diversity (∝)	6.3	4.3	7.1	4.6	4.0	0	5.0	6.5	7.7	7.3	7.6	3.9	1.7	3.9	1.9	4.2	6.8	4.8	9.4	8.3	7.6	3.0	3.0

Table 4-1, Cont'd.

Environmental Factors	Sample Site and Location																						
	Q - 1							Q - 5							Q - 2		Q - 3				Q - 4	Q - 6	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Habitat type	Vz	M	Vz	Vz	-	nVz	D	Vz	nVz	Vz	P	Vz	nVz	D	Vz	nVz	P	nVz	Vz	P	P	SP	Vz
Date	7/8	7/8	7/13	7/15	7/15	7/15	8/26	8/9	8/10	8/15	8/15	8/21	8/21	8/26	7/24	7/25	8/3	8/3	8/6	8/6	8/5	9/2	9/2
Time (AM-PM)	AM	AM	AM	AM	PM	PM	PM	AM	PM	AM	AM	AM	PM	PM	PM	AM	AM	PM	AM	PM	AM	AM	AM
Temperature (^oC)	15°	15°	15°	15°	-	15°	-	19°	12°	13°	16°	15°	17°	-	23°	24°	24°	25°	19°	15°	24°	19°	19°
pH	6	6	6	6	-	6	9	5.5	5.5	6	6	6	6.5	9	7	7	8	8	7.5	5.5	8	6.5	6.5
Alkalinity (ppm)	-	34	34	36	-	-	-	-	20	17	19	-	-	-	24	-	-	-	-	-	-	-	-
Dissolved Oxygen (% sat'n)	-	94	94	94	-	-	-	-	92	98	113	61	61	-	99	100	-	-	-	-	-	-	-
Current velocity (m/s)	.5	.1	.4	.3	n	.2	n	.4	.35	.35	n	.35	.35	n	.4	.5	n	.35	.2	n	n	.1	.2
Av.Stream Width	50	75	60	50	-	150	-	120	300	200	-	75	60	-	100	40	-	120	60	-	-	75	15
Depth (cm)	10	3	9	4	-	8	-	4	15	4	-	8	7	-	3	4	-	5	5	-	-	22	20
Vm	4	5	2	3	4	0	0	2	0	5	5	5	0	0	4	0	5	1	4	5	5	1	5
Va	3	5	3	3	4	1	0	4	1	4	3	4	1	0	3	1	3	1	3	3	1	1	4
Substrate Comp.(%)																							
Cobbles	40	-	50	10	-	0	0	50	10	10	-	30	20	-	20	5	0	0	10	0	0	0	-
Gravel-pebbles	40	-	30	40	-	20	0	30	40	20	-	30	20	-	30	15	10	30	25	0	0	0	-
Coarse Sand	10	-	10	20	-	20	0	10	40	40	-	20	20	-	30	20	30	20	20	0	0	0	-
fine sand,silt, clay	10	-	5	30	-	60	100	10	10	30	100	20	30	100	20	60	60	50	40	100	100	100	-

KEY: Qualitative samples (QL) reported on a 1-3 abundance index-size index:

1 = rare	mi = minute (< 1 mm)
2 = common	s = small (1 - 5 mm)
3 = frequent	m = medium (5 - 10 mm)
	x = large (> 10 mm)

Table 4-1, Cont'd.

KEY: Quantitative sample (QN) methods: R = ring sampler S = surber sampler (reported as number in sample). Developmental stage listed as capital letters in Table: L = larva N = nymph or naiad P = pupa A = adult. Productivity in QL samples = Abundance indices/no. of taxons (l-3 scale). Diversity calculated from Margalef equation:

$$\alpha = \frac{S - 1}{\log_e N}$$

S = no. taxa
N = no. individuals

Habitat types: V = stream vegetated zone nVz = stream non-vegetated zone P = pond D = detrital mud flat M = marsh SP = stream pool.' Dissolved oxygen determined by Winkler method, Alkalinity determined by phenolphthalein and methyl orange (total alkalinity).
Current velocity: n = none or negligible current. Vm = marginal vegetation. Va = aquatic vegetation, vegetation index: 0 = no cover to 5 = 100% cover. Substrate composition arranged according to U.S. Standard Sieve size.

AQUATIC MICROHABITAT DESCRIPTIONS

By geographic location and sample site

(Q-l) Dechambeau (sites l-7 are in series approaching lake)

(1) Poplar, aspen, willow, bluegrass and sedge margined stream riffle, Relatively far above lake level, contains much plant debris.
(2) Open grassy marsh formed from a distribution at the above stream over this locality. Dense Kentucky bluegrass and sedges predominate.
(3) Run to riffle conditions on this section at stream basically similar to site 1 but without tree cover. Prolific filamentous algae.
(4) Stream riffle with nearby spring source. Aquatic plants: Rumex, water cress, sedges and filamentous algae.
(5) Tufa spring-fed marsh, among standing water and detritus with growth of sedges, distichulus, rumex, arrow-weed and algae.
(6) No marginal vegetation, adjacent to alkali sand flats, sparse algal growth on the few submerged rocks and sticks present.
(7) Detrital mud flats formed adjacent to lake shore and Dechambeau creek delta.

(Q-5) Gull Bath Creek

(8) The rocky substrate of this atypical stream continues down to lake inlet. Source is Mono Vista spring, riffle conditions. Sample site 50 ft. distance from lake.
(9) Large spring source stream, barren of marginal vegetation and below a marsh zone (see sites 10 and 11).
(10) Spring source stream above site 9 with heavy growth of grasses, sedges, willow, water parsnip, f. algae. Substrate primarily sand with detrital cover.
(11) Spring source marsh pond with sandy substrate overlain by detritus. Marginal vegetation composed of water parsnip, water cress, willow, sedges.
(12) Hanson spring source stream, in vegetated zone (salt & alkali grass, water cress, f. algae, sedges, willow, arrow-weed). Run-riffle conditions.
(13) Non-vegetated zone below site 12 on the same spring stream.
(14) Detrital mud flats delta adjacent to lake and stream of sites 9 - 11.

Table 4-1, Cont'd.

(Q-2) Sneeker Flat

(15) Vegetated zone of this small spring source stream. Sedges, paintbrush, thistle, water cress, grasses. Shallow run conditions.
(16) Non-vegetated zone of the above stream. Adjacent to sand-alkali flats, 50 years from lake, run conditions.

(Q-3) Simon Springs complex

(17) Shallow marsh pond at the edge of the marsh-sand flat transition. Sedges, tule, salt grass. Substrate sandy with detrital cover.
(18) Non-vegetated sand flat adjacent stream zone below the marsh, Run conditions. 100 meters from lake.
(19) Vegetated zone of a second stream running out of the marsh, Sedges, foxtail, salt grass and f. algae. Much rubble in portions of this stream. Run conditions.
(20) Extensive causeway pond adjacent to marsh, formed by sulphur containing springs. Detrital mud substrate. Abundant f. algae floating in water. 100 yds. from lake.

(Q-4) (21) Pond in the warm springs marsh area. Marginal vegetation of sedges, arrow-weed, salt and alkali grass. Detrital mud substrate.

(Q-6) East Paoha Spring

(22) Stream pool formed at edge of marsh vegetation-sand flat transition. Silt bottomed, 20 feet from lake edge.
(23) Vegetated zone of the (E. Paoha cove marsh) spring stream (f. algae, foxtail, sedges, arrow-weed, distichulus). Run conditions in this deep, narrow channel.

Note all numbers with Q-n prefix refer to location map code.

Table 4-2

SHORE SURVEY LIST

Organism	A	B			C	D		E			F		
	1	2	3	4	5	6	7	8	9	10	11	12	13
Diptera													
Chloropidae	10	+	450-750	+	10	+	+	+	50	3	1000	40	40
Dolichopodidae	1												
Anthomyiidae Lispe								+	+	+	+	+	+
Ephydridae													
Ephydra													
(Hydropyrus) hians		750-1500	+	+	40	2000-2500		150	+	+		625	+
Paralimna multipunctata(?)					+								
Dichaeta atriventris(?)								+	+	+			
Notophilinae													
Scatella													
Scatophila													
Hemiptera													
Saldidae													
Saldula arenicola			+	25	+	+	+		3	5			10
Coleoptera													
Staphylinidae	+				+			+	+	10			+
Environmental Parameters													
Surface Temperature	-	-	-	-	30°	33°	28°	19°	19°	19°	24°	24°	24°
Soil pH	-	10	-	-	-	10	10	9.5	9.5	-	9.5	9.5	9.5
Vegetation cover	1	0	0	0	0	0	0	0	0	0	1	1	0
Proximity to water	1	2	1	0	1	2	1	2	1	.5	2	2	1
Date-time	7/13 PM	7/15 PM	7/15 PM	7/15 PM	7/24 PM	7/25 PM	7/25 PM	8/4 AM	8/4 AM	8/4 AM	8/4 PM	8/4 PM	8/4 PM
Substrate	D	M	S	AS	D	M	AS	M	S	G	G	M	AS
Stream or Lake shore (S or L)	S	L	-	-	S	L	-	S	-	-	L	L	-

Table 4-2, Cont'd.

Organism	G					H			I		
	14	15	16	17	18	19	20	21	22	23	24
Diptera											
Chloropidae	8	20	20	50	750		5	+	+	+	
Dolichopodidae	4										
Anthomyiidae Lispe	3	+	+	+	3	+	+	+	+	+	
Ephydridae											
Ephydra											
(Hydropyrus) hians	5	+	+	+	450	1000	5	+	500	+	+
Paralemna multipunctata(?)											
Dichaeta atriventris(?)										+	+
Notophilinae					+						
Scatella					+						
Scatophila					+						
Hemiptera											
Saldidae											
Saldula arenicola	5	10	3	10	5	+	15	+		5	10
Coleoptera											
Staphylinidae										+	+
Environmental Parameters											
Surface temperature	28.5^{o}	27.5^{o}	-	-	25^{o}	23^{o}	23^{o}	23^{o}	30^{o}	31^{o}	31^{o}
Substrate pH	5.5	-	-	-	6	10	-	-	10	10	10
Vegetation cover	0	0	0	0	0	0	0	0	0	0	0
Proximity to water	1.5	.5	.5	.5	1.5	2	1	.5	2	1	.5
Date-time	8/10 AM	8/10 AM	8/10 AM	8/10 AM	8/10 AM	8/10 PM	8/10 PM	8/10 PM	8/21 PM	8/21 PM	8/21 PM
Substrate	G	S	G	S	G	M	S	AS	M	S	AS
Stream-Spring or Lake shore	S	-	-	-	L	L	-	-	SL	-	-

Table 4-2, Cont'd.

Vegetation cover index: 0 = no vegetation at microhabitat sample site
1 = sparse cover (10%)
2 = moderate cover (20%)

Proximity to water index: 0 = no water (dry)
1 = interstitial or adsorbed water present
2 = water film, pool or aquatic (liquid)

Predominant substrate type: M = mud; AS = alkali-sand; S = sand; G = gravel and pebbles; D = alluvial soil

Table 4-3

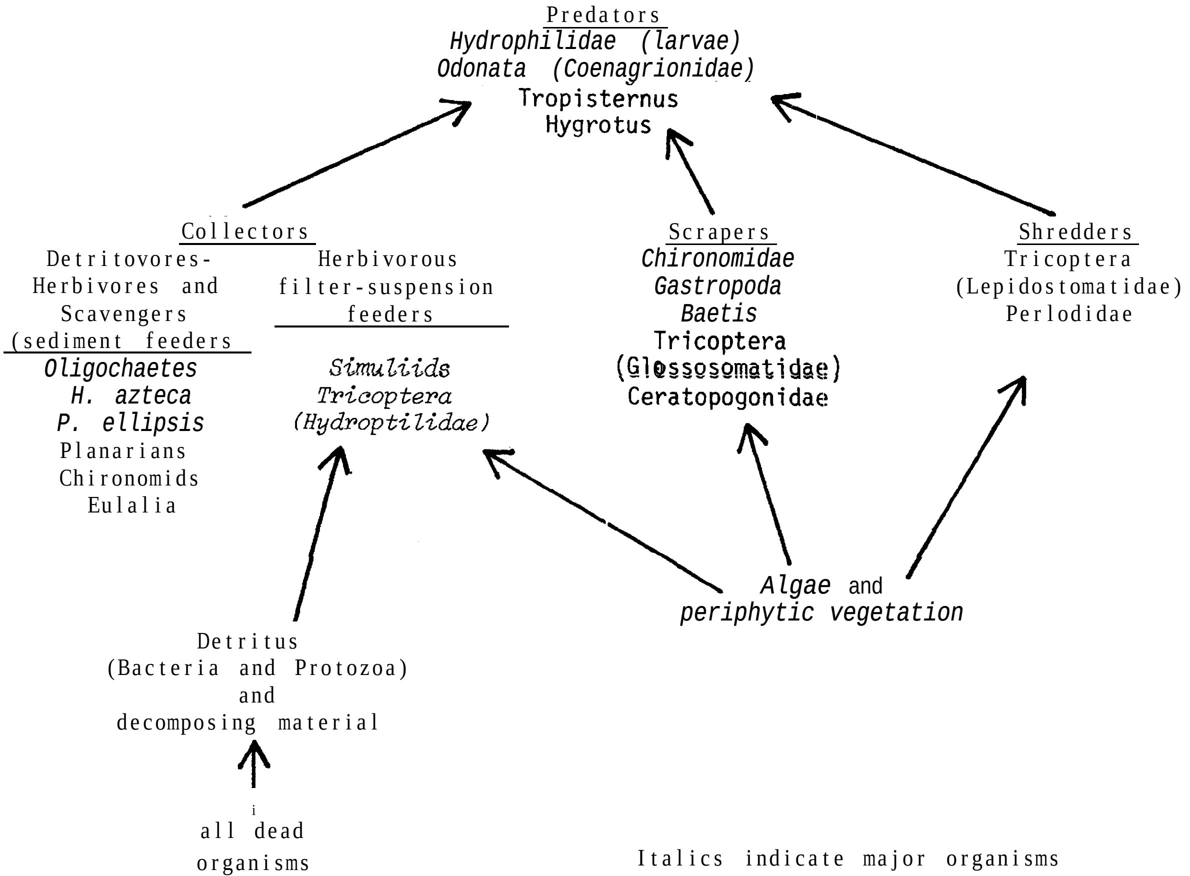
STREAM DRIFT

	Simon springs creek	Gull Bath spring creek	Dechambeau creek	Sneeker Flat spring creek
Biomass (grams/12 hr. day period)	3.6	154.0	.72	2.4
Number of insects (#N/12 hr.)	3840	67000	1296	950
Stream depth x width (cm)	4 x 150	8 x 550	5 x 150	4 x 40
Current velocity (m/s)	.1	.35	.3	.25
Sampling time (min.)		6	10	
Sample width (cm)	75	60	75	40

Insects caught in water current, sampled with net near inlet to lake for the indicated sample time. Biomass and numbers calculated from that portion of 12-hour day period and stream cross-section sampled.

Figure 4-2

STREAM TROPHIC RELATIONS



Italics indicate major organisms contributing to energy flow.

Figure 4-3

POND TROPHIC RELATIONS

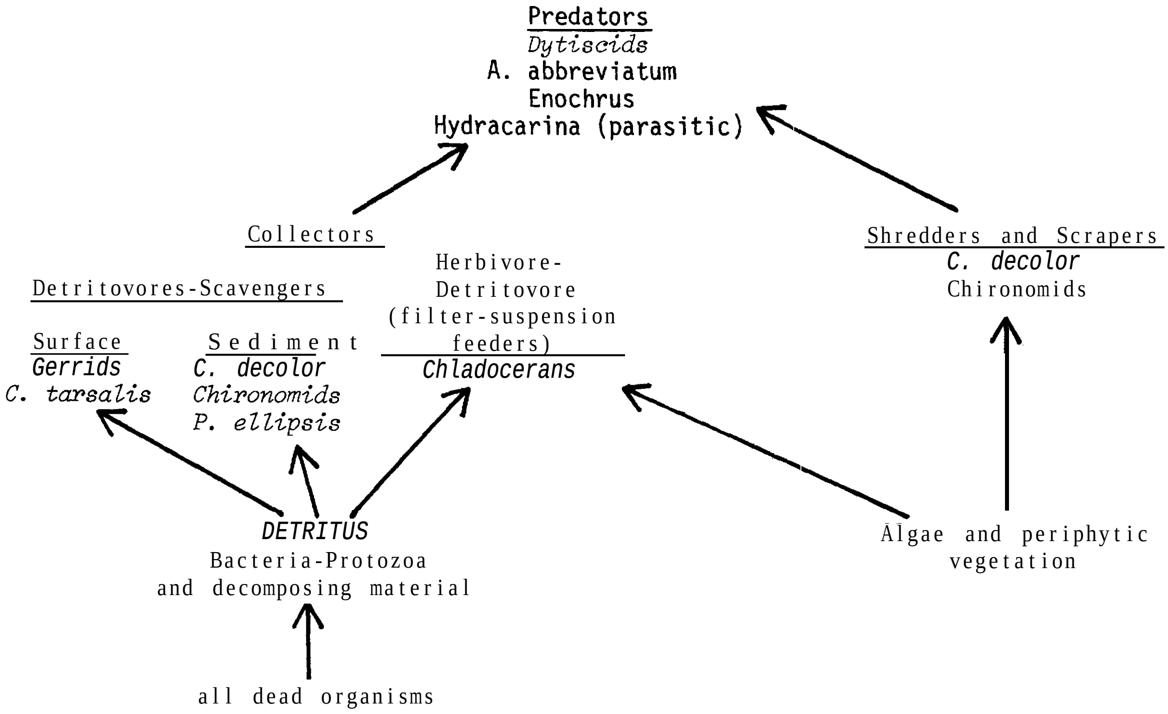
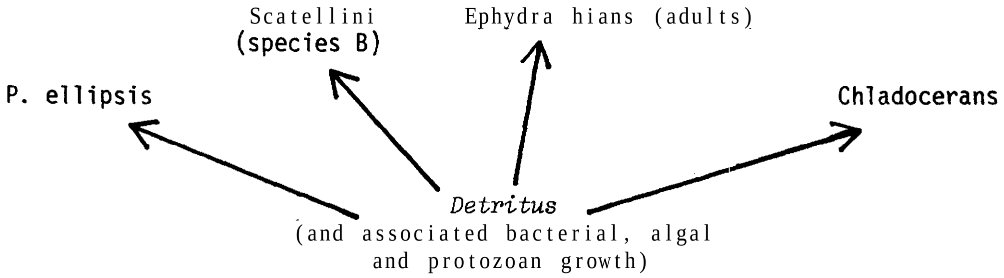


Figure 4-4

TROPHIC RELATIONS OF DETRITAL MUD FLATS



arenicola. The division of the shore into microhabitats on the basis of substrate type and water availability (see sampling section) is valuable in describing the distribution of the dominant insect types on the shore. While the insects (especially the flies) have a locally patchy disposition, they each appear predominantly in one of the three microhabitat zones paralleling the shore. This arrangement is indicative of a habitat partitioning of resources.

The prolific brine fly, Ephydra (Hydropyrus) hians, dominates at the lake or stream edge in the wet detrital mudflat microhabitat. Densities of thirty individuals per square inch (36,000-45,000/m ^{2}) were observed in some instances, though average figures would typically be around 500 per square foot. Though the brine fly may range over the whole periphery of the lake, observations indicate that the flies occur in significant numbers only in the vicinity of shallow water formations and fragments of tufa rock. This is probably related to the' oviposition, larval development and emergence occurring at these sites.

The Chloropid flies, while not as large or as obvious as the brine flies, are often equally or even more abundant than Ephydra hians and also have a range which extends over the entire lake shore. Chloropids usually dominate in the sandy zone (interstitially adsorbed water) next to the mud flats and on the stream and lake shore where the substrate is composed of sand and gravel. Although there is considerable overlap of chloropids and shore bugs between this zone and the drier alkali sand flats, it is in this latter microhabitat that Saldula arenicola is most often encountered. Both nymphs and adults have been collected from the shore; though not truly aquatic, they survive accidental landing on water by virtue of a fine bed of water-repellent hairs. The shore bugs and large Anthomyid flies are predaceous, the shore bugs probably feeding on small insects, the Anthomyid flies hunting the brine and chloropid flies.

Because it embraces a gradient of substrate and moisture conditions from freshwater spring shore (site 14) to lake shore (site 18), sampling area G is of particular interest. Both Ephydra and the chloropid fly apparently prefer to congregate on shores near alkaline water, although, in this particular case, the low pH and gravel composition of the lake shore substrate may be more favorable to the chloropid flies which predominate there.

Aldrich (1912) and Wirth (1970) have given accounts of the biology and systematics of Ephydra. Following are additional comments on the adult brine flies of Mono Lake. The adults of Ephydra hians have the unique ability to climb into the water on objects exposed above the water surface in order to lay eggs or scrape algae off rocks. When ready to go to the surface, the flies let go of the submerged object and float to the surface on the bubble of air held beneath their wings. In addition to the algae they obtain in this way, the flies feed on detritus, actually forming small, shallow depressions in which groups of flies can be seen feeding. When feeding, the flies usually assume a position in which the head is inclined downward and the abdomen tilted upward. This behavior may also be related to thermo-regulation, as the tip of the abdomen is usually oriented towards the sun (reducing surface area exposed), returning to a horizontal position when cloud shadows pass over. While the flies can be found on the shore during the day, they rest by night or during high winds in the salt grass or other near-shore vegetation.

The larvae of the tiger beetles (Family Cicindelidae, genus Cicindela), of the lake basins insect community, can be found in burrows which they dig as deep as eight inches in well-packed sand. These are most common in the wet sand flats on the east side (Simon springs and Warm springs; usually far from the lake shore) where meandering spring delta and seepage keep the sand solid enough to be burrowed in. A larva will wait at the top of the burrow with flat, shovel-shaped head flush to the surface, siezing any small insect in its jaws and dragging it into the burrow with the help of pincer-like dorsal (back) appendages which it uses to grasp the sides of the burrow. The greatest enemy of the larval tiger beetle is the Long-billed Curlew, a bird whose long beak enables it to feed on this type of burrowing prey. The adult tiger beetles can be found flitting about among the sand dunes. Large numbers of the adults have been observed on the sandy eastern shores of Paoha Island, though few larvae occur there. This may represent a division in the population by suitability of habitat to development stage. Oviposition (egg-laying) occurs immediately after mating, with the male still grasping the female. Pushing her abdomen deep into the sand, she lays one egg at a time, covering it with sand afterward. This egg soon develops into a larva which will dig its own burrow.

Except for one spring on the east side of the island, Paoha is dry. This is a typical habitat of the darkling beetle (Tenebrionidae, Eleodes) and indeed this insect dominates over most of Paoha Island. Among the few insects that are found on the dry, volcanic Negit Island in late summer were flesh flies (Sarcophagidae), blue butterfly (Lycaenidae, Plebeiinae), and Dermestid beetles in abandoned gull nests. Except for great numbers of field crickets (Gryllidae,Gryllinae) reported from a visit during the late spring, these insects are probably of no trophic significance to the gull colony.

As the level of the lake drops and the shoreline recedes, the shore insects will undoubtedly follow. However, since the brine fly spends its larval development period in the lake, physiological changes with increased salinity may be the key to predicting the future of this most productive insect of Mono Lake (Salinity Tolerance section, Chapter 3-4)*

SUMMARY

(I) A survey of freshwater aquatic and shore insects of the Mono Lake basin is shown in Table 4-1.

(2) Distribution of aquatic insects is restricted by geographic location and habitat type. Diversity, productivity and stability of this component of the biotic community are considered.

(3) Distribution of the shore insects follows a microhabitat partitioning by each of the three major insect types into zones determined by water availability and substrate composition. Brine flies prefer wet mud, frit or chloropid flies prefer moist sand or gravel, and shore bugs are found mainly on dry alkali sand.

(4) The quantity of insect biomass drifting into the lake from a large spring stream (an important site of gull congregation) could constitute a supplemental source of food to the birds.

Chapter 5

ORNITHOLOGY

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F. Brett Engstrom, and S. Elliot Burch

INTRODUCTION

Mono Lake's bird populations are important for their variety, but the overriding factor in any evaluation of the ornithological significance of the Mono basin must be the numbers of birds coming to the lake. Mono has long been known as the home of one of the largest California Gull colonies in the western Great Basin, and previous estimates of the numbers of Eared Grebes on the lake in the fall have ranged to over a million. In addition to the grebes, Mono's transient avifauna includes such species as the Northern and Wilson's Phalaropes and American Avocet, all of which occur by the thousands.

The ornithologists in this study had the task of determining the effects of the lake's declining levels on these bird populations and the possible implications of those effects. Despite considerable interest in the lake by ornithologists over the past seventy-five years, a comprehensive description of the lake and its avifauna had never been made. Baseline data were needed in order to assess Mono Lake's relative importance and the large-scale implications of the alteration of its avifauna. These Ibaseline data were collected through a series of censuses aimed at determining seasonal and spatial patterns in bird populations at Mono Lake over the three-month period of the study. Mono Lake's large bird populations presented the greatest single censusing problem. Field estimates of large flocks are difficult to obtain and it is for this reason that special efforts were made to standardize censusing procedure and to account for potential sources of inaccuracy in censusing techniques.

The establishment of baseline data on bird abundance and seasonality places Mono's ornithological importance in perspective, but it does little to answer the most critical question of all: how will a shrinking Mono Lake affect the birds there? The simplicity of Mono Lake's ecosystem made feasible a three-month investigation of possible effects of changing lake levels on the future integrity of the lake's avifauna. It is easy to ascertain the role and importance of birds in this ecosystem. Those aspects of the ecosystem which are most vital to continued support of the bird populations visiting the lake are also simple to study. The investigations of the ecology of the bird community on Mono Lake inevitably require research into the biology of individual species; thus all studies of this type have been placed under the heading of "biological investigations" in sections to follow.

Of the breeding species on Mono Lake, the California Gull is the most important. In order to establish its functioning in the Mono ecosystem, the gull's diet had to be determined. Additionally, details on its nesting biology (e.g., clutch size and nesting density) were needed in order to provide a comparative base for evaluating the population on Mono in the light of earlier work done on the Mono gulls and research on California Gull populations in other areas.

Nesting species have an obvious reason for being at the lake, but it is often difficult to determine what brings transient species there. Since the Eared Grebe comprises the bulk of all avian biomass to use the lake in the course of a year, it would have been the ideal transient species to study; however, despite considerable research and efforts in the field, no satisfactory method of safely capturing and releasing grebes was found. As a result, our attention was focused on the next most abundant transient species: the Wilson's and Northern Phalaropes.

Shorebirds replace all their feathers at least once annually in a molt during the fall season. Some shorebirds go through this molt on the breeding grounds before they head south, and others wait to molt until they reach their wintering grounds. This large annual molt requires a great deal of energy, and it is presumably for this reason that shorebirds generally avoid heavy molt during long migratory flights. With this timing of feather replacement in mind, the molt of migrant shorebirds at Mono Lake was investigated in order to ascertain whether they are using Mono as a rest stop at which molt is carried out before continuing south. a

Because Mono is an important stop on the birds' migrations, it is also helpful to find out whether the birds have the ability to fly to the next stop on the flyway if they can no longer stop at Mono. Flight ranges are estimated through estimation of and extrapolations from the birds' fat reserves.

Any investigation of the shorebirds' place in the Mono ecosystem must also determine whether the phalaropes feed while visiting the lake and, if so, the composition of their diet.

In summary, the ornithological investigations at Mono Lake were aimed at collecting baseline data on species diversity and abundance and at investigating the biology of several of the most abundant species. These biological investigations were aimed at assessing diet, breeding biology, molt and migratory capabilities. These data were used as a base for a general assessment of the future of Mono's bird populations.

METHODS

A reconnaissance visit to Mono Lake on May 29-31, 1976, included a partial census of the gull colonies on Negit Island and casual observations elsewhere along the shore. Field work was initiated in earnest on June 11 and continued without interruption until September 14. On November 20 and 21 a final visit included a partial Eared Grebe census and casual observations. The following sections describe census methodology as well as the materials and methods of the biological investigations.

I. Censusing:

Three methods were used to census bird populations on Mono Lake: 1) all-lake census, 2) spot census, and 3) gull colony census. Most of our efforts were directed toward censusing the "wet birds" (the bird orders Gaviiformes through Charadriiformes, excluding Falconiformes and Galliformes).

The all-lake census (ALC) was designed to determine the abundance of all species present on the lake during a given day. Five complete ALCs were made during our study on the following dates: July 8, August 8, August 21, August 30, and September 14. Two additional censuses, on July 23 and July 26, were only partially completed because of unfavorable weather conditions.

The lake was divided into seven census routes (Figure 5-1). Of these, six consisted of shoreline covered either on foot or by canoe. The seventh consisted of the islands and the water surrounding them. From sunrise to early afternoon, the observers on each census route recorded the species, numbers, times, and locations of sightings.

All census observers were equipped with 7 x 35, 7 x 50 or 10 x 50 binoculars. In addition, two spotting scopes, a 25x and a 20-45x zoom were employed on the west and southeast shores to count shorebirds and grebes. A third scope, a 15-60x zoom, was used on the seventh leg to count birds on the open water from the islands.

Methods used for counting and estimating numbers are summarized in Table 5-1.

Eared Grebes presented special problems for censusing, because they were distributed nearly evenly over the entire lake. Mono Lake's large size made censusing the center of the lake from the shore impossible. At lake level one can see, at most, one mile offshore. Elevated spots (usually the tops of tufa towers) were sought to extend the field of view and to minimize the mirage effects of heat waves on distant water. The total numbers of Eared Grebes were estimated by extrapolation, since the entire surface of the lake could not be covered. First, the size of the uncensused area was estimated. Next, the average density of birds in this area was estimated based on densities of the surrounding areas. Finally, the area was multiplied by the density to obtain the extrapolated number. The extrapolated increment added to the original unextrapolated number never amounted to more than 35% of the total.

To obtain a better understanding of the trends in distribution and density of birds,

DENSITY CATEGORIES	CENSUSING METHODS	FACTORS INFLUENCING ACCURACY
Small numbers	Direct count	
Fairly large numbers distributed linearly along shore.	Direct count	Movement of birds affects accuracy of count.
Large numbers concentrated along shore.	(1) Direct partial count extrapolated to total area. (2) Direct counts for an average "row" and "column" of birds in the census area, multiplied together to give total number.	In both methods, movement of birds affects accuracy of partial count. (2) is based on the assumption that birds are evenly distributed in a rectangular grid pattern.
Large numbers distributed over wide area of lake's surface.	Direct partial count extrapolated to areas of same density. Same technique applied independently to areas of different densities.	Visibility of the lake's distant surface is impaired when observer is at lake level. Also, it is difficult to ascertain the area of the lake's surface being censused.
Large numbers flying in flocks.	Estimated partial count extrapolated to total size of flock.	Flying flocks require quick estimation; therefore, some accuracy is sacrificed.

Table 5-1. METHODS USED FOR COUNTING AND ESTIMATING NUMBERS OF BIRDS.

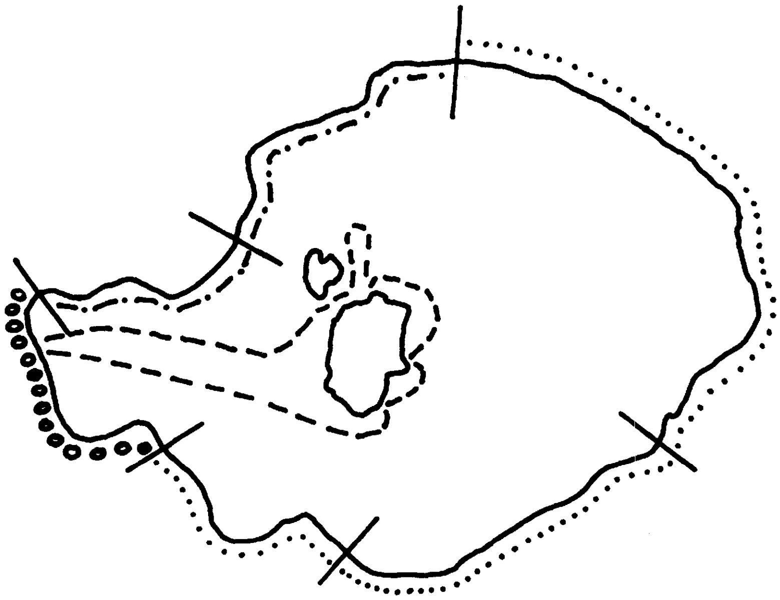

Figure 5-1. CENSUS LEGS USED FOR THE ALL-LAKE CENSUSES. Dotted lines represent those areas which were censused on foot; dashed line is the boat leg; line of circles represents the area done mostly by car; and the line of alternate dashes and dots represents the legs done by canoe.

spot censuses were conducted at various times around the lake. The censuses consisted of counting species and individuals in limited areas. Locations which had high bird densities, such as Mono Park and the southeast shore, were most frequently censused. Although the censuses were not always taken at the same time of day and occasionally only partial censuses were made, the numbers gave an indication of the trend of distribution for a variety of species. The same methods employed during the ALCs for counting and estimating numbers were used in spot censuses.

Informal censuses were occasionally conducted at other western Great Basin lakes, and numbers of gulls and phalaropes visiting sources of fresh water were occasionally tallied.

The gull colonies were censused in two ways: 1) through censuses conducted from canoes, and 2) through direct counts of nests with eggs or young. Both methods are subject to error, and, as far as possible, the method deemed most appropriate was chosen for each area of the colonies.

The gull colonies on the small islands northeast of Negit were censused by canoe, because most if not all of the active gull colonies there are visible from the water. This method results in low estimates, for young gulls are easily hidden in the uneven terrain of many of the islands. This visibility problem was partially alleviated by multiplying the estimates by ratios corresponding to variations in observability for each island. These ratios (Table 5-2) are subjective and are probably conservative. Canoe censuses were done on all the small islands on June 23-24 and July 21. The data from July 21 were used in the final calculations, for, on that date, a maximum number of young had hatched and very few had reached fledging age.

The area presenting the greatest censusing difficulty was the main colony on Negit. The bulk of the colony is hidden by high terrain and vegetation. The number of nesting gulls was estimated by counting the number of active nests, eggs, and young in areas of known size and extrapolating to estimates for the entire colony. Counts of this type were made in two major habitat areas on the island, white rock and greasewood. The approximate square area of the colonies was determined through superimposition of graph paper on maps of the colonies. Allowances for the unhatched eggs were made according to egg hatching proportions reported by Behle and Goates (1957); however, these adjustments never resulted in a significant increase in estimated numbers of young.

Once an estimate of numbers of young was obtained, the total number of adults present on all colonies was estimated by multiplying the number of young by a factor for the number of adults per young. This factor was determined through consideration of values given by Vermeer (1970) and Behle and Goates. It was assumed that approximately 1.2 young per clutch would survive to the age at which they were censused. Therefore, each young gull represented l/1.2 or .833 pairs, or 1.67 adults. In other words, for every 1.67 adult gulls, one young hatching-year gull was seen on the islands.

II. Biological Investigations:

A. California Gull

In addition to being aimed at obtaining an estimate of total numbers on the lake, the investigations of the California Gull were designed to identify those parts of the Mono ecosystem which are most crucial to the continued maintenance of their large population. In an effort to determine the food items most heavily used by the gulls, stomach samples were procured by collecting crop contents which were spontaneously regurgitated by hatchling gulls during our visits to the islands. These samples were analyzed by estimating the percent (by volume) composition. Clutch sizes of all nests with eggs were recorded during the May 31- June 1 visit to Negit Island.

B. Shorebirds

The biology of the migrant shorebird species at Mono Lake was investigated in an effort to ascertain: 1) the diet of the birds while at Mono, 2) the age and sex ratios of the populations, 3) the extent of Mono's importance as a stopover for molting, and 4) the approximate flight range capabilities of the birds. All of these facets were explored through observations and measurements of captured birds.

The shorebirds were captured with mist nets. The most successful set-up for

	Ratio	Young	Adults
Twain (Tw)	1.0	2264	3781
Little Tahiti (LT)	1.3	634	1059
Pancake (P)	1.0	626	1045
Little Norway (LN)	1.5	435	726
Steamboat (St)	1.3	374	625
Java (J)	1.3	367	613
Spot (Sp)	1.0	110	184
Tie (T)	1.0	96	160
Krakatoa (K)	1.3	79	132
Hat (H)	1.0	22	37
TOTALS FOR ALL ISLANDS		5007	8362

Table 5-2. SUMMARY OF CENSUSING EXTRAPOLATION RATIOS AND ESTIMATED POPULATIONS OF CALIFORNIA GULLS ON THE SMALL ISLANDS NORTH AND EAST OF NEGIT ISLAND. See Figure 5-2 for the locations of the islands.

Habitat type	Clutch size category (eggs/nest)				Total nexts	Mean clutch size
	1	2	3	4		
	(Number of Nests)					
Greasewood (G)	16	20	6	-	42	1.76
Greasewood	4	11	1	-	16	1.81
Greasewood	3	32	4	-	39	2.12
White rock (WR)	24	144	19	-	187	1.97
White rock	29	100	18	1	148	1.94
Total G	23	63	11	-	97	1.88
Total WR	53	244	37	1	335	1.99
All colonies	76	307	48	1	432	1.94

Table 5-4. MEAN CLUTCH SIZES OF CALIFORNIA GULLS IN COLONIES OF DIFFERENT HABITAT TYPES ON NEGIT ISLAND, MAY 31, 1976.

phalaropes proved to be a series of three to five nets (with a combined length of 50 to 100 meters) set perpendicular to shore over waist deep water with a comparatively hard substrate. This net set was used in a narrow cove (Canoe Launch, Figure l-l) in which the water was often calm and large numbers of phalaropes were usually present. Sandpipers were most successfully trapped with nets set across and parallel to the muddy deltas of small creeks entering the lake.

On all birds captured, measurements of culmen (bill length), and tarsus were taken with vernier calipers accurate to 0.1 mm. Unflattened and unstraightened chord (an index of wing length) was measured with a metric ruler to the nearest mm. The birds were weighed with Pesola 100 gm spring scales to the nearest 0.1 gm. Molt and feather wear on the birds was quantified according to a four point scale on all body feather tracts (Page 1974). Molt in the wing and tail feathers was described according to the system proposed by Collins (1975).

The shorebirds were placed in age categories on the basis of plumage characteristics and condition of the soft parts (e.g., bill and feet). Birds with buffy or rust edged tertials and wing coverts were considered young of the year unless other factors indicated otherwise (Page 1974, Palmer 1967, Witherby et al 1943). Condition of the soft parts was considered a secondary aging criterion LO be used only in instances of borderline plumages. If any doubt remained, the bird was considered of unknown age.

The sex of Least and Western Sandpipers was determined by reference to criteria based on culmen measurements determined by Page (1974, 1971).

Criteria for determining the sex of phalaropes was not available. In order to establish these criteria, all phalarope specimens in the Museum of Vertebrate Zoology (MVZ), University of California, Berkeley, were measured. With the specimens from MVZ of known sex as reference standards, a multivariate discriminant function analysis of the data was run by computer (packaged programs from SPSS) to determine which characteristics were most meaningful in separating the sexes and what the discriminating values of these characteristics were. All the phalaropes banded at Mono Lake were placed in sex categories according to the standards determined by the computer.

Stomach samples were obtained from phalaropes through a method developed by Gary Page (Point Reyes Bird Observatory). This method involves the insertion of a thin walled plastic straw down the esophagus into the stomach of the bird!, injection of 2 - 3 cc of water from a syringe attached to the straw, and withdrawal of an approximately equal volume of stomach contents. The samples thus obtained were analyzed by visual scanning with a compound microscope at 80 - 100x and estimation of their percent composition (by number).

All birds captured were banded with standard U.S. Fish and Wildlife Service aluminum leg bands and released,

Fat content of phalaropes was estimated by use of the relationship between wing chord and body weight (Mascher 1966). Chord is a rough indication of absolute body size (i.e., birds with longer wing feathers tend to be larger in all body dimensions). By plotting chord versus body weight, one obtains a regression line. For any given body size (i.e., a fixed chord value), the lightest individuals are birds with little or no fat. A "fat-free line" was drawn parallel to the original regression line through the data points for the lean birds. This fat-free line was estimated by eye. A few data points lie below the line, since some shorebirds will consume other sources of energy (e.g., protein in their muscle) when their fat stores are depleted (G.Page,pers.comm.,McNeil and Cadieux 1972) and will thus weigh less than their fat-free weight. Fat content of each bird was estimated by subtracting the fat-free value corresponding to the bird's chord measurement from its total weight.

Several workers have attempted to estimate migratory flight range in shorebirds (Johnston and MacFarlane 1967; McNeil and Cadieux). The general technique is to estimate the flight metabolism (FM), the migratory flight speed (FS), and the magnitude of energy reserves (E). The flight range (FR) is then calculated from the following equation:

$$FR = \frac{FS \times E}{FM}$$

Flight metabolism is difficult to measure. In this study it was computed according to conversions and equations based on body weight (Hart and Berger 1972). Flight speed was estimated through consideration of previously published flight speeds for other shorebirds (Meinertzhagen 1955, Johnston and MacFarlane). Energy reserves were estimated by determining the amount of fat present and converting this weight into the amount of energy it can provide once it is metabolized. The conversion factor used was 9.1 kcal per gram of fat (Johnston 1970).

RESULTS

I. Censuses:

The results of the all lake censuses are presented in Table 5-3. On the three dates asterisked, the censuses did not include the east shore leg (Figure 5-1). The 38,943 figure for adult California Gulls on the July 8 ALC represents a partial count, since the adults at the colonies were not censused.

Spot census and all lake census data for the "wet birds" collected over the entire summer were used to compile a list of species accounts (pp.97 -700) which summarizes general trends in abundance and status for each species. Species accounts are presented in taxonomic order according to three major classifications: (1) species sighted 3 times or less, (2) species sighted 4 to 12 times, and (3) species sighted over 12 times. For those species which were sighted 3 times or less, each sighting shows numbers per sighting and date. For the second category, the total number of sightings is given first as an indication of species abundance. This is followed by first sighting, high count, and last sighting; each showing numbers and date, For the third category, the number of sightings is not included because it does not provide a meaningful indication of abundance. For these species, records of major fluctuations are included in addition to data on numbers of first sighting, high count, and last sighting. Habitat descriptions are given for those species which were sighted at least 6 times and showed an affinity to a particular habitat. For those species which breed on the lake, "breeder" is given next to the species' scientific name. Only direct evidence (nest, eggs, and/or young) is given to document breeding status. Data on age is included for those species whose age can be determined in the field. A special "migration" subheading is included under Wilson's Phalarope and California Gull, since these were the only two species for which migration was actually observed. The abbreviations used are: ad.=adult, imm.=immature, HY=hatching year (i.e., the bird in question is less than one year old), AHY=after hatching year (i.e., bird is at least one year old), and sght.=sighting.

The freshwater source at Mono Lake most heavily used by gulls is Gull Bath. The results of a single 24-hour census conducted there indicate that the numbers of gulls visiting the area rise from an overnight low of zero to highs of 6,000 and 7,000 at 1400 and 1800 hrs. respectively, with a mid-afternoon drop to about 4,300 gulls at about 1600 hrs. Numbers dropped abruptly following the late afternoon high to near zero at 2100 hrs. Sporadic observations from Dechambeau Ponds together with those from Gull Bath indicate a generality in patterns of freshwater use by gulls: numbers visiting freshwater areas rise gradually through the morning hours to highs in the late afternoon followed by abrupt drops to zero at night. Upon arriving, most gulls follow a progression of activities from drinking and shaking the submerged bill to extensive bathing and preening. The observations indicate that the gulls use the freshwater area primarily for drinking and bathing and only secondarily, if at all, for feeding.

The densest assemblages of Northern Phalaropes were observed at Dechambeau Ponds. Tight flocks of 5 to 5,000 birds were observed bathing in one pond and then flying quickly to the other to repeat the bathing activities. Flocks rarely bathed for more than a minute at each pond; the bathing activities were usually finished and the flock gone within fifteen minutes of their arrival at Dechambeau. Phalaropes were not observed feeding at Dechambeau Ponds.

The few casual censuses conducted on other Great Basin lakes resulted in some interesting data. On September 15, at a time when there were approximately 5,000 phalaropes and 700,000 grebes on Mono, 8 Eared Grebes were seen on Walker Lake, 8 on Washoe Lake and 1 on Lahontan Reservoir. No phalaropes were seen on any of the lakes. On October 1 there were no phalaropes on Mono Lake; apparently, they had all migrated further south. On November 20 there were no Eared Grebes on Washoe or Topaz Lakes, and on November 21 there were 35 on Grant Lake, 5 on June Lake, and 1 on Little Gull Lake. On the same dates there were approximately 500,000 Eared Grebes on Mono Lake.

SPECIES	JULY 8	AUG. 8*	AUG. 21*	AUG. 30*	SEPT. 14
Eared Grebe (counted)	50,270	102,717	417,942	540,750	614,200
(extrapolated)		(103,117)	(494,042)	(730,250)	(707,000)
Western Grebe				1	
Double-cr. Cormorant					8
Great Blue Heron	3			1	
Green Heron		1			
Snowy Egret		1			
Black-cr. Night Heron				1	
White-faced Ibis		8			
Mallard	2	2	39	13	11
Gadwall	1			10	
Pintail	30	110	366	764	297
Green-winged Teal		3	183	195	84
Cinnamon Teal		6	3		
Blue-w. or Cinnamon teal		60	79	3	
Unidentifiable teal	1	44	50	453	987
Shoveler		29	2	1080	2230
Redhead	1				
Ruddy Duck	4	3	2	27	62
Unidentifiable ducks		32	36		47
Virginia Rail				1	
American Coot	7	2	7	154	347
Semipalmated Plover		22	10	19	2
Snowy Plover	50	7	5		100
Killdeer	153	154	314	269	254
Black-bellied Plover			3		1
Common Snipe	24	1	3	1	1
Long-billed Curlew	2	9	3	1	2
Spotted Sandpiper	44	22	16	11	7
Solitary Sandpiper				1	
Wandering Tattler					1
Willet	1	22	24	13	5
Greater Yellowlegs	3	5	6	2	4
Lesser Yellowlegs		2	13	6	
Knot				2	
Pectoral Sandpiper					6
Baird's Sandpiper			3	1	
Least Sandpiper		152	128	417	323
Dowitcher		10	171	38	
Western Sandpiper	21	26	97	182	356
Calidris spp:		30		178	239
Marbled Godwit	5	22	21	36	
Sanderling					1
American Avocet	2679	2537	2010	3950	995
Black-necked Stilt	15	6		2	
Wilson's Phalarope	15,586	16,269	1335	2495	29
Northern Phalarope	613	13,797	18,497	21,613	4829
Unidentifiable phalaropes		2751	175		15
California Gull, adult	38,943	19,973	14,714	12,134	10,775
California Gull, HY		3164	675	244	32
Ring-billed Gull	1				
Bonaparte's Gull	2	3	2		
Forster's Tern	25	6			
Caspian Tern	38		1	24	14
Black Tern		1			

Table 5-3. ALL-LAKE CENSUS RESULTS.

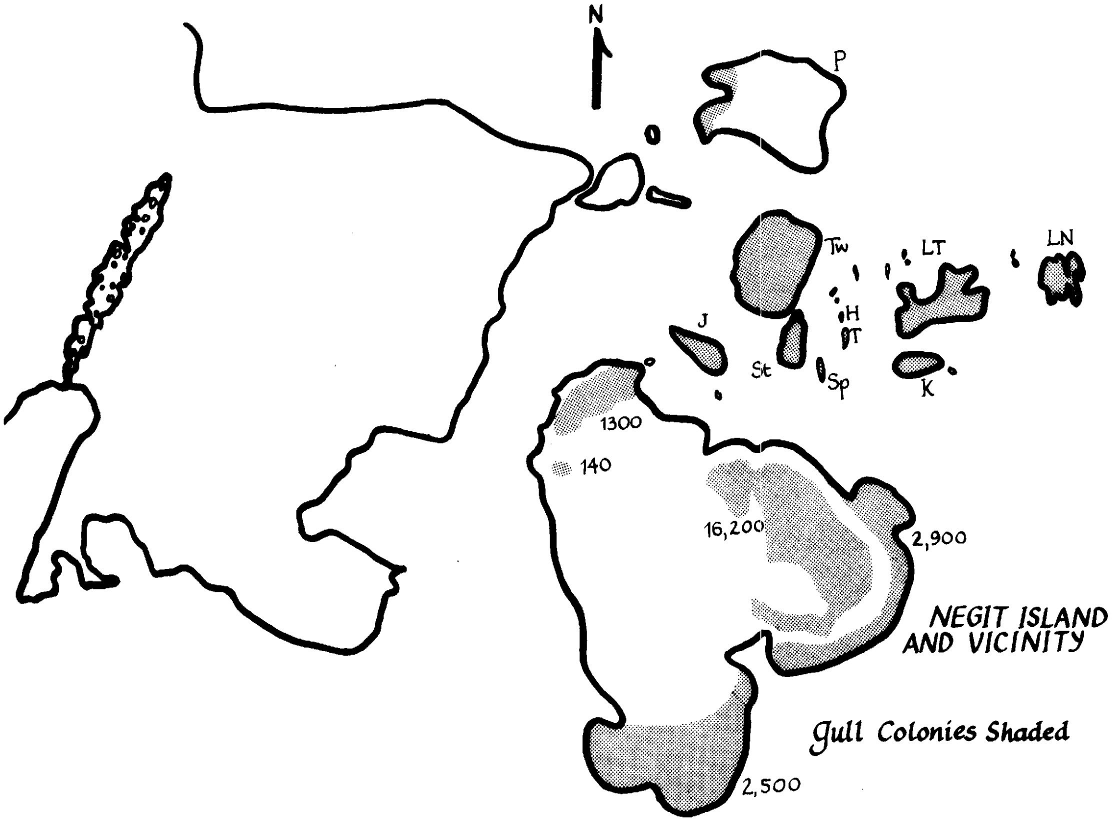

Figure 5-2. LOCATIONS AND EXTENT OF CALIFORNIA GULL COLONIES. Letters adjacent to the small islands are the abbreviations for the island names given in Table 5-2. Numbers adjacent to each colony are the estimated number of young for each.

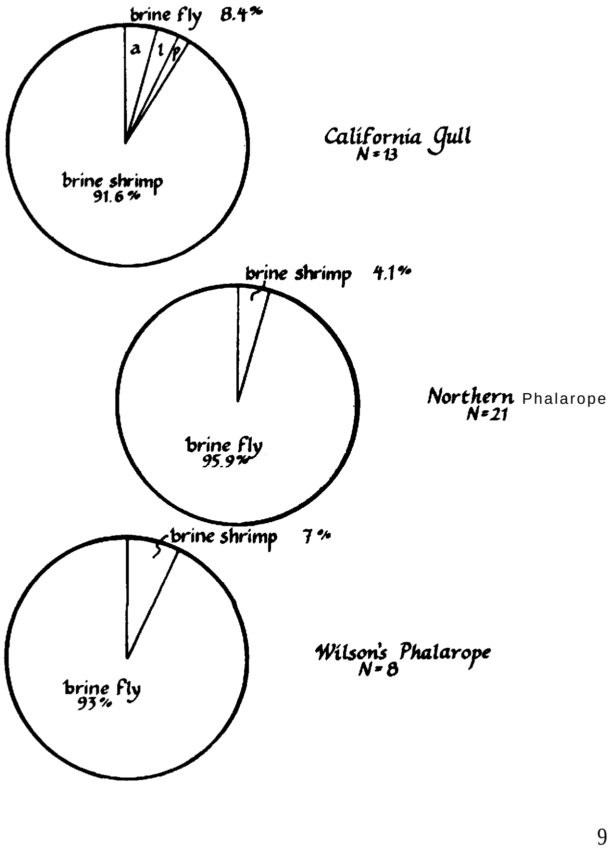

Figure 5-3. DIETS OF THE CALIFORNIA GULL AND NORTHERN AND WILSON'S PHALAROPES AT MONO LAKE. "N" represents the numbers of samples analyzed. The brine fly component of the gull's diet is divided into adults (a), larvae (l), and pupae (p).

II. Species Accounts:

Common Loon (Gavia immer)
1 on August 23
1 dead on June 26
1 dead on July 15

Red-throated Loom (Gavia stellata)
1 on June 11

Horned Grebe (Podiceps auritus)
5 sght.
First-l on June 24
High-l
Last-l on August 14

Eared Grebe (Podiceps caspicus)
First-300 on June 19
First ALC- 50,270 on July 8
High-707,000 on Sept. 14 ALC
Last-500,000 on Nov. 21
Habitat: open water

Western Grebe (Aechmophorus occidentalis)
1 on August 30
2 dead on June 28
1 dead on Nov. 20

Pied-billed Grebe (Podilymbus podiceps)
2 dead on August 2

White Pelican (Pelecanus erythrorhynchos)
1 dead on August 23
1 dead on Sept. 2

Double-crested Cormorant (Phalacrocorax auritus)
5 sght.
First-l on June 11
High-8 on Sept. 14 ALC
Last-8 on Sept. 14 ALC

Great Blue Heron (Ardea herodias)
9 sght.
First-3 on July 8 ALC
High- 4 on August 17
Last- 1 on Nov. 20
Habitat: creeks and freshwater marshes

Great Egret (Casmerodius albus)
2 on July 31

Green Heron (Butorides virescens)
1 on July 25
1 on August 8 ALC
1 on August 18

Snowy Egret (Egretta thula
20 in one flock on July 30
1 on August 8 ALc
1 dead on June 28

Black-crowned Night Heron (Nycticorax nycticorax)
2 imm. on August 17
1 imm. on August 30
1 imm. on Sept. 9

White-faced Ibis (Plegadis chihi)
4 sght.
First-l on July 25
High- 8 on August 8 ALC
Last- 1 on August 9

Mallard (Anas platyrhynchos)
12 sqht.
First- 2 on July 8 ALC
High- 39 on August 21 ALC
Last- 11 on Sept. 14 ALC
Habitat: creek deltas and freshwater ponds

Gadwall (Anas strepera) breeder
7 sght.
First- 2 on June 28
High- 10 on August 30 ALC
Last- 10 on August 30 ALC
Breeding details:
-1 female on nest with 9 eggs, July 4, interior of Negit Is.
-1 female with 6 young, July 25, W shore
Habitat: creek deltas and freshwater ponds

Pintail (Anas acuta)
First- 100 on June 11
Subsequent low- 30 on July 8 ALC
High- 764 on August 30 ALC
Last- 297 on Sept. 14 ALC
Habitat: creek deltas, especially at Gull Bath; freshwater ponds and tufa

Teal (Anas spp.)
First- 1 on July 8 ALC
High- 987 on Sept. 14 ALC
Last- 987 on Sept. 14 ALC

Green-winged Teal (Anas carolinensis)
First- 1 on July 30
High- 350 on August 14
Last- 84 on Sept. 14 ALC
Habitat: creek deltas and freshwater ponds

Blue-winged and/or Cinnamon Teal (Anas discors and/or A. cyanoptera)
First- 1 on July 5
High- 100 on August 17
Last- 2 on Sept. 6
(definite Cinnamon Teal seen on August 8 and August 21)
Habitat: same as Green-winged Teal

Shoveler(Anas clypeata)
First- 7 on June 28
First influx- 125 on August 14
Subsequent low- 2 on August 21 ALC
High- 2230 on Sept. 14 ALC
Last- 1 on Nov. 20

Shoveler (Anas clypeata), Cont'd.
Habitat: creek deltas, tufa areas along the north shore and fresh water ponds

Redhead (Aythya americana)
5 sght.
First- 2 on June 29
High- 2
Last- 1 on August 2

Bufflehead (Bucephala albeola)
1 on Nov. 21

Ruddy Duck (Oxyura jamaicensis)
First- 1 on June 24
High- 62 on Sept. 14 ALC
Last- 1 on Nov. 21
Habitat: tufa areas and open water

Hooded Merganser (Mergus cucullatus)
1 on Nov. 21

Red-breasted Merganser (Mergus serrator)
1 on June 12

Virginia Rail (Rallus limicola)
1 on June 25
1 on August 30 ALC
1 dead on June 27

Sora (Porzana Carolina)
1 on July 2
1 on July 24
1 dead on July 24

American Coot (Fulica americana)
First- 2 on June 28
High- 380 on Sept. 11
Last ALC- 347 on Sept. 14
Last- 16 on Nov. 20
Habitat: creek deltas, especially Gull Bath

Semipalmated Plover (Charadrius semipalmatus)
First- 1 on July 23
First influx- 72 on August 5
Subsequent low- 22 on August 8 ALC
High- 105 on August 20
Last- 2 on Sept. 14 ALC
Habitat: mudflats and wet sandy areas, especially on the SE shore

Snowy Plover (Charadrius alexandrinus) breeder
First- 1 on May 31
First ALC- 50 on July 8
Subsequent low- 0 on August 30 ALC
High count- 100 on Sept. 14 ALC
Last- 100 on Sept. 14 ALC
Breeding details:
-1 ad. on nest with 2 eggs, June 26, N shore

Snowy Plover (Charadrius alexandrinus) breeder, Cont'd.
-3 ad. with 1 young each, June 26, N shore
-3 ad. with 1 young, July 2-4, Canoe Launch
-2 ad. at nest with 3 eggs, July 5, E. shore
-1 nest with 3 eggs and 1 nest with 2 eggs, July 8, E. shore
-2 young, July 23, SE shore
-2 ad. with 3 young, August 2, Mono Park
-2 ad. with 2 young, and different ad. with 2 young, August 16, SE shore
Habitat: dry sand and alkaline areas high up on beach; frequently at seeps and springs. Nests small scrapes in the middle of the wide dry sand and alkaline beaches located on the eastern shores of the lake

Killdeer (Charadrius vociferus) breeder
First- 8 on May 29
First ALC- 153 on July 8
High- 314 on August 21 ALC
Last ALC- 254 on Sept. 14
Last-34 on Nov. 20
Breeding details: 1 young on July 20-21, Mono Park
Habitat: all shorelines, although concentrated near tufa and freshwater springs and seeps

Black-bellied Plover (Pluvialis squatarola)
12 sght.
First- 4 on July 22
High- 17 on July 23
Last- 1 on Sept. 14 ALC
Habitat: mudflats and open sandy shoreline; all except 1 sght. on the SE shore

Ruddy Turnstone (Arenaria interpres) ,
1 on July 30
1 on August 7
1 on August 23

Common Snipe (Gallinago gallinago) breeder
First- 3 on May 30
High- 24 on July 8 ALC
Last ALC- 1 on Sept. 14
Last- 2 on Nov. 21
Breeding details:
-1 ad. on nest with 4 eggs, June 28, sedge marsh at Sneeker Flat
-1 ad. with 1 young, July 5, Gull Bath
Habitat: freshwater marshes

Marbled Godwit (Limosa fedoa)
First- 1 on July 1
High- 36 on August 30 ALC
Last- 4 on Sept. 1
Habitat: most shorelines, especially on the SE shore

Long-billed Curlew (Numenius americanus)
* First- 2 on June 22
High- 33 on August 4
Last- 2 on Sept. 14 ALC
Habitat: high beach and dune/grassland areas, especially on the SE shore

Dowitcher (Limnodromus spp.)
First- 2 on July 21
First influx- 47 on August 5
Subsequent low- 10 on August 8 ALC
High- 171 on August 21 ALC
Last- 1 on Sept. 12
Habitat: muddy shorelines, especially on the SE shore

Least Sandpiper (Calidris minutilla)
First- 2 on July 12
High- 417 on August 30 ALC
Last ALC- 323 on Sept. 14
Habitat: muddy seeps and shorelines

Semipalmated Sandpiper (Calidris pusilla)
1 on August 5 - hypothetical; description sent to the California Rarities' Committee

Western Sandpiper (Calidris mauri)
First- 21 on July 8 ALC
First influx- 189 on July 26
Subsequent low- 26 on August 8 ALC
High- 356 on Sept. 14 ALC
Last- 356 on Sept. 14 ALC
Habitat: muddy seeps and shorelines

Baird's Sandpiper (Calidris bairdii)
5 sght.
First- 3 on August 21 ALC
High- 3 on August 21 ALC
Last- 2 on Sept. 3

Pectoral Sandpiper (Calidris melanotos)
6 on Sept. 14 ALC

Sanderling (Calidris alba)
3 on August 16-17
1 on Sept. 14 ALC

Knot (Calidris canutus)
9 sght.
First- 1 on July 21
High- 7 on August 5
Last- 2 on August 30
Habitat: open mudflats and wet sandy areas

Solitary Sandpiper (Tringa solitaria)
6 sght.
First- 1 on August 5
High- 3 on August 16
Last- 1 on August 30 ALC
Habitat: freshwater marshes, especially on the SE shore

Greater Yellowlegs (Tringa melanoleuca)
First- 3 on July 8 ALC
High- 15 on July 29
Last- 4 on Sept. 14 ALC
Habitat: mudflats, shallow ponds, and marshy areas, especially on the SE shore

Lesser Yellowlegs (Tringa flavipes)
First- 2 on August 5
High- 14 on August 16
Last- 1 on Sept. 6
Habitat: same as Greater Yellowlegs

Willet (Tringa semipalmata)
First- 1 on July 8 ALC
High- 29 on August 16
Last- 5 on Sept. 14 ALC
Habitat: all shorelines, although concentrated on the SE shore

Wandering Tattler (Tringa incana)
1 on Sept. 14 ALC

Spotted Sandpiper (Tringa macularia)
First- 10 on May 29
High- 44 on July 8 ALC
Last- 7 on Sept. 14 ALC
Breeding details:
-1 nest with 4 eggs, June 1, Mono Park
-2 nests with 4 eggs each, June 19, Gull Bath
-1 nest with 4 eggs, July 1, Sneeker Flat
Habitat: along most shorelines, although most frequently in vicinity of tufa and springs.

American Avocet (Recurvirostra americana)
First- 8 on May 29
First ALC- 2679 on July 8
High- 3950 on August 30 ALC
Last- 995 on Sept. 14 ALC
Habitat: all shorelines, although concentrated on the N and SE shores

Black-necked Stilt (Himantopus mexicanus)
11 sght.
First- 15 on July 8 ALC
High- 15 on July 8 ALC
Last- 2 on August 30 ALC
Habitat: open shorelines and seeps, especially on the E and SE shore

Northern Phalarope (Phalaropus lobatus)
First- 1 on June 29
High- 21,613 on August 30 ALC
Last- 4829 on Sept. 14 ALC
Habitat: open water amongst tufa and in the shallow water at creek deltas

Wilson's Phalarope (Phalaropus tricolor)
First- 4 (2 pair) on May 29
First ALC- 15,586 on July 8
High- 93,000 on July 26
Last- 29 on Sept. 14 ALC
Habitat: dense tufa areas, especially creek deltas on the SE shore
Migration:
All flights were observed heading SSE from the SE shore at dusk
-August 4;750
-August 7;200 plus 1800 circling over lake in preparation for migration
-August 8;750 plus 3250 circling
-August 20; 400 plus 600 circling

Parasitic Jaeger (Stercorarius parasiticus)
1 imm. on Sept. 6-12
1 additional imm. on Sept. 9

California Gull (Larus californicus) breeder
AHY
First- large numbers on May 29
First ALC- 38,943 on July 8
High- 38,943 on July 8
Last ALC- 10,775 on Sept. 14
Last- 5 on Nov. 21
HY
First- 1 on June 28
First ALC- 0 on July 8
High- 3164 on August 8 ALC
Last ALC- 32 on Sept. 14
Last- 1 on Nov. 21
Habitat: all shorelines islands, and open water
Migration:
-August 1; 60 (80%HY)
-August 2; 455 (66% HY)
-August 4; 766 (468 AHY, 298 HY)
-August 9; 78 (57 AHY, 21 HY)
-August 15; 11 (2 AHY, 9 HY)
All flights were observed flying NW in the morning hours.
(*See below for more detailed gull colony census results and details of breeding*).

Ring-billed Gull (Larus delawarensis)
5 sght.
First- 2 HY on June 24
High- 2 HY on June 24
Last- 1 on August 13

Bonaparte's Gull (Larus philadelpia)
2 imm. from June 14-July 8
8 sght. afterwards
High- 4 on July 26
Last- 2 ad. on August 27

Forster's Tern (Sterna forsteri)
6 sght.
First- 13 (12 ad. and 1 HY) on June 28
High- 25 on July 8 ALC
Last- 4 on August 25

Caspian Tern (Hydroprogne caspia) breeder
First- 2 ad. on June 24
High- 38 on July 8 ALC
Last- 14 on Sept 14 ALC
Breeding details:
-12 ad., 1 fledgling, and 6 young were seen on Twain Is. on August 30
-5 ad. and 4 young were seen on Pancake Is. on Sept. 1

Black Tern (Chlidonias niger)
4 sght.
First- 4 on July 23
High- 12 on August 17
Last- 12 on August 17

III. Biological Investigations:

A. California Gull

Table 5-4 lists the clutch sizes observed on the first census visit to Negit Island in areas of different habitat types. Data from subsequent visits were not used, because, once the young hatch and begin wandering from the nests, it is impossible to measure clutch size.

The determination of the habitat preferences of the gulls can be approached from two directions: 1) a comparison of nesting densities in different habitats and 2) a consideration of those habitat types which were occupied first.

Unfortunately, it was not possible to determine the actual number of nests, because of the tendency of the young birds to wander about. Consequently, the only consistent index of nesting density available is the number of young per unit area of colony. For the greasewood colony on Negit, the nesting density was approximately 106 young per unit area of colony. The density in whiterock was approximately 52 young per unit area of colony. Considering the timing of habitat nesting occupancy leads to few, if any, real generalizations. The extent of colonies in both habitat types increased in approximately equal proportions between the May 31 and July 4 visits. In conclusion, there are two major habitat types for the nesting California Gulls at Mono, greasewood and white rock. The greasewood areas appear to be preferred over the white rock areas, because the gulls reach their highest densities there. The distribution of the colonies on the islands is outlined in Figure 5-2.

California Gulls at Mono Lake feed their young a diet composed predominantly of brine shrimp with smaller amounts of brine flies of all developmental stages (Figure 5-3).

B. Shorebirds:

Young Western and Least Sandpipers arrived after the adults. Patterns of wear and molt are essentially identical to those reported on the Pacific coast (Page, Fearis, and Jurek 1972 , Page 1974, pers. comm.).

With summer breeding activities completed, phalaropes migrate south to their wintering grounds. Northern Phalaropes breed in the arctic regions of the Northern Hemisphere and migrate to the subtropics to spend the winter on the open sea, whereas Wilson's Phalaropes breed throughout the interior of western North America and migrate to the grasslands and estuaries of South America (Figure 5-4).

Wilson's Phalarope numbers at Mono Lake reach their peak in late July, whereas Northern Phalaropes peak in late August (Figure 5-5). This difference in times of passage is explained by a consideration of the two species' breeding and wintering ranges. The more southerly breeding range of the Wilson's allows for earlier breeding and earlier arrival at Mono Lake. Techniques for trapping phalaropes were devised in August at a time when the bulk of the Wilson's Phalaropes had already left the area. Consequently, banding data for the Northern Phalarope are the only extensive phalarope data obtained. These data reveal a difference in migratory timing among different age classes (Figure 5-6). Young birds arrive at Mono later than the adults, because many of the adults leave the breeding grounds before the young of the year are prepared to migrate. None of the Northerns banded at Mono were molting extensively, and the pattern and extent of molt did not change significantly as the season progressed. Northern Phalaropes seem to be using Mono simply as a stop-over on their long journey south and do not appear to be using the lake as a refuge for extensive molting.

The criteria determined for sexing phalaropes through discriminant function analysis of data from MVZ were capable of correctly classifying 85% of the Northern Phalaropes and 97% of the Wilson's in the collection.

Phalaropes feed extensively while at Mono and the data on diet collected from stomach samples is summarized in Figure 5-3 along with similar data collected for the California Gull.

The estimation of flight range capabilities is extremely statistical in nature, and large numbers of data points are needed to obtain a reasonable analysis. In this study the Northern Phalarope was the only species for which sufficient data were obtained. The required plot was performed by computer (SPSS). The equation resulting from the computer analysis is:

$$\text{Total weight} = (0.44 \times \text{Chord}) - 10.52$$

$$(r^2=0.12\ ; p=0.0001)$$

This equation predicts a phalarope's weight given its chord measurement. The equation for the fat-free line is:

$$\text{Fat-free weight} = (0.44 \times \text{Chord}) - 19.52$$

In other words, the fat-free weight of a phalarope will be approximately 9 grams less than the regression line value corresponding to its chord measurement.

With the estimates of fat contents made available by the above equations, an

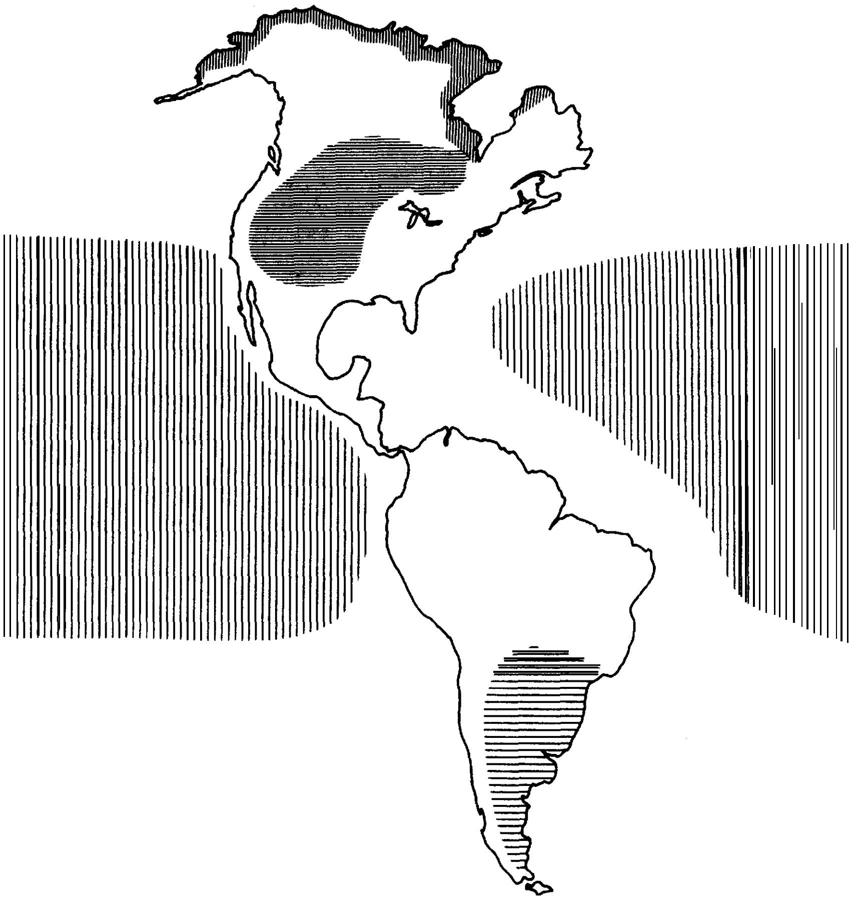

Figure 5-4. RANGES OF WILSON'S (HORIZONTAL HATCHING) AND NORTHERN (VERTICAL HATCHING) PHALAROPES. Both summer (dense hatching) and winter (loose hatching) areas are shown.

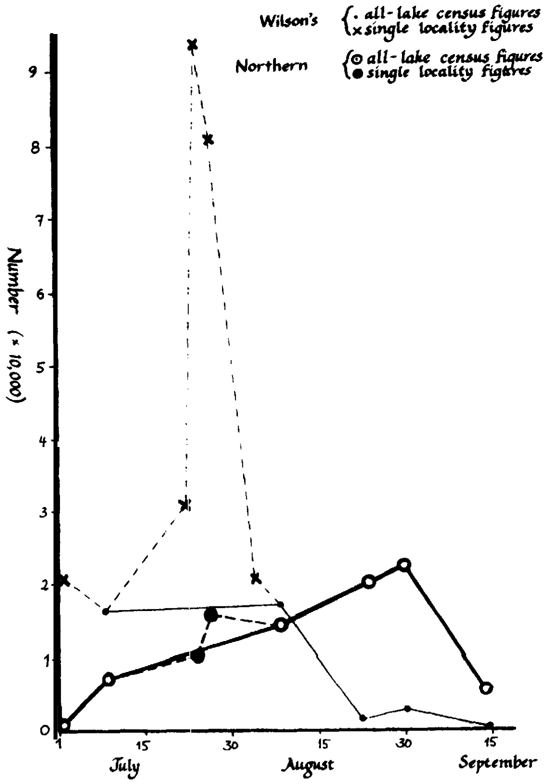

Figure 5-5. VARIATION IN NUMBERS OF NORTHERN AND WILSON'S PHALAROPES BETWEEN JULY 1 and SEPTEMBER 14.

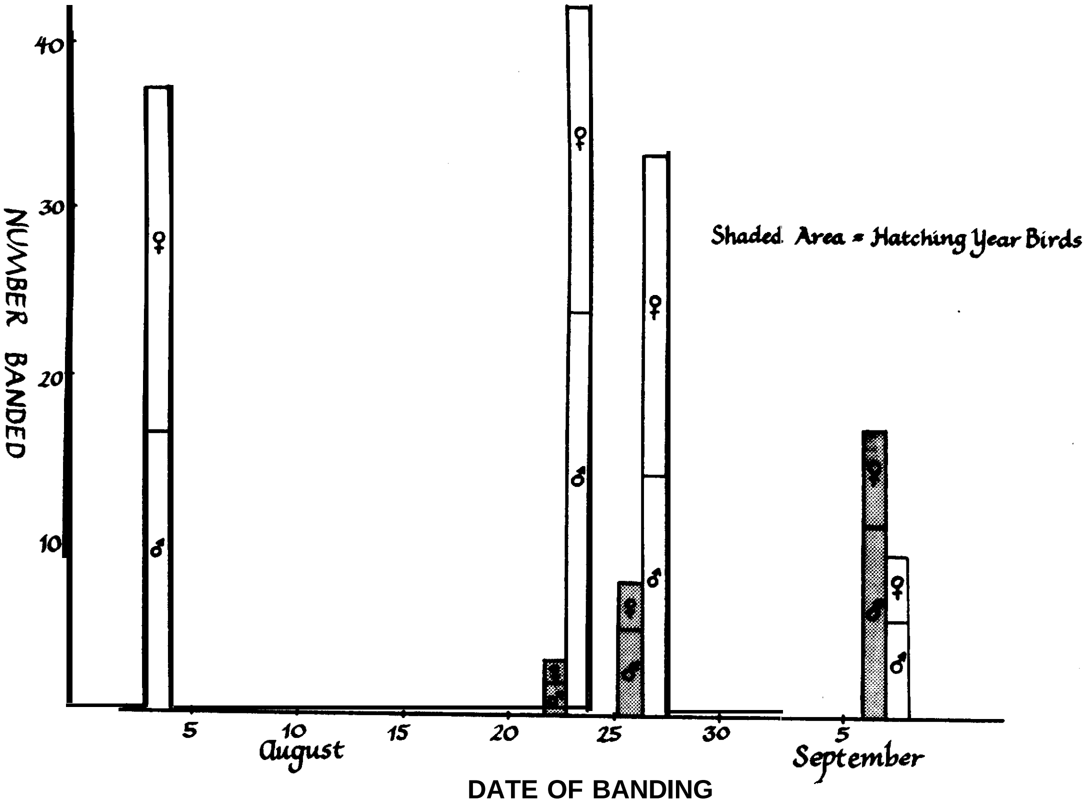

Figure 5-6. AGE AND SEX COMPOSITION OF NORTHERN PHALAROPES BANDED BETWEEN AUGUST 3 AND SEPTEMBER 8.

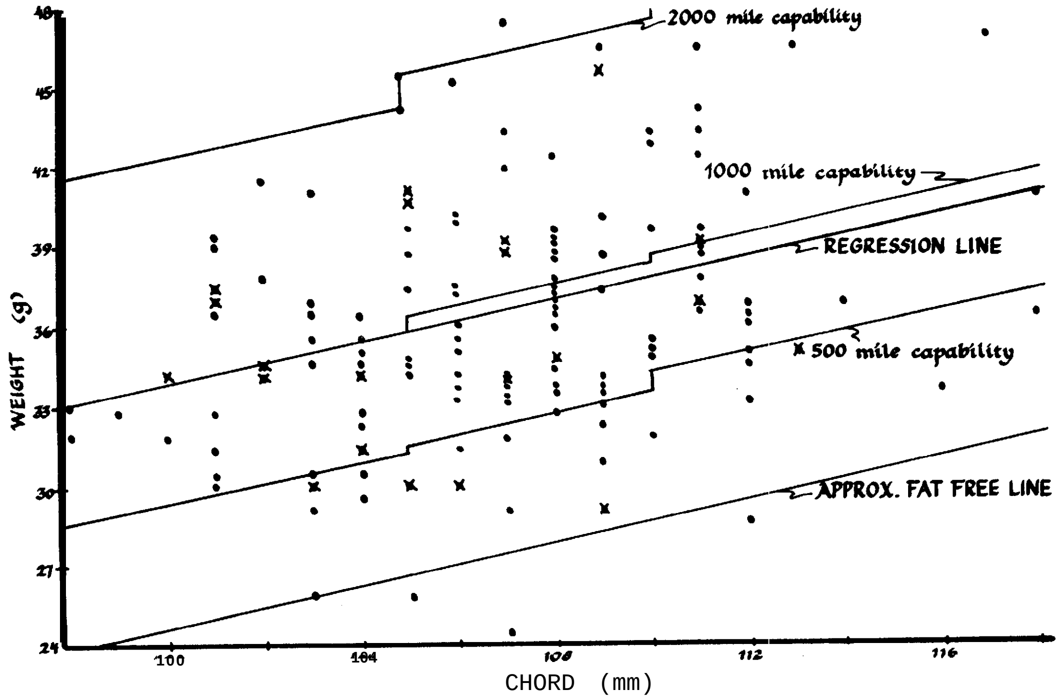

Figure 5-7. CORRELATION OF WEIGHT WITH CHORD IN THE NORTHERN PHALAROPE. Birds with data points above a given capability line can theoretically fly that distance non-stop.

estimate of flight range capabilities can be performed once the values of the factors in the flight range equation are established. Flight metabolism was computed for each of three size classes which were arbitrarily defined on the basis of chord measurements. The size classes and their corresponding flight metabolism values are: up to 105 mm (FM= 3.85 kcal/hour), 106-109 mm (FM= 4.04 kcal/hr), and 110 mm and over(FM= 4.22 kcal/hr). These differences in flight metabolism values used in the calculations of flight range capabilities explain the abrupt steps in the capability lines (Figure 5-7). Flight speed was set at 45 mph. The energy content of fat was taken to be 9.1 kcal/hr.

In summary, the flight range of a Northern Phalarope with a chord length of 100 mm and a weight of 35 g is computed in the following manner: 1) The amount of fat available for fueling migration is computed:

1) Fat= Total Weight - Fat-free Weight

$$= 35 \text{ g} - (0.44 \text{ g/mm} \times 100 \text{ mm}) - 19.5 \text{ g}$$

$$= 35 \text{ g} - 24.5 \text{ g}$$

= 10.5 g of fat available

2) The amount of energy available is calculated:

$$\text{Energy available} = 10.5 \text{ g} \times 9.1 \text{ kcal/g}$$

$$= 95.5 \text{ kcal}$$

3) The flight metabolism for phalaropes with chords measuring less than 105 mm is calculated to be 3.85 kcal/hr. The flight range can now be calculated:

$$\text{Flight Range} = \frac{FS \times E}{FM}$$

$$= \frac{45 \text{ mph} \times 95.5 \text{ kcal}}{3.85 \text{ kcal/hr}}$$

$$= 1115 \text{ miles}$$

Through rearrangement of the flight range equation, the intercepts for capability lines of any given flight range can be determined. These lines are plotted for several flight ranges in Figure 5-7.

DISCUSSION

I. Problems and Shortcomings:

The nature of Mono Lake's climate and shoreline presents many obstacles to research. The lake's large size makes census coverage of its entire surface and shoreline practically impossible. The tremendous numbers of grebes and phalaropes at Mono also caused censusing problems. Our banding and censusing operations did not enable us to discover the rate of population turnover, which is the most important factor in determining the total number of birds using Mono Lake. The census results presented in this study must, therefore, be considered to be minimum estimates, for it is almost certain that no bird populations remained for the entire summer without a considerable turnover in the actual individuals present. The all-lake censuses are like instantaneous snap-shots taken weeks apart, and they reveal very little about how many birds have come and gone in the interim.

The following paragraphs deal briefly with some of the shortcomings associated with each of the censuses attempted. Enumeration of these shortcomings may lead to the improvement of future censuses.

Coverage of the lake was incomplete. First, the extreme eastern shore was covered on only two of the five ALCs. Second, areas in the middle of the lake cannot be censused directly and can only be accounted for through extrapolations. Third, censusing techniques and routes used by observers were not completely standardized. Finally, each ALC was made over a five to eight hour time period. The movement of birds during an eight hour census could result in misleading data due to birds being censused by observers on two or more different census legs.

The principal shortcoming of the spot censuses was sparseness and irregularity of data collection. An extensive all-day census at Gull Bath was done only once, whereas two or three censuses would have led to more conclusive determinations of the importance of fresh water to the gulls. More data also needs to be collected before conclusions can be made about the patterns of freshwater use by the gulls and phalaropes at Dechambeau Ponds.

Our efforts to avoid disruption of the gull colonies probably led to a sacrifice in accuracy. Human visitations to gull colonies can often result in predation of young and eggs by neighboring gulls (Behle 1958). Our methods delivered the greatest accuracy possible at a minimum disturbance to the nesting birds.

The greatest potential weakness of the shorebird biological investigations is that some of the techniques used in placing the birds into age and sex categories may be inaccurate. Fortunately, the criteria for these determinations are well established for the sandpipers (Page and Fearis 1971, Page 1974, pers. comm.). There has been debate in the literature over the accuracy of the criteria used in this study for aging phalaropes (e.g., Hilden and Vuolanto 1972, vs. Palmer). On the basis of discussions with several shorebird researchers (Page, J. Jehl, T. Prater, pers. comm.) and our own experience in the field and at MVZ, we are convinced that the aging criteria we used are accurate. To our knowledge, the determination of sexing criteria for phalaropes has never been reported. We feel that the accuracy of the criteria we have used for sexing phalaropes is sufficient. The techniques used for the measurement of fat reserves is indirect, but the only obvious alternative, the sacrifice and fat extraction of the birds, was not consistent with the aims of our study.

II. Taxonomic List:

This section is essentially a collection of miscellaneous thoughts on a few of the bird species at Mono which do not readily fit anywhere else in the discussion. The section follows a roughly taxonomic order, and the discussion on the California Gull is presented following in a section of its own.

A. Eared Grebe

The population of Eared Grebes at Mono Lake is apparently composed of non-breeding migrants. Although the species has bred at Washoe Lake, two hundred miles to the north (Linsdale, field notes, MVZ), the closest major breeding ground is probably Malheur Lake in southeastern Oregon (Willett 1919). Despite the fact that the Eared Grebe has never been reported breeding at Mono, it is difficult to deny that the lake is one of the most important bodies of water in the Great Basin for this species. Informal censuses conducted at three other lakes in the western Great Basin on September 15, at a time when there were over half a million of the species on Mono(Figure 5-8), revealed no more than twenty Eared Grebes on all the other lakes combined. Published reports from the other lakes of comparable size near Mono, Tahoe (Orr and Moffett) and Pyramid (Marshall and Giles 1953) include no mention of the large numbers of grebes there. Great Salt Lake is apparently the only lake in the Great Basin which serves as the home of a comparable number of grebes (Behle, N. Collins, pers. comm.). Eared Grebes were never seen flying during our three month stay at Mono, and we have no indication of the magnitude of individual turnover throughout the summer. Therefore, our estimate of three-quarters of a million grebes could be considerably less than the actual numbers. Very little is known about the composition of the grebe populations. The birds seen in June and July could be late spring migrants still heading north to breed, early fall migrants finished with breeding and on their way south to their wintering grounds, birds which are not breeding and staying at Mono all summer, or a combination of all these. There is a preliminary indication that a regular decline in numbers occurs in October following the peak in September and preceding a second smaller peak in November (T. Heindel, pers. comm.). This secondary peak in November may be composed of Young birds migrating south following their parents' migratory departure.

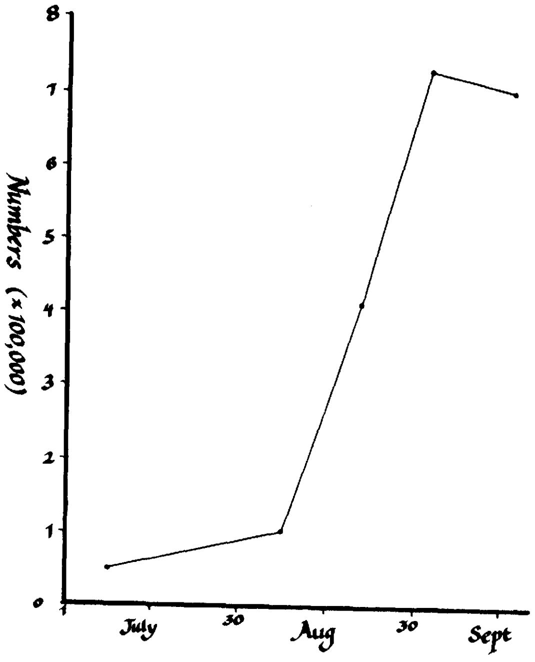

Figure 5-8. VARIATION IN NUMBERS OF EARED GREBES BETWEEN JULY 8 AND SEPTEMBER 14.

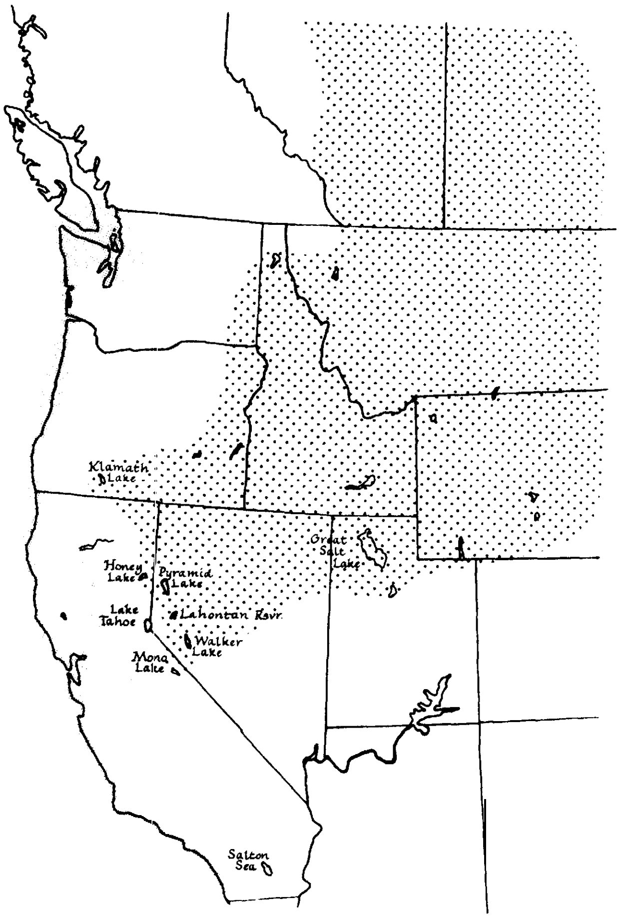

Figure 5-9. RANGE OF THE CALIFORNIA GULL. Both breeding areas (loose dotting) and wintering areas (dense dotting) are shown.

The most mysterious aspect of our study of the Eared Grebes' occurrence at Mono Lake remains the identification of those factors at the lake which are attracting the birds. The stomachs of the few specimens obtained at Mono have contained brine shrimp (R. Stallcup, pers. comm., J. Dixon, field notes). Our casual behavioral observations at the lake also indicate that the grebes are diving for some food source, presumably shrimp, while on the lake, If brine shrimp is accepted to be the major item in the grebes' diet, the occurrence of half a million birds on the lake in late November becomes difficult to explain on the basis of food requirements alone, for at that time, there are very few shrimp left in the lake (Chapter 3-3). It is possible that these birds. if they are young and inexperienced, are going through motions of feeding in vain.

There are at least two other reasons why grebes may visit Mono. As a large, usually calm body of water, the lake may provide a relatively safe place to undergo extensive molt. Large numbers of grebe feathers were found over the entire lake's surface in late summer, but it is impossible to quantify this observation in such a way as to determine the extent of molt on the Mono birds. Secondly, the birds may come to Mono for its highly alkaline waters. The high pH of the lake's waters may provide protection and/or relief from ectoparasitic infections.

B. Shorebirds

Several shorebird species which were observed frequently at Mono were strongly suspected of breeding, but no firm evidence for such could be obtained this year. The American Avocet bred in large numbers in the mid-1960's on the south shore of Paoha (Lajoie, pers. comm.), but it is not clear what their breeding success was at that time. Avocets probably bred at Mono during the summer of 1975, as a fledgling which had probably been dead for one year was found near Canoe Launch in early July.

The Wilson's Phalarope breeds throughout much of Nevada (Linsdale 1936) and at Lake Tahoe (Orr and Moffett). It very likely breeds at Mono, as territorial males and pairs were observed at Mono Park and Sneaker Flat from the end of May until the end of July. If this species did breed, its population at Mono did not exceed thirty pairs.

The breeding of Snowy Plovers at Mono Lake is documented for the first time by this study. At least ten pairs were observed with eggs or young. Another seven pairs were territorial and therefore suspected of breeding. The total of fifty birds on the July 8 ALC indicates that even more pairs may breed at Mono or in the immediate vicinity. The high count of 100 on the September 14 ALC was almost certainly comprised of migrants from breeding areas to the north. The breeding population at Mono Lake is apparently one of the largest in inland California.

The shorebird habitats of the Great Basin are little known compared to those of the coast and the Great Plains. As observer coverage in the Great Basin increases, it is expected that more and more species which are considered strictly coastal migrants (e.g., Ruddy Turnstone, Wandering Tattler, etc.) will be reported with increasing frequency.

The southeast shore seems to be ideal habitat for many migrant shorebirds. At least 19 of the 25 shorebird species recorded reached peak numbers there. Large freshwater mud flats, springs, and seeps high in insect productivity characterize the area. Warm Springs, Mono Park, and a few locations on the west shore offer similar habitat characteristics.

One of the most fascinating relationships brought to light through banding studies is the difference in age ratios observed between the Northern Phalarope at Mono Lake and those banded on Bolinas Lagoon, Marin County, California (Page, Pt. Reyes Bird Observatory, pers. comm.). The Northern Phalaropes banded there in 1971 were approximately 93% young birds from the time they appeared (August 14) to the time of their last trapping (October 11). Adult Northern Phalaropes seem to avoid coastal estuaries, although they are abundant at open sea, in areas of south San Francisco Bay (pers. obs.), and at Mono Lake. It seems probable that the Northern Phalarope finds the open sea and waters such as Mono preferable to coastal estuaries, and that the only phalaropes which find their way to the latter habitats are young and relatively inexperienced birds.

It is difficult to interpret the results of the flight range capability estimates, for there are no reliable data on the length of time birds stay at the lake. Without this information it is impossible to determine whether the fat stores observed in phalaropes are the result of a long stay of feeding at Mono or are present on the birds when they arrive at the lake. All that can be said is that many of the birds at Mono are able to fly at least as far as the Salton Sea if not the Gulf of California upon their departure from Mono without the need to stop and feed between points. It is hoped that research to be conducted during the summer of 1977 will help to answer questions regarding the relative importance of Mono as a feeding area on the phalaropes' long south-bound journey.

C. Fish-eating Birds

The small colony of Caspian Terns found on the islands north of Negit at the surprisingly late date of August 30 is the only evidence of nesting obtained for any fish-eating bird. The terns must have commuted at least as far as Grant Lake, approximately 15 miles away, in order to secure fish for themselves and their young. Mono Lake's lack of fish probably helps to explain the absence of other fish-eating birds as breeding species. Such species as Western Grebe, Double-Crested Cormorant, and White Pelican nest at scattered lakes throughout the Great Basin. Avoidance of Mono Lake as a breeding ground cannot be totally attributed to a lack of fish, for pelicans and cormorants nest in great numbers on islands in Great Salt Lake from which they must commute to areas at least thirty miles distant for fish (Behle).

D. California Gull

Very few writers who have reported on Mono Lake have neglected to mention the California Gull. The gull pervades the entire atmosphere of Mono Lake in summer. In winter, when the gulls have returned to the oceans where most of their congeners breed, the inland sea at Mono seems barren without them. The following discussion is arranged to explore the relationships of Mono's gulls to the other gulls in western North America, the relative significance and history of the Mono colony, and the effects which changing lake levels may have on the future of the Mono population.

1. Evidence for genetic distinctness

Several lines of evidence suggest that the California Gull population which breeds in the western Great Basin is genetically distinct from populations which breed farther to the east. The average clutch size of California Gulls in the Canadian prairies and Utah is three (Behle, Vermeer), while that at Mono, Pyramid, and Honey Lakes is two (Johnston 1956a, Johnston and Foster 1954, Marshall and Giles).

The gulls at the Utah colonies usually arrive in late February or early March (Behle). They return to the Alberta colonies in the last week of March (Vermeer) and to the Mono colonies in the first half of April (Johnston 1956a). In mid-April the gulls in the Utah colonies begin laying eggs which begin hatching in mid-May (Behle). In Montana, a colony began laying April 22 (Rothweiler 1960 in Vermeer). Alberta colonies begin laying about May 2 and begin hatching in the first and second weeks of June (Vermeer). The Klamath Lake colony in northern California apparently has timing very similar to that at Mono: clutches initiated about May 10 and hatched about June 10 (Woodbury and Knight 1951, Johnston 1956a) (See Figure 5-9 for a range map of the California Gull).

Apparently, California Gull populations are timing their migration and breeding according to at least two selective pressures. Gull populations at similar latitudes must leave the Pacific coast progressively earlier the farther away from the coast they breed. Thus, Salt Lake populations must leave the coast three weeks to a month earlier than gulls nesting at Mono or Klamath Lakes in order to finish their long migratory flight and complete breeding in time for the young to travel to the coast before winter arrives. The gulls' timing also appears to respond to the influence of later winters, in the northern parts of their range. Gulls in Alberta set up territories while their rookeries are still under snow, and the first eggs are laid just as the ice on their nesting lakes melts (Vermeer). The Alberta Gulls thus push their breeding schedules as far ahead as possible.

The gulls at Mono Lake (or any other California Gull population) are not known to return to any breeding area other than that in which they fledged (Woodbury and Knight). Experiments with transplantation of eggs to other colonies could help to determine the extent to which orientation is learned by the gulls. It is possible that orientation is entirely genetically controlled. The evidence provided by the breeding-schedule differences between Mono and Great Salt Lake gulls strongly suggests that there are significant genetic differences between the different colonies. Both populations winter in the same area (Woodbury and Knight) and are thus exposed to identical photoperiods. Photoperiodic stimuli have been implicated as the major environmental cue for accurate biological timing in nearly every bird species studied (Berthold 1975). It is almost certain that photoperiod must play a role in the timing of both the Mono and Salt Lake gulls. In order to respond to the same photoperiodic stimuli with such different migratory and breeding timing, the two populations must have inherently different photoperiodic response mechanisms. In considering the fate of the gull colonies at Mono Lake one must bear in mind that the disappearance of these colonies will mean more than the loss of "just another gull colony." If the gull colony at Mono Lake collapses, it will mean the demise of a population which, over the thousands of years since the last ice age, has evolved fine-tuned reproductive timing and orientation mechanisms geared specifically to breeding at Mono Lake. This is a population which is, in all probability, unlike any other in the world.

2. Colony significance and history

Breeding populations of California Gulls are relatively well documented, and comparisons with other nesting populations of California Gulls permit an assessment of Mono Lake's importance as a breeding area for the species. The total population of nesting California Gulls on Great Salt Lake is approximately 80,000, and the largest single colony there once numbered 60,000 adults (Behle). None of the colonies reported from other areas of the species' breeding range rival the size of those at Mono and Great Salt Lake (Vermeer; Johnston and Foster; Marshal'1 and Giles; P. Baird, pers. comm.). The colonies at Mono Lake are apparently the second largest aggregation of California Gulls in the world.

Difficulties in the interpretation of the history of the Mono colonies are due to the scarcity of recorded observations. The first documented visit to the islands by an ornithologist was Dixon's in 1916 (field notes). He reported at least 1,000 pairs breeding on the north end of Paoha and no nesting gulls on Negit. Three years later, Dawson (1924) found the main colony on Negit, but he did not estimate the numbers of gulls there. He did estimate that 850 pairs nested in the colony on the north end of Paoha. Between 1938 and 1940, Nichols banded 1510 young gulls at the Mono colonies (Woodbury and Knight; Nichols 1938), at which time the main colony of approximately 1,500 pairs was on Negit. In 1950 and 1951, Young (1952) found nesting gulls only on Negit and estimated the population at 750 pairs. Two years later in 1953, Johnston (1956a) reported approximately 1,500 to 2,500 pairs in the Negit colony. Finally, in 1972, Jurek (pers. comm.) found the main colony on Negit and the small islands to the northeast, although a very small colony was found on the north end of Paoha. The colonies have apparently changed little since his visit except that the Paoha colony has disappeared. In summary, Dixon's 1916 report is the only indication that the main gull colony has not always been on Negit. The reliability of Dixon's observation is questionable, for he discharged a shotgun on Negit several times, and it is not easy to imagine a gull colony remaining quiet and undetected during such a disturbance. Marked fluctuations in the size and/or location of the gull colonies in the early 1900's may have been a result of commercial egging operations on the islands late in the previous century.

The present study is apparently the first to include an accurate determination of the number of gulls nesting at Mono Lake as one of its major objectives. In light of the nearly ten-fold deviation of the census figures presented in this paper from those previously presented, a consideration of factors affecting the accuracy of censuses on the islands and a search for corroborating data from other sources must be undertaken. All previous visitors to the Negit colonies either spent little or no time in the colonies and estimated the numbers of nesting gulls from the water or estimated numbers from the cove and large cone on the south end of the island. Not only would large numbers of nesting gulls be hidden beneath greasewood scrub, but the minor cone and the large plateau to its north, which presently supports the bulk of the Negit population, is invisible from the south and from the water. Additionally, any estimate based on the number of adult gulls observed in the vicinity of the island would be an underestimate, for at any given time large numbers of the adult gulls are scattered along the shores of the lake and throughout the surrounding country in search of food and/or water.

Jurek (pers. comm.) conducted an aerial survey of Mono Lake on August 24, 1973, and counted approximately 42,500 gulls. While this number is substantially less than the estimate presented in this study, it is considerably higher than the ALC estimate for August 21 of 15,400 gulls. A considerable reduction in the numbers of gulls on Mono is to be expected in late summer (Johnston 1956a). The ALC data agree well with our colony estimates of gull populations when this seasonal reduction is considered. Jurek's estimate may be higher than the nearest corresponding ALC data either because of an inability in the present study to census areas which Jurek censused from the air or because gulls left the Mono basin later in 1973 than in 1976. In either case, the population estimate presented in this study is of the same order of magnitude as that of Jurek and accurate enough for most management and biological applications. Comparison with Jurek's data leads to the conclusion that the present estimate is an underestimate.

3. Future of the colony

The dropping level of Mono Lake will have an immediate effect on the California Gull colonies. In September, 1976, Negit Island was separated from the mainland by a channel with a maximum depth of 2-3/4 feet at one crossing (Appendix 5-1). If water diversions are continued at the present rate, a land bridge will-connect Negit to the mainland by 1977 or 1978. The California Gull is dependent on the isolation of islands for nesting. No colony near the size of the Negit colony has been reported on anything but islands. There have been a few colonies reported on levees in Great Salt Lake, but these appear to be of no more than a thousand nests in natural situations. (One colony of 4,000 pairs on a levee in a steel plant suggests that predators may have been prevented from reaching the colony by the steel plant's activities (Behle).)

It must be emphasized that colonies on levees and dikes are the exception. The tendency of gulls to avoid nesting areas which are connected to the mainland is well documented (Behle, pp. 28-29; Vermeer; Johnston and Foster) as is the ability of land predators to destroy a colony (Vermeer). In a distressingly human manner many land predators will destroy many more eggs and young than they need. In the past two years there have been several reliable reports of coyotes on the islands, and coyotes are frequently seen and heard on the adjacent shore of the lake. Long-tailed Weasels were occasionally sighted near shore, and the carcass of a Puma was found on one of the small islands north of Negit. Several species of snake are common in the area. The size and diversity of potential predator populations on the mainland near Negit Island is large enough to make the occurrence of these predators on a land-bridge-connected island near certain.

The fate of the Negit colony will be decided by the equilibrium established between the killing propensities of the islands' predatory visitors and the time between the gulls' arrival in April and their departure in August. Each year the ebb of predators from land will come to the islands in March, staying, if the gulls are still unfortunate enough to return, until the gulls' century-old timing calls them back to the Pacific coast.

McNicknoll (1975) has pointed out two strategies of nest site selection and relocation in gulls. On one extreme are those populations, the individuals of which show a great deal of site tenacity, returning to the same nest site year after year. In apposition to this strategy is the tendency in some populations for whole groups of a colony to show little special preference for returning to sites formerly occupied; rather, the priority seems to lie in preserving the coherence of small sub-colonies during nest-site selection. Gulls which use the latter strategy would stand a better chance of colonizing a previously unoccupied area.

What are the chances that the colony will move to Paoha or other islands if predation pressure makes Negit unsuitable for nesting? California gull colonies on Great Salt Lake have fluctuated enormously in size and location in the past 100 years, apparently in response to dropping lake levels and the opening up of better nesting habitat in new areas (Behle). However, Vermeer (p. 22) indicates that at least a third of the California Gulls may return to their previous year's nesting site for breeding. When overwinter mortality is taken as a cause for the non-reappearance of some of the birds, it is apparent that many California Gulls may be relatively set in their tendency to return to the same nesting site year after year. At best, the evidence for the degree of nesting site tenacity is equivocal in the California Gull. The future success of the Mono gull colonies will depend largely on whether the gulls will continue to return to their previously successful nest sites on Negit or, once the unsuitability of Negit for nesting is apparent to them, will move in cohesive units to other areas.

One possibility is for all the gulls to nest on the smaller islands to the north of Negit. These islands were heavily populated during the summer of 1976, yet they supported less than one-fifth of the total number of breeding gulls on Mono Lake. The falling lake level will not substantially increase the available nesting area on these small islands, for they have steep sides which, when exposed, will provide a minimal amount of flat nesting area.

In any case, whether the gulls all colonize Paoha or make an attempt on the smaller islands, success will be short-term. Under the present diversion rate, all the islands, including Paoha, will be connected to the mainland by the year 2010, and, although new islands may form as a result of the falling lake level, the extent of available prime nesting habitat will be reduced.

III. Importance of Freshwater Areas:

Freshwater areas are crucial for sustaining bird populations in the Mono basin. Gulls rely heavily on freshwater areas (springs, seeps, and creek deltas) around the lake. There is no open fresh water on the shore of Mono Lake which is not heavily visited by gulls. Most ducks at Mono prefer areas in or near fresh water (creek deltas, ponds, and tufa with fresh-water seepage). Both Wilson's and Northern Phalaropes also prefer areas near fresh water. Phalaropes frequently bathe in fresh-water creeks, and the number of Northern Phalaropes bathing on Dechambeau Ponds can exceed 5000. Peak numbers of Wilson's Phalaropes were always observed in the fresh-water areas on the southeast shore. The marshes associated with fresh water along the lake's shore support an avifauna which includes herons, rails, snipe, and other marsh birds.

IV. Effects of Salinity:

The predicted lake level and ionic concentration at stabilization bears strong implications for the future of Mono Lake's major bird populations, even though aquatic birds generally are well adapted to saline environments, Most aquatic birds have a gland in their heads specialized to secrete salt out of the bird's bloodstream through the nares in addition to self-regulation of blood salt levels through the kidney (Shoemaker 1972). The salt glands play the major role in the regulation of salt concentrations in the blood and have capabilities which vary from species to species (Shoemaker; Staaland 1967). The salt-secreting capacities of the California Gull have been superficially investigated (McFarland 1964). Although no other bird species from Mono have been investigated in this regard, inferences made from closely-related species which have been more thoroughly investigated (Staaland, Hughes 1970, 1975) lead to several generalizations. The secretion of the salt gland is typically composed primarily of NaCl with small amounts of other cations (e.g., K^+, Ca^{++}, Mg^{++}) and anions (e.g., HCO_3^-, SO_4^{--}) present. The rate of salt gland secretion is generally varied according to the magnitude of the osmotic stimulus to which the bird is exposed, while the concentration of the secretion remains relatively constant. Salt gland secretions range in concentration roughly between one and two times that of sea water (0.5-1.0 M NaCl). The highest concentration of secretion observed for any gull is apparently 0.9 M (Staaland), but most gulls seldom secrete at concentrations higher than 0.7-0.8 M NaCl. (Shoemaker). The water of Mono Lake is currently approximately 0.6 M NaCl, and projected values for future concentrations lie in the vicinity of 2 M.

In order for birds to maintain osmotic equilibrium they must be able to secrete salt solutions at least as concentrated as the water they ingest. From consideration of NaCl concentrations alone it is apparent that the birds at Mono Lake will soon be faced with a situation in which freshwater is an absolute necessity for survival. Mono Lake contains a large amount of ions besides Na^+ and Cl'. The relatively high concentrations of HCO_3

may be particularly important, for this ion can elicit a salt gland secretion in several different bird species (Shoemaker) and may serve to keep birds on the lake constantly secreting from their salt glands even if blood NaCl levels are below stimulatory concentrations. This response would place a constant demand on the birds' energy reserves (it takes energy to excrete salt) but could do a great deal to offset the osmotic load imposed by the presence of ions which are not excreted by the salt glands. The major components of salt gland secretions are Na+ and Cl-; therefore, ions other than these which are ingested in Mono water can be construed as an osmotic load which is difficult to get rid of.

The concentrations of NaCl in the blood of birds are in the neighborhood of 0.1 to 0.15 M (Welty 1975). 1% is thus clear that foods with osmolalities less than O.lM (e.g., brine shrimp) present a very low salt load. Evidence from casual observations made in this study indicates that the birds at Mono have a variety of strategies, ranging from those in which freshwater is never visited and osmoregulation is handled solely by the bird's excretory system (e.g., Eared Grebes) to those in which freshwater is regularly visited to deal with osmoregulatory problems (e.g., California Gulls and Northern and Wilson's Phalaropes). In the act of feeding, birds unavoidably take in some water. As ionic concentrations in the lake increase, this portion of their total salt intake will increase dramatically. This increase in salt intake will probably affect birds of different osmoregulatory strategies in different ways. Those species like the Eared Grebe which do not use freshwater now may eventually be forced to either leave the basin or change their strategy to one in which they use freshwater. For birds such as the gulls and the phalaropes, the most likely response will be an increase in the frequency of visits to sources of freshwater. Eventually, however, a point may be reached where visits to freshwater become so frequent that other activities (e.g., feeding or breeding) become impossible. If this happens, they will not be able to survive at Mono.

CONCLUSIONS

Mono Lake stands apart from the variety of western Great Basin lakes, not only in its size and location, but also in its unique water chemistry and shrimp and brine fly biomass. Its importance as the home of one of the 1argest California Gull colonies in the world and the resting place of millions of transient grebes and shorebirds cannot be over-estimated.

Among the predicted effects of a shrinking lake, several appear certain. The most obvious and pressing of these is that, given an average climate and the present diversion rates, Negit Island will be connected to the mainland within the next two years. Although there are no extensive data to predict furher, it appears from consideration of bathymetric maps that Paoha Island and the islands tohe north and east of Negit will follow within fifty years. Published reports of the effects of land predators on other gull colonies provide the only means of gauging the results of an influx of novel land predators following the formation of a land bridge. These data from other gull colonies indicate that the Mono colony will be substantially reduced in size, if not totally eliminated, after the islands are connected to land.

As Mono Lake shrinks, the concentrations of dissolved ions in the lake's waters will increase. This increasing salinity and alkalinity poses a double threat to Mono's bird populations. Osmoregulatory capabilities of the species at Mono have never been studied in detail, but comparisons with closely-related birds which have been well studied and observations in the field indicate that the lake's waters presently put birds under osmotic stress. Fresh water is crucial to their survival on the lake and will become more important as ionic concentrations increase. Not only may the increasingly-concentrated water make survival ever more difficult, but it may eventually lead to a reduction or elimination of the populations of the birds' two significant food organisms, the brine fly and brine shrimp The disappearance of these prey populations would certainly mean the disappearance of the great majority of the birds presently visiting the lake.

If the bird populations on Mono Lake are to be preserved, several recommendations can be made. The continued value of Mono Lake as a nesting area for California Gulls relies on the maintenance of islands suitable for nesting. If Negit Island cannot be maintained, the next most desirable alternative is that the integrity of Paoha Island and the small islands to the north and east of Negit be maintained. It must remain clear however, that the retention of these islands will not insure the preservation of the gull population.

No one can predict whether the large Negit colony will move to Paoha Island and maintain its present large size in a new location. Measures to protect the gull colonies (e.g., the maintenance of higher lake volumes) will also lessen the threat of osmotic stress. If diversions continue to the point that all the lake's islands are connected to the mainland, some of the lake's value as a migratory stop-over for grebes and shorebirds may be retained if freshwater springs and seeps along the lake's shore continue flowing. Without these sources of fresh water, it is doubtful that birds will be able to survive on the lake. Management practices which reduce the amount and distribution of fresh water around Mono Lake (e.g., groundwater diversion) will almost certainly serve as the coup de grace to Mono's bird populations.

Chapter 6

BOTANY

Jefferson B. Burch, Jeffery Robbins, and Thomas Wainwright

INTRODUCTION

As the lake level recedes at Mono Lake, many thousands of acres of barren lake bottom are exposed. The succession of plant species on the exposed lake bottom has numerous implications to humans. First, plants act as stabilizers of the soil. At Mono Lake, dust storms occur because exposed lake sediments can be blown easily. These dust storms present a health hazard both to humans and to other organisms. Second, as primary producers, plants bring energy into the food web. Third, their physical structures provide habitats for other organisms. (For example, the marshes which occur at Mono Lake provide productive habitat which is rare in the Great Basin.)

This study seeks to forecast the succession (i.e., movement) of vegetation onto exposed areas. The approach involves two steps. First, it describes the plant associations and the distribution of plant species near the shore. Second, it discusses certain relationships between these associations and selected physical variables which describe the environment. Using these data, it projects possible changes in plant distributions based upon expected changes in the physical environment. We hope that the information presented here will serve as a basis for more detailed studies of the Mono Basin terrestrial ecosystem in the future.

GENERAL VEGETATION DESCRIPTION

All life zones from Upper Sonoran to Artic-Alpine occur in the Mono Basin (Storer, 1963). Because the emphasis of this study is on plant succession on exposed lake sediments, only portions of the basin near the lake were investigated. The vegetation of this area can be classified into the Upper Sonoran zone with its Great Basin Sagebrush Scrub association. For descriptive purposes, this area can be further divided into scrub, marsh, and near-lake non-vegetated areas.

Scrub areas completely surround the lake and are the dominant vegetation form in the basin. In those areas most recently exposed by the receding lake, shrubs are typically absent, and a border limiting their range is clearly defined around most of the shore. (The dashed line surrounding the lake in Figure 1-1 represents this border.) The dense vegetation of the scrub areas stabilizes the soil and minimizes wind erosion. Because their soils are commonly dry, these areas support little herbaceous growth. The major scrub species are _Sarcobatus vermiculatus_ (greasewood), Ar_temisia tridentata_ (sagebrush), Chrysothamnus _nauseosus_ and C. _viscidiflorous_ (rabbitbrush), _Prunus andersonii_ (desert peach), and _Purshia tridentata_ (bitterbrush). The distribution and abundance of these species are generally related to soil types and textures.

On the east side of the lake, soils are composed mainly of lake sediments and wind-blown sands. These fine-textured soils with small pores commonly create areas of poor drainage and poor soil aeration. A. _tridentata,_ C. nauseosus, and S. _vermiculatus_ are the dominant shrubs in these areas, and C. _viscidiflorous_ occurs occasionally. (Pr. _andersonii_ and Pu. _tridentata_ were not observed-in these areas.) Paoha Island, the white island formed by volcanic uplifting of lake sediments, has a similar soil texture and is also dominated by S. _vermiculatus._ _Grayia spinosa_ (hopsage) occurs in great abundance on the island but is-irregular in the mainland areas. No other shrub species, with the exception of an individual A. _tridentata,_ were found on the island.

On the south side of the lake, volcanic pumice soils are common. A. _tridentata_ and Pu. _tridentata_ are the dominant shrub species, and other species occur occasionally. These two species are distributed in a mosaic pattern. Pu. _tridentata_ is limited to occasional occurrences in the remaining areas around the lake, whereas A. _tridentata_ is the major species on the southwest, west and northwest shores. These areas are composed of granitic soils from glacial deposition and erosion. C. nauseosus is common, and two common mountain shrubs, Cercocarpus ledifolius (mountain-mahogany) and Rosa woodsii (mountain rose) occur occasionally. In several marsh areas the abundant ground water breaks surface near the lake on the west side. These areas are frequently bordered by Salix hindsiana (willow) and Shepherdia argentea (buffalo berry). S. vermiculatus was not observed on the west side of the lake.

The north shore has no single dominant shrub species. This is due, in part, to the zonation of soil types that characterizes the area. The northwest shore has granitic soils, the Black Point area volcanic ash, and the northeast lake sediments and windblown sands. On the volcanic ash soils, no species is clearly dominant. All major shrub species with the exception of S. vermiculatus occurred. Tetradymia spp. (horsebush) and G. spinosa are also found. In the northeast sector a similar pattern prevails in areas distant from the shore, except that S. vermiculatus occurs and Pr. andersonii and Pu. tridentata are absent. At the scrub-boundary, however, C. nauseous is the dominant species. Negit Island has a volcanic soil composition similar to that of the Black Point area but is clearly dominated by S. vermiculatus and G. spinosa; the other species occur infrequently.

Marsh areas occur in select regions of the lake shore where groundwater is found on or near the surface. They cover approximately ten percent of the 1976 shoreline or five percent of the surface area between the scrub border and the lake (the hatched areas in Figure l-l). As discussed in the geology chapter, the area of seepage typically follows the receding lake shore. Unlike the shrubs which are very slow to colonize new areas, the marsh species are quick to move onto the newly exposed areas following the movement of the groundwater.

The zonation of the dominant species in the marsh is associated primarily with the availability of water. Marsh areas show a pattern of bands paralleling the lake shore. A wet, alkaline mud flat is immediately adjacent to the lake, followed by a slightly raised and medium wet bar. This bar is followed by an extremely wet "fresh" water zone which fades into dry land at higher elevations. In the alkaline mud flat areas, Bassia hyssopifolia, Cleomella parviflora, and Puccunellia airoides are the common inhabitants. In the areas wet with surface water, Ranunculus cymbalaria, Castilleja exilis, Epilobium adenocaulon, Mimulus guttatus, and Typha spp. predominate. These species merge with Scirpus americanus and Scirpus robustus as the dominant species in the medium wet areas. In the drier areas of the marsh, the dominant species are Muhlenbergia asperifolia, Scirpus nevadensis, Hordeum jubatum, Polypogon spp. and Distichlis spicata. The marshes on the west side of the lake, at Gull Bath, Warm Springs, Simmon's Springs, and Paoha Island show this water distribution pattern. Marshes at Sneeker Flat, Lee Vining Tufa, South Tufa, and DeChambeau Ponds are drier, with only limited occurrences of the vegetation characteristic of extremely wet areas. These marshes, especially the DeChambeau Ponds area, have large occurrences of the grass and sedge vegetation common in moderate-to-dry marsh areas. In marsh areas, the herbacious vegetation is commonly dense, providing good soil stabilization against dust.

Most of the landmass between the scrub border and the lake shore supports very little vegetation. The soils here are mainly lake sediments and windblown sands, and the future exposed areas left by the falling lake (see Figure 2-22) are expected to be of similar soil composition. These fine-textured sediments with sparse vegetation cover cause the current dust hazards. Only a handful of species occupies these non-vegetated areas, the most important being Distichlis spicata (salt grass), which occurs in a band paralleling the lake shore. With its rhizomatous growth form, it occurs commonly in sandy areas, forming mats which help to stabilize the soil. These mats are raised on miniature sand dunes created by the lower rate of erosion beneath the grass clumps. These matted areas, although beneficial in keeping down the dust, represent less than one percent of the non-vegetated areas. Other species occupying this zone are Bassia hyssopifolia- in alkaline mud flat areas, Salsola pestifera in sandy areas, and Psathyrotes annua on the volcanic soils of Black Point. These species do not prevent dust movement.

FIELD METHODS

This section deals with the procedures for collecting field data. The techniques used in the analysis of this data are presented in the next section.

As discussed in the preceding section, plant life is varied in the regions immediately surrounding the lake. We studied a representative sample of this variation. We excluded areas extremely altered by humans (such as the irrigated meadows of Mono Park) from our sampling. Also, we excluded the few riparian zones near the northwest shore.

We chose twelve study sites around the lake to represent all the obvious successional patterns (see Figure 1-1). These sites consist of approximately linear bands parallel to the lake shore and extending from the lake shore into the climax scrub vegetation. Within each site, we selected six to fifteen sample plots (releves) to represent each type of vegetation occurring within the band. A total of 116 such plots were sampled.

The study plots were circular, usually with an area of 200 square meters (.02 ha.). This size gave adequate representation to all species in a given habitat association while remaining small enough for easy study. The size was chosen after the results of two species-area determinations (after Mueller-Dombois and Ellenberg, pp. 47 ff.) which were made, one for a sedge meadow near Mono County Park and one for a scrub area near the Wilson Creek wash (Figure 1-1). Exceptions to the 200 m^2 size were made when a plot of that size obviously did not include all major species of the association (as in a pinon-juniper area), or when the 200 m^2 plot exceeded the limits of an obviously distinct association (as in some of the mosaic marsh areas).

Each plot was described in terms both of its physical environment and of its vegetation. Environmental data included gross physical features (location, slope, direction of exposure, elevation above and distance from the lake shore) and more detailed information concerning the substrate (soil surface texture and color, surface moisture, water table depth, soil pH, and soil conductivity). Surface characteristics were visually estimated using a modification of methods proposed by Emlen (1956). Environmental data were also collected in areas where no vegetation occurred.

Vegetation in the plots was evaluated both in terms of overall physiognomy (i.e., the external appearance of the vegetation) of the association and abundance of individual species. The physiognomic description included overall vegetation color and dispersion (Emlen, pp. 568-570) and visual estimates of percent cover, upper canopy height, and lower canopy limit (clearance) for each of the three strata: herb/grass, shrub, and tree. For each plot, a complete list of species of vascular plants was made, with abundance recorded according to the system of Braun-Blanquet (Mueller-Dombois and Ellenberg, pp. 59-62, and Kershaw, 1973, pp. 12-14.). The Braun-Blanquet system is a seven point scale for estimating percent of the ground covered by a species. The scale is presented in Table 6-2.

Code	Description of Cover Rating
R	Solitary, with small cover
+	Few, with small cover
1	Numerous, with cover up to 5%
2	Any number, with 5-25% cover
3	Any number, with 25-50% cover
4	Any number, with 50-75% cover
5	Any number, with 75-100% cover

TABLE 6-2 The Braun-Blanquet Cover-Abundance Scale Values refer to percent of the ground covered by a species based on the size of the plot. The values are absolute and do not refer to percent of the vegetated ground cover.

Initially, the visual estimates of cover were checked by averaging more detailed measurements made with a one-quarter square meter frame with a one decimeter grid, but this procedure was eliminated after the correlation between visual estimates and measurements with the frame became evident. Detailed quantitative analysis of the species abundance data was not possible, and the Braun-Blanquet cover estimates were satisfactory for our purposes. Specimens of the species were collected as they were found, and identifications were made using Munz (1968) with supplement from Abrams (1940); Jepson (1925); and Mason (1957). (The collection will be placed in the Dudley Herbarium at the California Academy

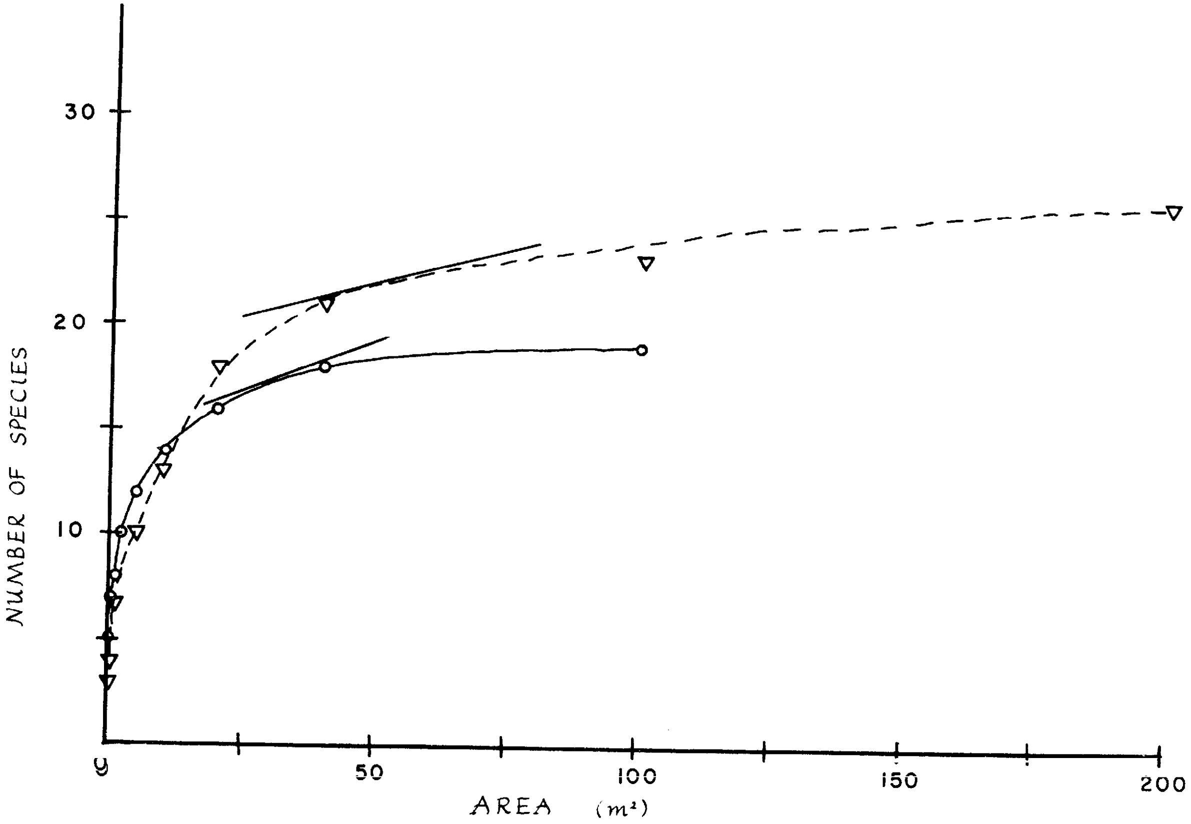

Figure 6-1. SPECIES AREA CURVES - for a sedge meadow (solid line), and for a sage shrub area (broken line). Tangents to the curves are drawn at points at which a ten percent change in area will produce only a five percent increase in number of species. The points of tangency lie at the minimum plot size for representative sampling. 200 m^2 plots were used to ensure adequate representation in all areas sampled.

of Sciences.) A more detailed account of field methods relating to the physical data is included as Appendix 6-1.

METHODS OF DATA ANALYSIS

This investigation can be divided into two phases of analysis: 1) an investigation of species distributions and associations, and 2) an investigation of how environmental factors affect species distributions.

Regardless of how the investigator chooses to describe the species associations, either by classifying them into communities or by considering their gradient relationships, the vegetation pattern is the same. Our approach to investigating species association relationships incorporates both perspectives.

The second phase of the analysis is an investigation of how environmental factors affect the vegetation pattern. By studying the distribution of physical factors in combination with species distributions, we gain insight into what physical factors are important in determining the plant distribution, Also, by studying the interrelationships between physical factors, we gain an understanding of the physical environment in general.

By investigating species associations, the distributions of species with respect to the physical environment, and the distribution of physical factors, we feel an understanding of the past succession of plants onto the exposed lake bottom is possible. With this understanding of past succession, we are able to make predictions of the future vegetation pattern.

Phase 1, Species Distributions and Associations:

In order to describe the vegetation patterns, we sought analytical methods for determining the association relationships between species. We intended to examine the data and extract indices of species-to-species correlations or co-occurrences. These indices represent the degree of similarity between species distributions. We used analytical techniques to order the species relative to one another and to create a diagram (called an ordination) to display similarities of distribution. These techniques serve to reduce the complex multi-dimensional interaction of species distributions to a two- or three-dimensional graphical representation. Many methods for ordination have been developed. Some are based on sophisticated mathematical models, while others are very simple. We used two methods of ordination in the study: 1) a modified version of indirect gradient analysis (Bray and Curtis, 1957), and 2) a plexus diagram of De Vries (Mueller-Dombois and Ellenberg, pp. 234.). A discussion of the analytical techniques we used follows.

Because of the large quantity of data collected, the aid of a computer was necessary. Hundreds of thousands of computations and comparisons were 'performed in an attempt to understand species distributions.

Because both methods of ordination compare species distributions, analysis of the 120 species present in the data proved unfeasible. We chose to focus on the major species, those occurring in 9 or more of the 116 sample plots. 29 species qualified under this criterion. Deadwood, the amount of intact dead shrubs regardless of species, had significant cover in some scrub areas and so it was treated as a species, bringing the total to 30.

For ordination analysis, data for the 30 major species was organized as a two-dimensional table or matrix with each species represented by a column and each of the 116 sample plots represented by a row. Values in the matrix indicated presence or absence rather than quantity. For each pair of species, (as indicated in a 2 X 2 contingency table below) numbers of occurrences together (a), of each species without the other (b, c), and of neither species (d) in all 116 sample plots were counted.

		Species A	
		+	-
Species B	+	a	b
	-	c	d

From these values an index of dissimilarity (ID) was calculated from the formula of Dice (Whittaker, 1973, pp. 112):

$$ID = 100 \times (1 - 2a/(2a + b + c)).$$

Note that this index measures dissimilarity or disassociation and ranges from a value of 0 for a perfect association between the pair of species to a value of 100 for species which never occurred together.

The ID values for each pair of species were organized into a 30 X 30 species-species association matrix. Both methods of ordination operate on this association matrix, which is an attempt to simplify the complexities of the association pattern to a two-dimensional diagram.

In the Bray and Curtis method of indirect gradient analysis, the process is an attempt to position the species on a two-dimensional graph such that the distances between the species approximates the ID value between them. To do this it is necessary to choose two species to serve as endpoints, These endpoint species can be viewed as being on the ends of a species association continuum or gradient, with the purpose of the ordination serving to position the remaining 28 species along this continuum. Endpoint species pairs are chosen under the criteria that they have a high ID value (i.e., are poorly associated with each other), and that they represent the ends of an association continuum based on our subjective judgements from field observations. Twenty pairs of species were tried in the process.

To perform the ordination, the endpoint species are placed on a line which represents one axis of a Cartesian plane, One endpoint is placed at the origin and the other on the line such that the distance between the two represents their ID value. Each of the remaining species are placed on the coordinate plane at the point of intersection of two arcs centered on each endpoint with a radius indicating the ID value between that species and the endpoint. Figure 6-3 illustrates this process where the general notation ID_{ij} represents the index of dissimilarity between any two species i and j, A and B represent the endpoint species, and P represents the species being positioned. The value d represents the position of species P along the association continuum between the endpoints A and B, The value e represents distortion caused by considering only one dimension of the multi-dimensional association continuum. A large e value implies large distortion. The values d and e can be calculated directly from the association matrix as follows:

$$d = \frac{ID_{AB}^2 + ID_{AP}^2 - ID_{BP}^2}{2 \times ID_{AB}}$$

$$e = (ID_{AP}^2 - d^2)$$

When the species are positioned in this manner by plotting d versus e for the X and Y coordinates, the resulting graph is called a one-dimensional indirect ordination along the association continuum from species A to B. Note that each non-endpoint species is placed on the graph by considering only the ID value of that species with the endpoints. No consideration is given to the ID values between non-endpoint species. With this in mind, it is possible for two species which have a large ID value to be placed near each other on the ordination. For a better approximation of the association relationships, the ordination must be extended to two or more dimensions.

To extend the ordination to two dimensions, two different species are chosen for endpoints for the second axis, endpoints C and D. The criteria for this choice are that they fall close to each other in the one-dimensional ordination (i.e., they have similar d values along the first axis), and that they have a large ID value between them. These endpoint species are then used to calculate the values d' and e' for the other 28 species in a manner analogous to the first axis. (The primes are added for notation to differentiate the two axes.) The value d represents the position along the one-dimensional gradient whereas the value e represents the distortion. In simplified form, the two-dimensional ordination is a plot of d versus d'. If the endpoints C and D do not have the same d value along the first axis, the second axis will not be perpendicular to the first. Consequently, when plotting d versus d' the ordination will be skewed because such a plot

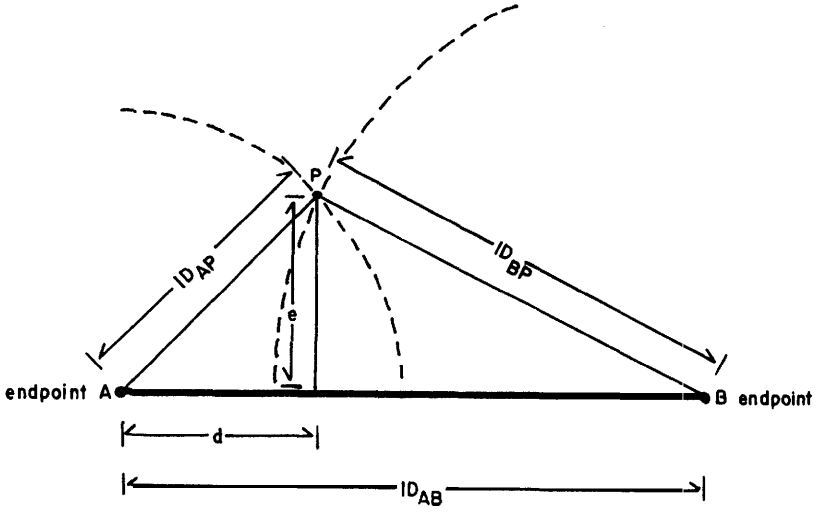

Figure 6-3. ONE DIMENSIONAL CONSTRUCTION, BRAY AND CURTIS INDIRECT GRADIENT ORDINATION

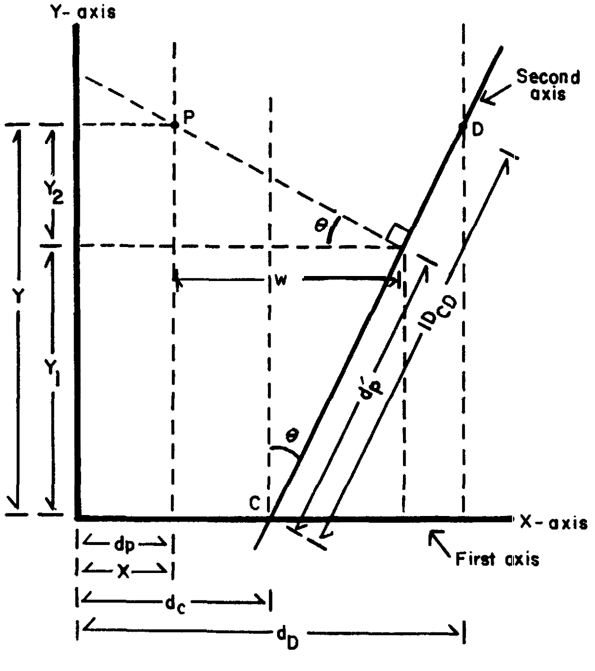

Figure 6-4. TWO DIMENSIONAL CONSTRUCTION, BRAY AND CURTIS INDIRECT GRADIENT ORDINATION

assumes perpendicular axes.

Formulas were derived to handle this problem. Given an axis between two endpoints, it is assumed that each species must be placed somewhere on a line perpendicular to and intercepting the axis at a distance d from the first endpoint. In the one-dimensional case, each species is placed on the perpendicular at a distance e above the axis. In the two-dimensional case, each species is placed at the intersection of perpendiculars to the axes (see Figure 6-4). Dummy variables 0, Y Y_2, and W were created to clarify the derivations and simplify calculations. The two-dimensional ordination is then completed by plotting X versus Y. If the axes are perpendicular, the results between this form and the simplified form are the same. These ideas and formulae are easily extended to three or more dimensions. However, in this case we found that neither was desirable, due to the increased complexity of graphing and interpretation in three or more dimensions. After inspection of many one-and two-dimensional ordinations, the relationships of species along association continua became apparent. The original problem of Bray and Curtis ordination still exists in that only the dissimilarity indices (ID values) of the species at the endpoints are used in the calculations. This shortcoming should be considered when interpreting the results.

The second approach to association analysis is the plexus diagram technique of De Vries (Mueller-Dombois and Ellenberg, pp. 234.). This technique has the advantage of using all dissimilarity indices, but it presents problems because it is more subjective in its representation of the associations. For each species, an associated species list is made. The list has two arbitrarily defined categories: strong associates, species with a dissimilarity value of less than 50 units; and weak associates, species with a dissimilarity value from 60 to 50 units The construction process begins by representing each species as a point somewhere on the plexus diagram. Strong associates are then interconnected by solid lines and weak associates by dashed lines. Because the distances between points and their placement on the diagram are arbitrary, the diagram is then redrawn changing the location of the points as many times as is necessary to simplify the interconnecting pattern of lines. The redrawing process is completed when the diagram has strong associates near each other forming groups with the groups positioned in such a way as to allow weak associations to indicate transitions. Since this was a manual redrawing process, to avoid bias no reference was made to the actual species represented by the points. From these two methods of ordination an understanding of the species association pattern was obtained.

The second phase of the analysis is a graphical investigation of how the environment affects species distributions. Because many species were found to have similar distributions (as illustrated by the ordinations in the section), and because a graphical analysis of 120 separate species against physical variables is a large undertaking, we investigated species associations in relation to environmental variables. We classified the 116 sample **plots** into seven categories representing species association types.

Because the classification process is somewhat subjective and because the categories are intended to represent species association types, a check on the validity of the categories was warrented. We sought to characterize the flora of each category by determining the number of occurrences for each of the 120 species. Using these counts, we compared the association types on the bases of co-occurring species. Two indices of similarity were calculated to quantify the comparisons. The first was the presence/absence index of dissimilarity (ID) mentioned earlier, and the second was the index of percent difference (PD) (Whittaker, 1973). PD compares the number of occurrences for the species in each association type to give a quantitative rather than qualitative measure of dissimilarity. When comparing two association types, A and B, over all, k, species, PD is given by:

$$PD = 100\ x_{i=1}^{k}\ X_i - Y_i\ /\ {}_{i=1}^{k}\ (X_i + Y_i)$$

where

$$X_i = \frac{\#\ \text{of occurrences of species i in association A}}{\#\ \text{of sample plots in association A}}$$

$$Y_i = \frac{\#\ \text{of occurrences of species i in association B}}{\#\ \text{of sample plots in association B}}$$

Note that this index tries to adjust for the different number of samples in the associations, gives a measure dissimilarity, and ranges between 0 and 100. These indices are intended to show how the association types are related to each other and to illustrate their position along the overall continuum.

By approaching analysis from both the continuum and community perspectives, we obtained a good understanding of the species distribution.

Environmental Effects on Species Distributions:

The approach to the second phase of the analysis of how environmental factors affect vegetation patterns was patterned after the direct gradient analysis techniques of Whittaker (1973). The process involves graphing physical variables against one another and against species abundance variables, This graphing approach allows us to visualize how the environment affects plant distributions. Although the technique is direct, the size of the task required the aid of computer graphics. Over four hundred graphs in two- and three-dimensions were generated during the analysis. Only the most important graphs are presented in the section. All graphs, however, are included in the Mono Lake data collection at Stanford University.

Two-dimensional graphs of species abundance versus physical variables were made for the major species. The following physical variables were used:

> elevation, distance, pH, conductivity, $\log_{10}$(conductivity), water availability, water table depth, time, soil texture index.

Three-dimensional graphs of physical variables in the XY plane with species and physiognomic abundance variables in the third dimension were made for the major species, for the habitat structural variables shrub cover, shrub height, and herb cover, and for the association types. The following pairs of physical variables were used:

> pH/elevation, elevation/distance, elevation/$\log_{10}$(conductivity), water table depth/shrub cover, elevation/shrub cover.

Two-dimensional graphs were made of pairs of physical variables for various combinations of the following:

> elevation, distance, pH, depth to water table, shrub cover, shrub height, herb cover, herb height, conductivity, log (conductivity), time since exposure, soil texture index, rainfall, slope.

RESULTS AND DISCUSSION

Our results are presented mainly in the form of graphs. In the first section, Phase 1, we investigate species distributions and associations. In the second section, Phase 2, we relate these distributions to physical factors.

Phase 1, Species Distributions and Associations:

The ordination methods used to investigate species distributions are based on assumptions. Here, we assume that the index of dissimilarity measures and quantifies species associations and that the two ordination methods display the major trends of the association pattern. The 30 major species considered in the ordinations along with abbreviated codes used to represent them are presented in Table 6-5. These species were compared using the index of dissimilarity as illustrated by the association matrix of Table 6-6. This index ranges from 0 (perfect association) to 100 (no association) and uses a presence/absence comparison criterion. Both methods of ordination operate on this matrix and attempt to graphically represent the association pattern.

The plexus diagram of Figure 6-7 shows the association pattern through the interconnecting pattern of lines. Because in its construction all dissimilarity values are considered, it is possible to interpret both the broad overall pattern and the details of any specific region on the diagram. The overall species association pattern appears to be a continuum. Sharp boundaries between distributions of groups of species, which would denote communities with non-overlapping floras, were not found. However, there occurred stronger species associations at the extremes of the continuum which we call the

Table 6-5

MAJOR SPECIES LIST AND ABBREVIATIONS

Deadwood	De
CAPPARIDACEAE	
Cleomella parviflora	ClP
CHENOPODIACEAE	
Bassia hyssopifolia	BaH
Salsola pestifera	SaP
Sarcobatus vermiculatus	SaV
Chenopodium fremontii	ChF
COMPOSITAE	
Artemisia tridentata	ArT
Chrysothamnus nauseosus	ChN
Chrysothamnus viscidiflorous	ChV
Psathyrotes annua	PsA
CYPERACEAE	
Scirpus americanus	ScA
Scirpus robustus	ScR
Scirpus nevadensis	ScN
GRAMINEAE	
Agrostideae	
Muhlenbergia asperifolia	MuA
Orzyopsis hymenoides	Or-H
Polypogon interruptus and P. monspeliensis	**Po**
Festuceae	
Bromus tectorum	BrT
Distichlis spicata	DiS
Puccinellia airoides	PuA
Hordeae	
Elymus cinereus	ElC
Hordeum jubatum	HoJ
Sitanion jubatum and S. hystrix	Si
JUNCACEAE	
Juncus effusus	JuE
ONAGRACEAE	
Epilobium adenocaulon	EpA
RANUNCULACEAE	
Ranunculus cymbalaria	RaC
SALICACEAE	
Salix hindsiana	SaH
SCROPHULARIACEAE	
Castilleja exilis	CaE
Mimulus guttatus	MiG
RQSACEAE	
Prunus andersonii	PrA
Purshia tridentata	PuT

	Deadwood	Cleomella parviflora	Bassia hyssopifolia	Salsola pestifera	Sarcobatus vermiculatus	Chenopodium Fremontii	Artemisia tridentata	Chrysothamnus nauseosus	Chrysothamnus viscidiflorus	Psathyrotes annus	Scirpus americanus	Scirpus robustus	Scirpus nevadensis	Muhlenbergia asperifolia	Oryzopsis hymenoides	Polypogon sp.	Bromus tectorum	Distichlis spicata	Puccinellia airoides	Elymus cinereus	Hordeum jubatum	Sitanion spp.	Juncus effusus	Epilobium adenocaulon	Ranunculus cymbalaria	Salix Hindsiana	Castilleja exilis	Mimulus guttatus	Prunus Andersonii	Purshia tridentata	TOTAL
Deadwood				4	4		14	11	4	2	3		1	4	6	1	9	8		7	1	8	2			7			5	9	23
Cleomella parviflora			4		1	5		1			8	2	10	4		3		13	8		6		1	2	4		2	1			14
Bassia hyssopifolia		76.5		7		3	2	3		8	2	1	10	3			3	16	11		5	1	2		2						20
Salsola pestifera	82.2		66.7		2		11	9	3	8			3	4	4		10	13	2	2	1	3	7			4			2	2	22
Sarcobatus vermiculatus	80.5	93.8		90.0			8	10	7	2	5	1	3	2	7	2		15		3	4		1						2	1	18
Chenopodium Fremontii		58.3	80.0								7	5	6	5		4		8	10		7			4	6		3	2			10
Artemisia tridentata	54.8		93.2	63.9	71.9			29	14	3			5	8	14		16	23	3	11	1	8	9	1		7			8	8	39
Chrysothamnus nauseosus	63.9	96.2	89.7	70.0	64.3		24.7		12	5			9	9	15		13	27	3	11	3	6	10	2		7	1		8	5	38
Chrysothamnus viscidiflorus	78.9			83.8	57.6		48.1	54.7		1				1	12		2	9		6		3							5	3	15
Psathyrotes annus	89.7		55.6	57.9	88.2		89.1	81.5	93.5				4	3	2		4	10	3	1	2	1	3						1		16
Scirpus americanus	88.7	63.6	92.0		79.2	65.0						7	14	17		11		17	12		15		9	12	10	5	9	9			30
Scirpus robustus		82.6	93.1		92.6	47.4					64.1		4	4		3		5	7		6			3	5		1	3			9
Scirpus nevadensis	96.5	58.3	63.0	89.3	88.5	72.7	86.3	75.0		84.0	56.3	81.4		10		5	5	30	19	1	17	1	10	6	7	1	5	4			34
Muhlenbergia asperifolia	84.0	80.5	87.2	83.7	91.1	73.0	75.8	72.3	95.2	86.0	40.4	77.8	67.2		2	8	8	13	10	4	13	2	13	11	9	9	8	7	1	1	27
Oryzopsis hymenoides	70.7			80.0	61.1		50.9	46.4	27.3	88.2				91.1			4	10		6		4				2			8	5	18
Polypogon sp.	94.1	76.0			86.2	61.9					46.3	70.0	77.8	57.9				6	5		8		3	7	7	2	7	4			11
Bromus tectorum	58.1		85.0	52.4			45.8	55.2	88.6	77.8			81.5	66.0	78.9			12	4	4	2	6	8	1		8			4	5	20
Distichlis spicata	83.0	69.4	64.8	72.0	66.3	80.2	58.2	50.5	79.1	72.0	66.3	87.5	42.9	73.5	72.5	85.4	73.6		21	8	19	3	13	4	6	2	4	1	3	2	71
Puccinellia airoides		59.0	51.1	91.5		42.9	90.6	90.5		85.4	56.4	58.8	35.6	61.5		72.2	82.2	56.3			14		5	6	9		4	4			25
Elymus cinereus	61.1			88.6	80.6		57.7	56.9	57.1	93.1			95.7	80.0	61.3		75.8	81.0				4	3			4			3	2	13
Hordeum jubatum	95.7	68.4	77.3	95.7	81.0	58.8	96.8	90.3		90.0	44.4	63.6	41.4	49.0		54.3	90.9	60.0	42.9				6	8	9		6	5			24
Sitanion spp.	50.0		93.1	80.6			66.7	74.5	75.0	92.0			95.4	88.9	70.4		58.6	92.5		63.6			1						5	6	9
Juncus effusus	91.3	94.6	90.7	68.9	95.1		71.0	67.2		84.6	66.0		64.9	48.0		82.4	62.8	72.3	79.2	83.3	74.5	93.6		6	2	7	5	4			23
Epilobium adenocaulon		85.7				66.7	96.2	92.3			45.5	73.9	75.0	46.3		44.0	94.1	90.6	69.2		57.9		67.6		9	4	10	9			14
Ranunculus cymbalaria		69.2	87.5			45.5					52.4	52.4	69.6	53.8		39.1		85.5	51.4		50.0		88.6	30.8		1	7	7			12
Salix Hindsiana	62.2			77.8			73.6	73.1			77.3		95.8	56.1	87.5	84.0	52.9	95.3		70.4			62.2	71.4	92.3		2	2		2	14
Castilleja exilis		83.3				70.0		95.8			55.0	89.5	77.3	56.8		33.3		90.1	77.1		64.7		69.7	16.7	36.4	83.3		6			10
Mimulus guttatus		91.3				78.9					53.8	66.7	81.4	61.1		60.0		97.5	76.5		69.7		75.0	21.7	33.3	82.6	36.8				9
Prunus Andersonii	68.8			87.1	85.2		66.7	66.0	58.3	92.0				94.4	40.7		72.4	92.5		72.7		55.6								5	9
Purshia tridentata	45.5			87.5	92.9		67.3	79.2	76.0					94.6	64.3		66.7	95.1		82.6		36.8				83.3			47.4		10

Table 6-6. SPECIES-SPECIES ASSOCIATION MATRIX. Upper half of the table is the number of co-occurrences between the species pair. Lower half indicates Index of Dissimilarity (ID). Total number of occurrences in all 116 sample plots is indicated in the extreme right column.

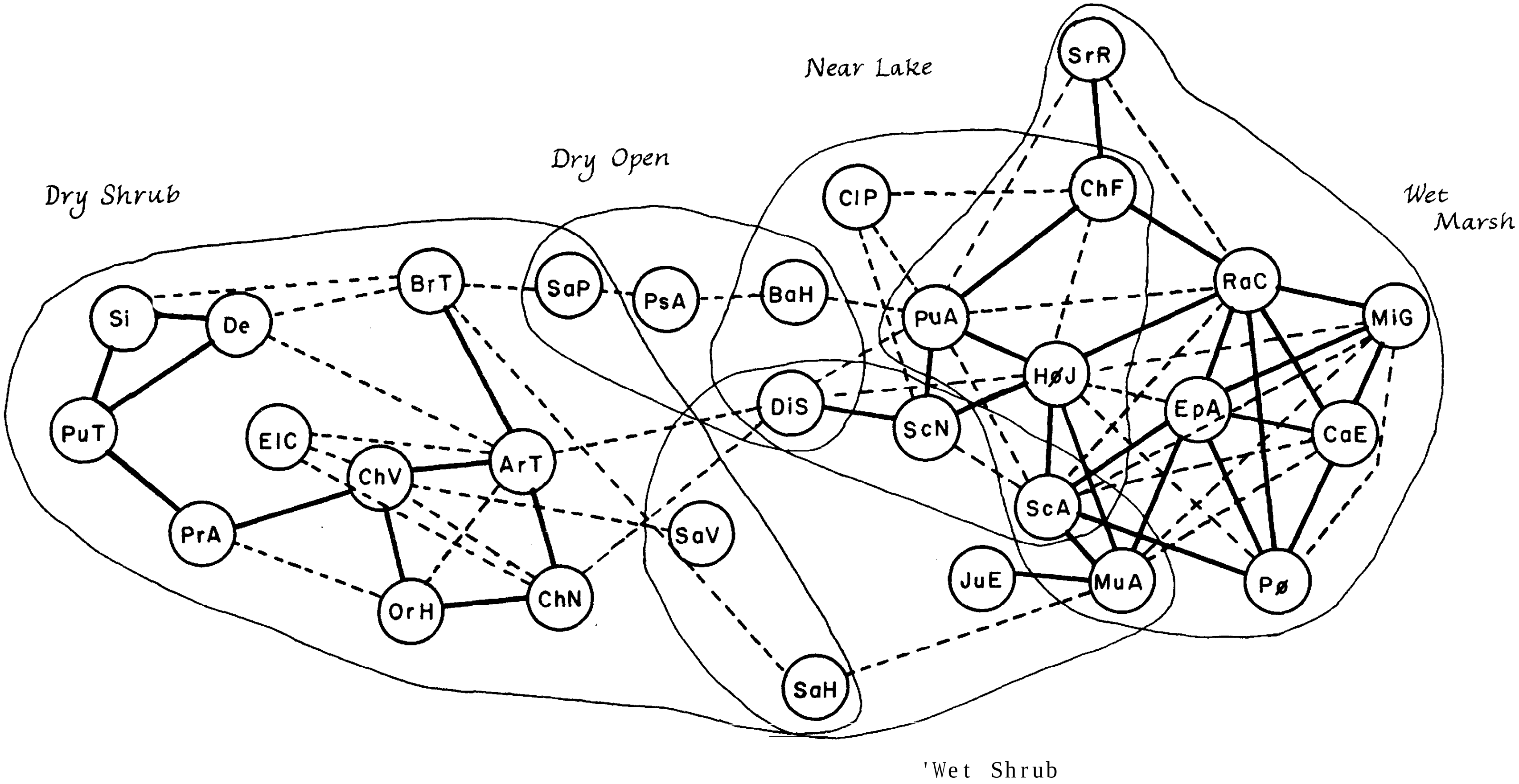

Figure 6-7. PLEXUS DIAGRAM. Solid line indicates an ID value less than 50, dashed line indicates an ID value between 50 and 60.

Dry-scrub and Marsh clusters.

To check and complement the association pattern as displayed in the plexus diagram, indirect ordinations were constructed. In the indirect ordinations, because only the dissimilarity values involving the endpoints are used, interpretation is commonly limited to either the broad overall level when endpoint pairs are very dissimilar, or the specific regions of the association pattern with less dissimilar endpoint pairs. Consequently, many indirect ordinations are included to illustrate both the overall association pattern and details of specific regions of the association continuum.

Figure 6-8 is a two-dimensional indirect ordination with very dissimilar endpoint species. The association pattern again appears as a continuum with tight clustering of species around the extremes.

To view the details of the Dry-scrub cluster, Figure 6-9 was constructed by choosing two shrub species as endpoints. It is a one-dimensional indirect ordination with e values (representing distortion) plotted along the Y axis. Species which are not integral members of the scrub association (i.e., the species inhabiting the Marsh cluster) have large e values and are positioned at the top of the graph. The transitional species have moderate e values and are positioned over the *Artemisia tridentata* rather than the *Purshia tridentata* endpoint. This indicates that species most highly associated with Pu. *tridentata* occupy the extreme position of the continuum. Also note that *Sarcobatus vermiculatus* has a large e value. It is not an integral member of the Dry-scrub cluster. Areas dominated by it, specifically areas with soils composed of lake sediments and windblown sands (see General Vegetation Description section), are of a different floristic composition than the rest of the shrub areas. Details of the Dry-scrub cluster presented in the plexus diagram support these findings.

To view the details of the Marsh cluster, a one-dimensional indirect ordination (Figure 6-10) and a two-dimensional expansion of this ordination (Figure 6-11) were constructed by choosing endpoint species from the cluster. By viewing both these together, it is possible to see the differences betweenthe one- and two-dimensional ordinations. Species from the Dry-scrub cluster fall in the upper portion of Figure 6-10 (i.e.,with large e values). These species are not directly associated with the Marsh cluster and consequently are excluded from Figure 6-11 to clarify the relationships. The substructure of the Marsh cluster appears as a gradient of species inhabiting three areas: the extremely wet marsh, the alkaline mud flat, and the drier marsh areas. This is similar to the water availability pattern discussed in the General Vegetation Description section. Note that S. *vermiculatus* is included in these ordinations and is positioned near *Salix hindsiana.* Although from the plexus diagram and from the association matrix (Table 6-6) these species are not associated (in fact they never co-occurred), they both occurred in drier areas of the marsh and represent a wet shrub association.

In summary, the overall species association pattern appears to be a continuum from the dry shrub species to the extreme wet marsh species. Sharp boundaries between groups of species were not found, but a stronger association of species into the Marsh and Dry-scrub clusters was observed.

In the second phase of the analysis of how the environment affects species distributions, we found it necessary to discuss groups of similarly distributed species. This entailed a classification of the 116 sample plots into seven categories: wet marsh, transition marsh/dry, near lake alkaline flat, wet shrub, dry open, transition dry/scrub, and dry scrub. The classification process relied heavily upon our subjective knowledge of the study areas. Criteria distinguishing the categories are shown in Table 6-12. Because the categories are intended to represent species association types, we sought to characterize the flora for each category. A tabulation of the number of occurrences in each category for all 120 species is presented in Appendix 6-3. A condensed version illustrating the 30 major species is presented in Table 6-13. Note that *Purshia tridentata* is the only major species limited to one category, and that *Distichlis* spicata, *Muhlenbergia asperifolia* and *Scirpus nevadensis* (two grasses and a sedge species) occur in all categories. Generally, the major species are not limited to any one category but vary in frequency of occurrence across the categories. This suggests that the categories can be positioned along an association continuum. The categories are compared as illustrated in Table 6-14. A two-dimensional indirect ordination of the categories was constructed using the PD index from the matrix (Figure 6-15). The positioning of the categories in this ordination indicate a continuum from the Wet Marsh to the Dry-Scrub association types.

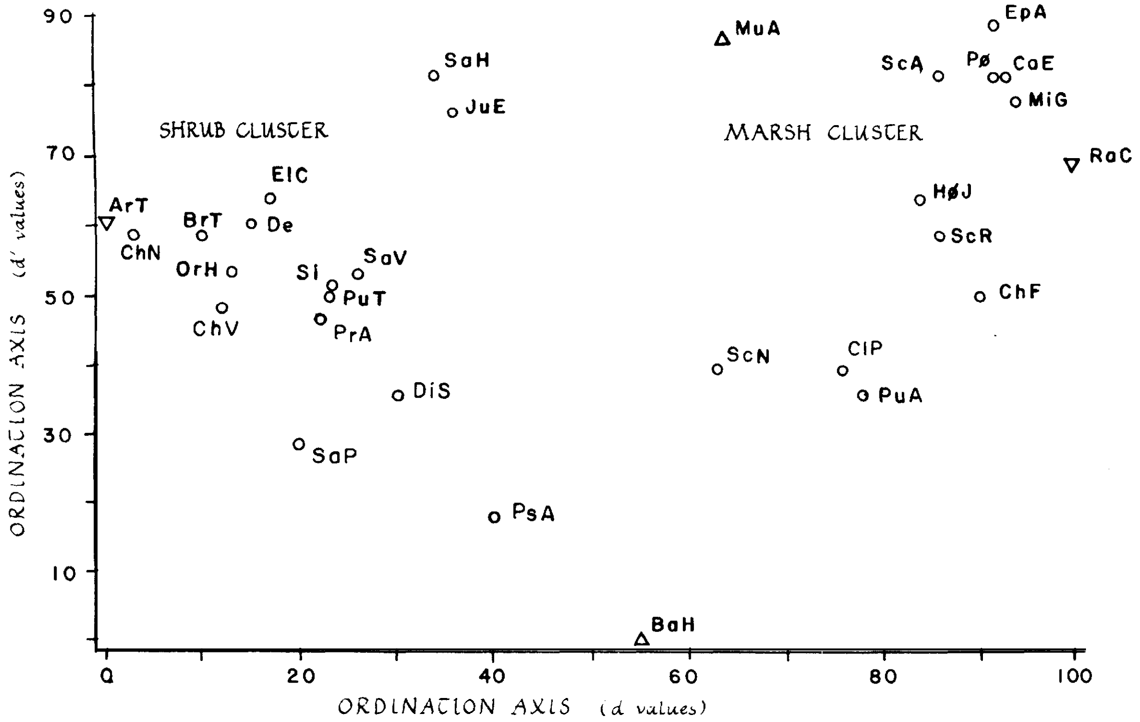

Figure 6-8. TWO DIMENSIONAL INDIRECT GRADIENT ORDINATION. Endpoint species are indicated by triangles. The first axis has Artemisia tridentata (ArT) and Ranunculus cymbalaria (RaC) as endpoints. The second axis has Bassia hyssopifolia (BaH) and Muhlenbergia asperifolia (MuA) as endpoints.

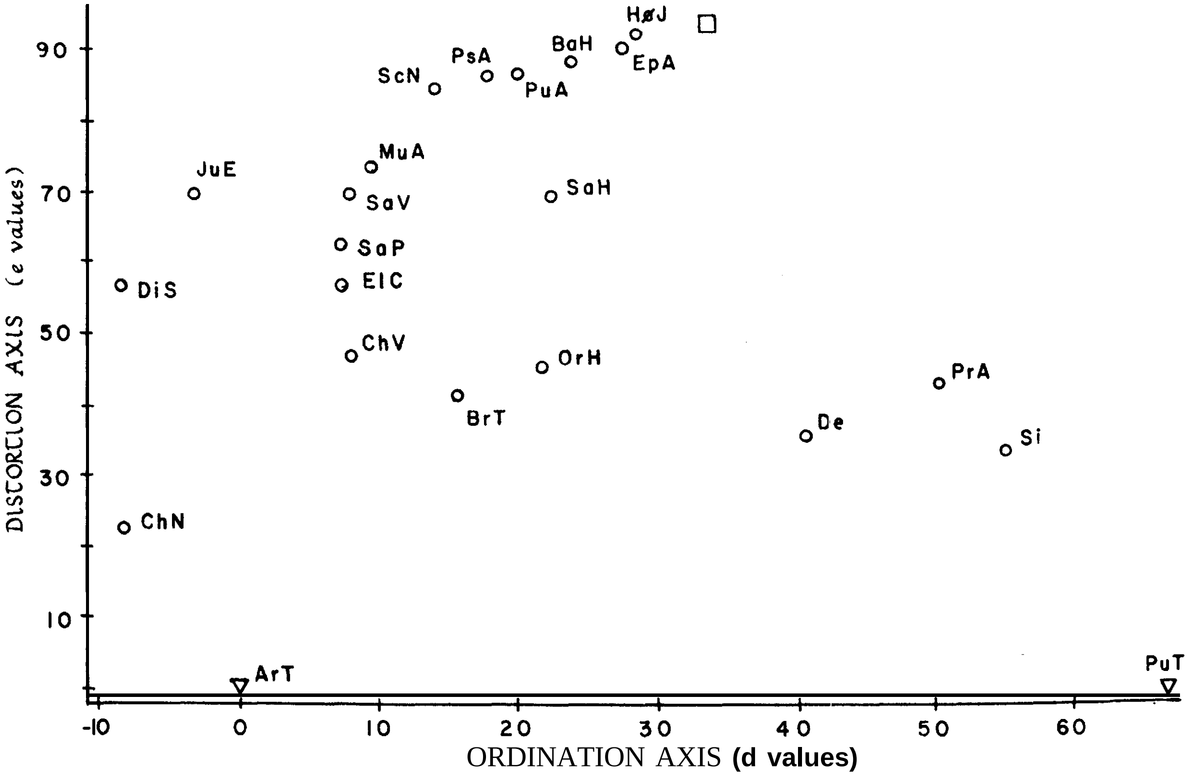

Figure 6-9. ONE DIMENSIONAL INDIRECT GRADIENT ORDINATION OF SCRUB CLUSTER. The axis has Artemisia tridentata (ArT) and Purshia tridentata (PuT) as endpoints. The square indicates the following marsh and near lake species: ClP, ChF, ScA, ScR, Po, RaC, CaE, MiG.

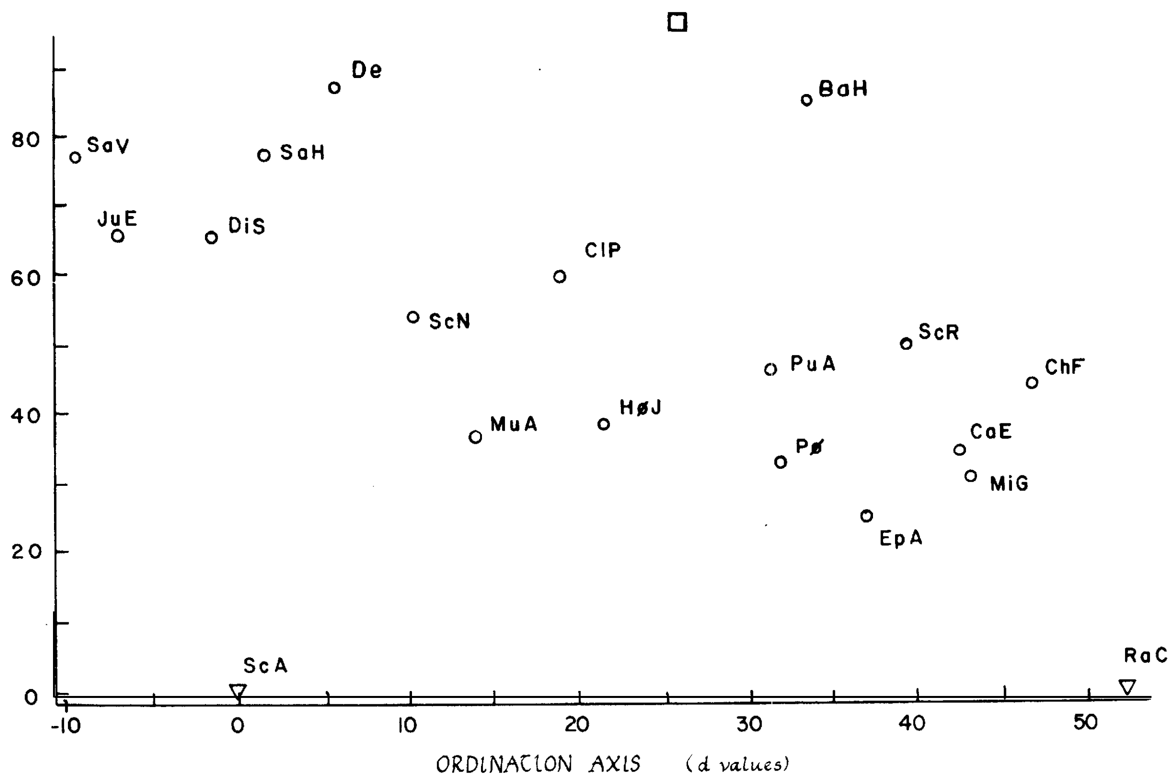

Figure 6-10. ONE DIMENSIONAL INDIRECT GRADIENT ORDINATION OF MARSH CLUSTER. The axis has Scirpus americanus (ScA) and Ranunculus cymbalaria (RaC) as endpoints. The square indicates the following species: SaP, ArT, ChN, ChV, PsA, BrT, ElC, OrH, Si, PuT, PrA.

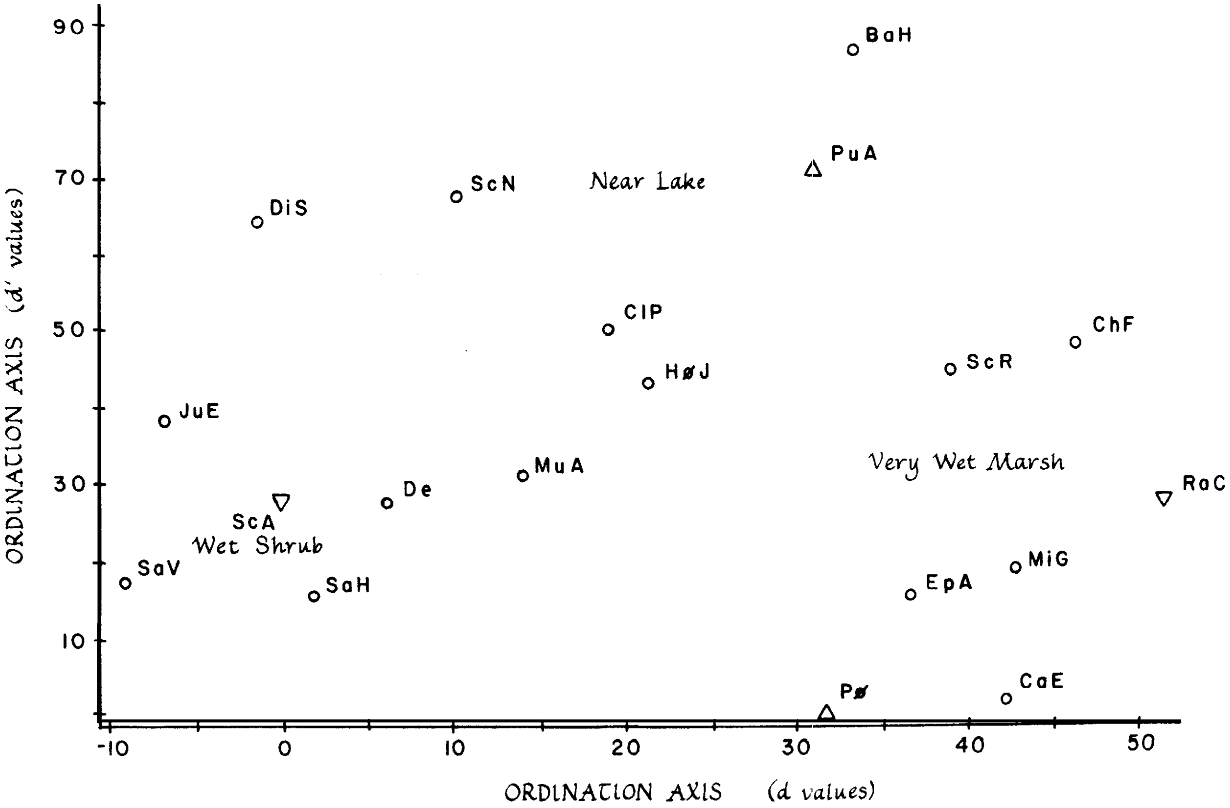

Figure 6-11. TWO DIMENSIONAL INDIRECT GRADIENT ORDINATION OF MARSH CLUSTER. The first axis is the axis of Figure 6-9. The second axis has Polypogon sp. (Po) and Puccinellia airoides (PuA) as endpoints. The species indicated by the square in Figure 6-9 are not included.

Table 6-12

CRITERIA FOR CLASSIFYING SAMPLE PLOTS INTO ASSOCIATION TYPES

Wet Marsh	Standing water from non-lake source or wet mud. Lush herbacious vegetation growth.
Transition Marsh/Dry	Areas lying geographically between wet marsh and near lake areas, with soil of variable moisture and containing species characteristic of each.
Near Lake Alkaline Flat	Dry or slightly moist, water availability greater than or equal to 3, non-shrub areas. Characterized by certain indicator species: Cleomella, Bassia H, Puccinella. Typical white alkaline crusted soil surface on unconsolidated mud.
Wet Shrub	Areas with greater than 5 percent shrub clover, typically moist soil and dense herb/grass layer.
Dry Open	Dry non-shrub areas. Distinguished from near lake by rarer occurrences of near lake species and by common occurrences of Salsola and Psathyrotes. Soil typically sandy or dry silts, not unconsolidated muds.
Transition Dry/Scrub	Dry areas with sparse l-5% shrub cover, shrubs usually less than average height. Dominated by dry open type species.
Dry Scrub	Areas with greater than 5% shrub cover, shrubs healthy, soil typically dry with water availability 4-5, herb/grass layer sparse.

Table 6-13

	Wet Marsh	Transition Marsh/Dry	Near Lake	Wet Shrub	Dry Open	Transition Dry/Scrub	Dry Scrub	Total
Deadwood				3	1		19	26
Cleomella parviflora	1	7	5		1			14
Bassia hyssopifolia		6	6		8			20
Salsola pestifera			1		10	2	9	22
Sarcobatus vermiculatus	1			5	1	1	10	18
Chenopodium fremontii	4	5	1					10
Artemisia tridentata				1	5	4	29	39
Chrysothamnus nauseosus		1	1	1	6	4	25	38
Chrysothamnus viscidiflorous						1	14	15
Psathyrotes annua			2		12		2	16
Scirpus americanus	11	8	2	9				30
Scirpus robustus	6	3						9
Scirpus nevadensis	4	14	7	1	4	1	3	34
Muhlenbergia asperifolia	8	2	2	7	3	1	4	27
Oryzopsis hymenoides					2	1	15	18
Polypogon spp.	6	2		3				11
Bromus tectorum			1	1	5	3	10	20
Distichlis spicata	3	14	9	5	17	5	18	71
Puccinellia airoides	6	9	7		3			25
Elymus cinereus						2	11	13
Hordeum jubatum	8	8	4	3	1			24
Sitanion spp.					1		8	9
Juncus effusus	4	1	2	4	2	4	6	23
Epilobium adenocaulon	8	2		4				14
Ranunculus cymbalaria	7	4		1				12
Salix hindsiana				6		1	7	14
Castilleja exilis	6	2		2				10
Mimulus guttatus	7			2				9
Prunus andersonii					1		8	9
Purshia tridentata							10	10
Number of Sample Plots	12	16	9	11	5	5	37	116

Table 6-14

ASSOCIATION MATRIX FOR ASSOCIATION TYPES

	Wet Marsh	Transition Marsh/Dry	Near Lake	Wet Shrub	Dry Open	Transition Dry/Scrub	Dry Scrub	TOTAL
Wet Marsh	****	20	11	26	8	6	6	
Transition Marsh/Dry	42.9 55.7	****	14	14	9	5	5	
Near Lake	66.2 71.6	40.4 32.4	****	9	12	7	8	
Wet Shrub	48.0 56.0	65.8 75.2	76.6 80.2	****	12	11	15	
Dry Open	80.0 89.9	71.0 72.0	57.9 62.3	73.9 85.0	****	13	27	
Transition Dry/Scrub	83.1 87.7	81.1 82.7	70.8 74.2	73.5 79.5	58.7 65.5	****	21	
Dry Scrub	89.4 93.2	89.5 89.7	82.2 84.0	76.0 79.0	48.6 63.2	56.2 48.1	****	
Total number of occurrences for all species in the association:	139	102	56	124	118	43	326	909
Number of species occurring in the association:	41	24	20	54	35	26	61	120
Number of sample plots in the association:	12	16	9	11	26	5	37	116

By consulting Table 6-13, the species on the plexus diagram can be roughly grouped into the association types. These groupings on the plexus diagram show a remarkable similarity to the positioning of the categories in the ordinate on Figure 6-15. This strengthens the validity of the categories.

A condensed version of the field data showing the Braun-Blanquet cover ratings for the 30 major species and the more important physical and physiognomic variables for all 116 sample plots is presented in Appendix 6-2. It also serves as a check on the association types.

Phase 2, Environmental Effects on Species Distributions:

Three physical variables: elevation above the lake level, soil pH, and soil conductivity, were most important in describing environmental differences between species distributions. Elevation above the lake, with knowledge of the historical lake level record, represents time since the area was exposed by the dropping lake. This relationship between elevation and time is illustrated in Figure 6-16. Elevation is the key variable in indicating rates of succession onto the newly exposed areas. Soil pH and conductivity represent the harshness of the soil, specifically the degree of alkalinity (the hydroxide ion activity) and salinity (the total ionic activity). Higher values for both variables indicate increasing harshness. By convention, the pH scale is logarithmic, and conductivity was found to give better separations when converted to the logarithm. In a logarithmic scale, an increase of one unit (e.g., from pH 8 to pH 9) represent a ten-fold increase in alkalinity.

The results are presented graphically with pairs of these physical variables representing the X and Y axes. For each pair, the Z axis represents either the association types or ground cover abundances of select species. The graphs are intended to show how distribution patterns are related to environmental gradients. This graphical approach to analysis has the limitation of presenting only two or three dimensions at a time to view. Ecological differences are multi-variate in nature. Advanced statistical techniques (e.g., factor analysis, and multiregression analysis) are available to handle this problem, but they are based on assumptions of linearity and normality. We did not feel that our data met these requirements. The graphs show only correlations to environmental gradients and do not show the causes or effects of environmental conditions on plant distributions. See Figures 6-17 through 6-23; the important results are summarized below.

Overall, the association types show a strong separation along the elevation gradient, indicating differential rates of succession. They show a weaker separation along pH and conductivity gradients. They are separated on the bases of water availability and depth to the water table (see Appendix 6-2), but trends along soil texture variables were not apparent.

The dry scrub association type occurs primarily at elevations greater than 45 feet (more than 50 years since exposure). It has large pH and conductivity variations which reflect a dominant species shift. Purshia tridentata occurs mainly in mild soils, Artemisia tridentata and Chysothamnus nauseosus in intermediate soils, and Sarcobatus vermiculatus in the most alkaline and saline soils. The rate of succession of these shrub species (indicated by the minimum elevation at which the species were found growing) is varied. ‘S. vermiculatus was observed with high cover (Braun Blanquet (BB) values of 4 and 5) at elevations of approximately 20 feet (time since exposure of 15 years) in the wet shrub areas on Paoha Island. In dry areas, it was found with high cover (BB values greater than 1) only at elevations greater than 49 feet (areas that have been exposed for unlimited time under the context of this study). C. nauseosus occurred with BB values of 3 at elevations of 30 feet (time since exposure of 25 years) in dry soils at the Simmon's Springs study site (P-8, Figure 1-1). Generally, however, this species and A. tridentata were found at recent elevations (elevations below 49 feet) only with insignificant covers (BB values of R and +). Commonly A. tridentata had sickly growth forms at low elevations. Pu, tridentata was not found at elevations below 49 feet.

The wet marsh association type was found mainly at low elevations, indicating a rapid rate of succession. It occupies the low pH and conductivity values over this elevation range. The transition marsh/dry and near-lake alkali mud flat association types occur over the same elevation range and commonly have large pH and conductivity values. These associations types typically precede the wet marsh association. Because the pH and conductivity values appear to drop along the transition from alkaline flat to wet marsh, the hypothesis

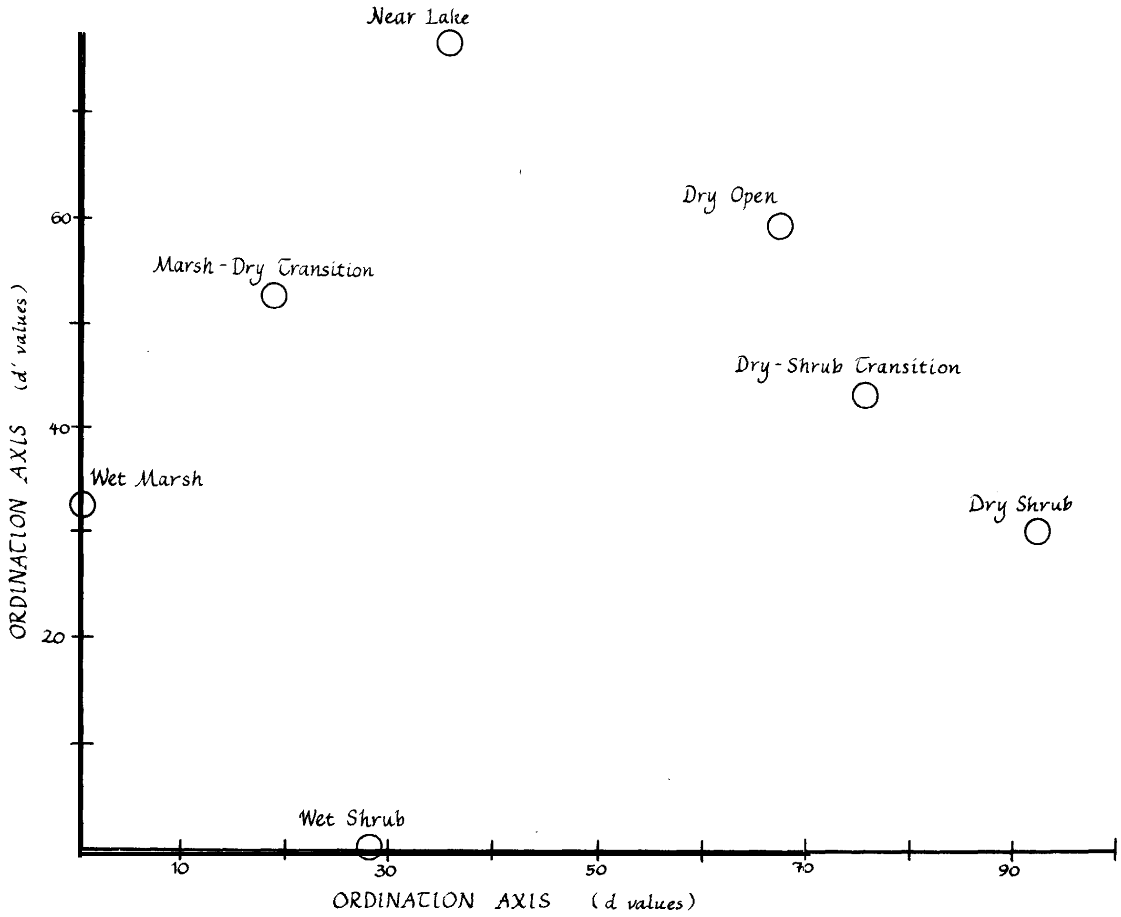

Figure 6-15. TWO DIMENSIONAL INDIRECT ORDINATION OF ASSOCIATION TYPES. Endpoints are Wet Marsh and Dry Scrub along the X axis and Wet Shrub and Near Lake along the Y axis. PD index was used to construct the ordination.

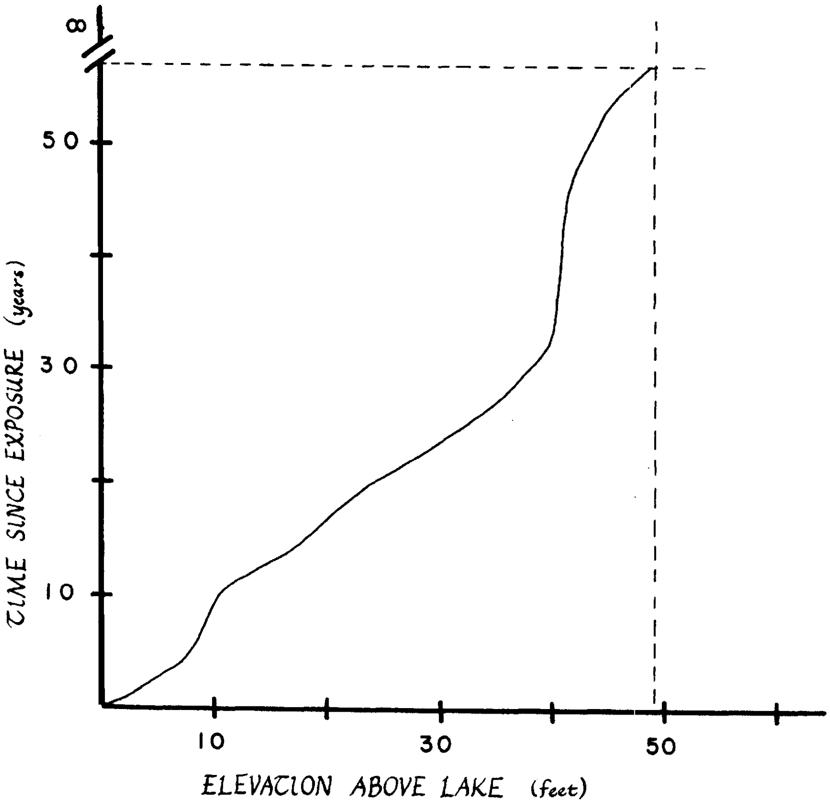

Figure 6-16. ELEVATION ABOVE THE LAKE vs TIME SINCE EXPOSURE CONVERSION GRAPH. Vertical dashed line at 49 feet indicates the highest point of recent lake fluctuation during 1919. Elevations above 49 feet indicate areas which have not been submerged during the past 200 years (Harding, 1962).

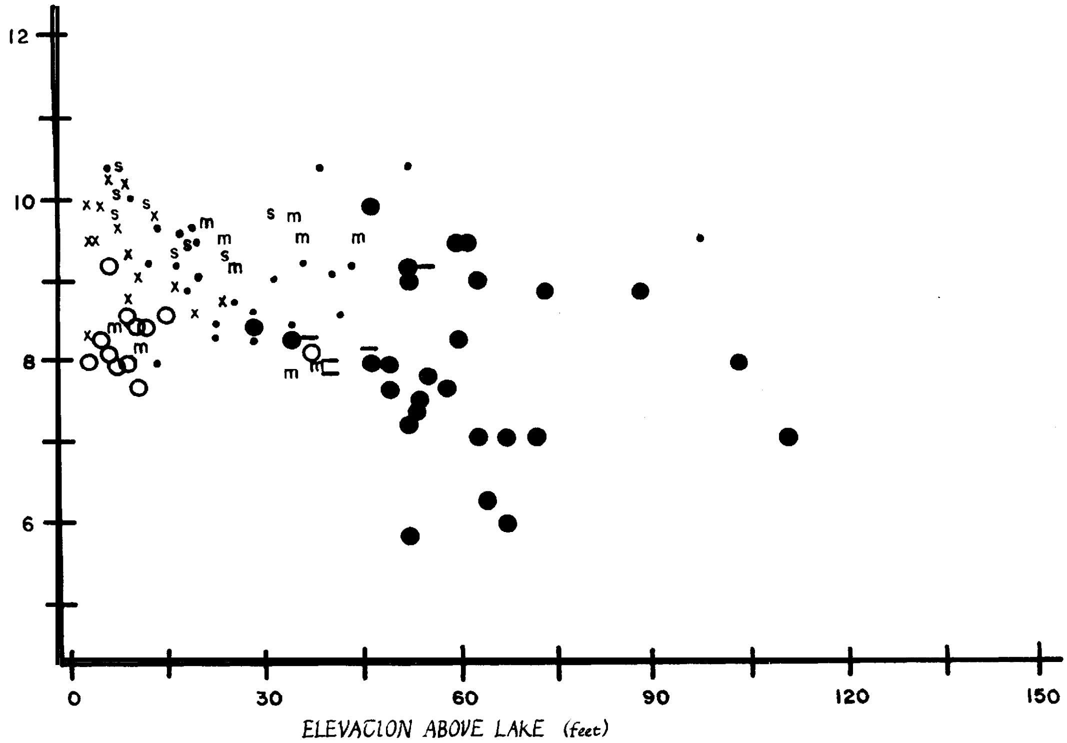

Figure 6-17. ELEVATION ABOVE THE LAKE vs SOIL pH, GROUPED BY ASSOCIATION TYPES. Codes for association types are:

open circle	Wet Marsh
X	Transition Marsh/Dry
S	Near Lake
m	Wet Shrub
dot	Dry Open
dash	Transition Dry/Scrub
solid circle	Dry Scrub

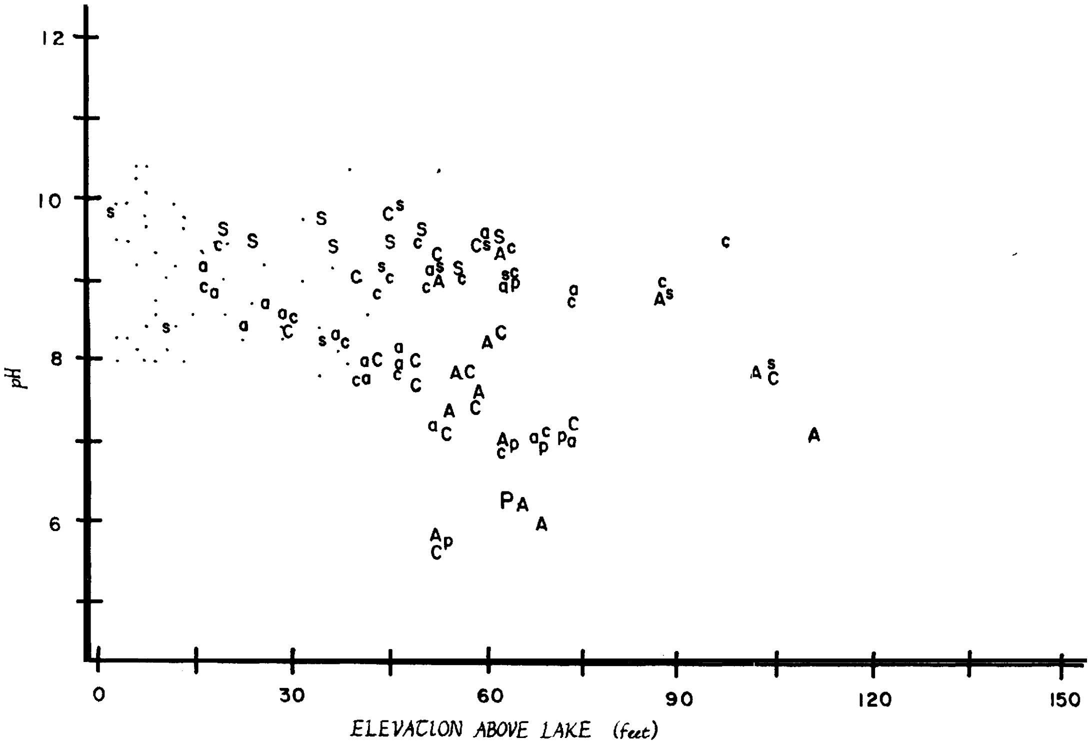

Figure 6-18. ELEVATION ABOVE THE LAKE vs SOIL pH, DISTRIBUTION OF FOUR SHRUB SPECIES: Sarcobatus vermiculatus (S), Artemisia tridentata (A), Chrysothamnus nauseosus (C), and Purshia tridentata (P). Capital letters indicate Braun-Blanquet cover values of greater than 1 (i.e. ground cover greater than five percent), and small letters indicate values less than or equal to 1. Dots indicate sample plots which do not have these species.

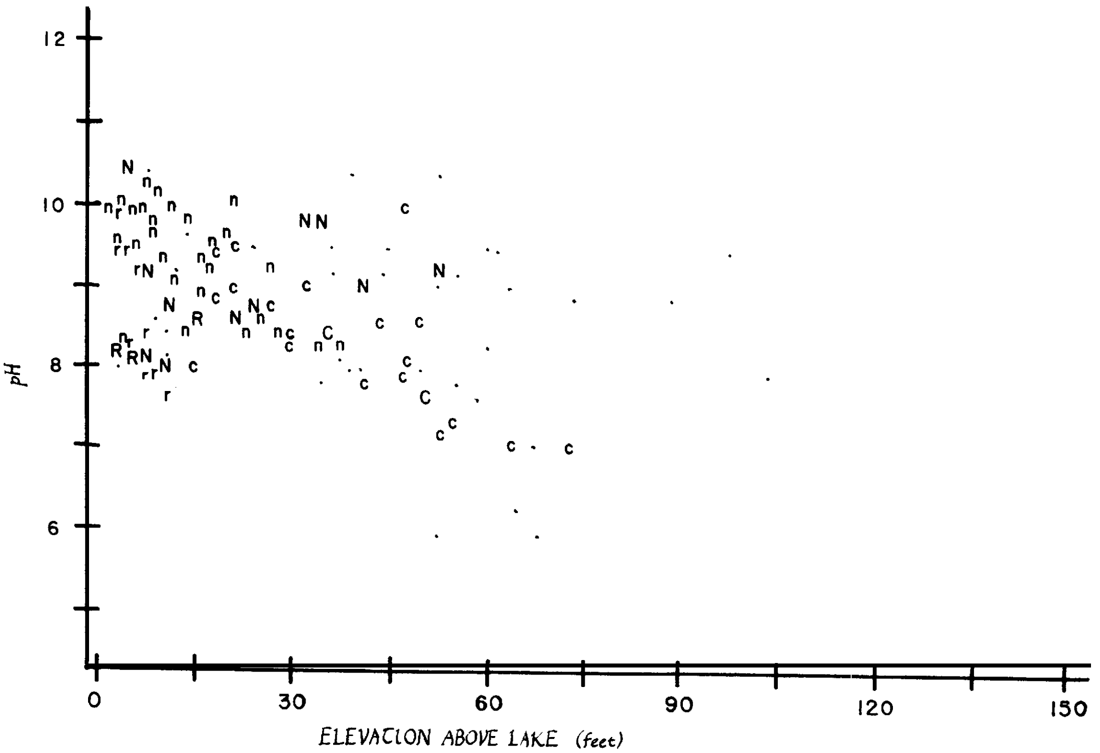

Figure 6-19. ELEVATION ABOVE THE LAKE vs SOIL pH, DISTRIBUTION OF Salsola pestifera (C), Scirpus nevadensis (N), AND Ranunculus cymbalaria (R). Codes as in ~~Figure 6-18.~~

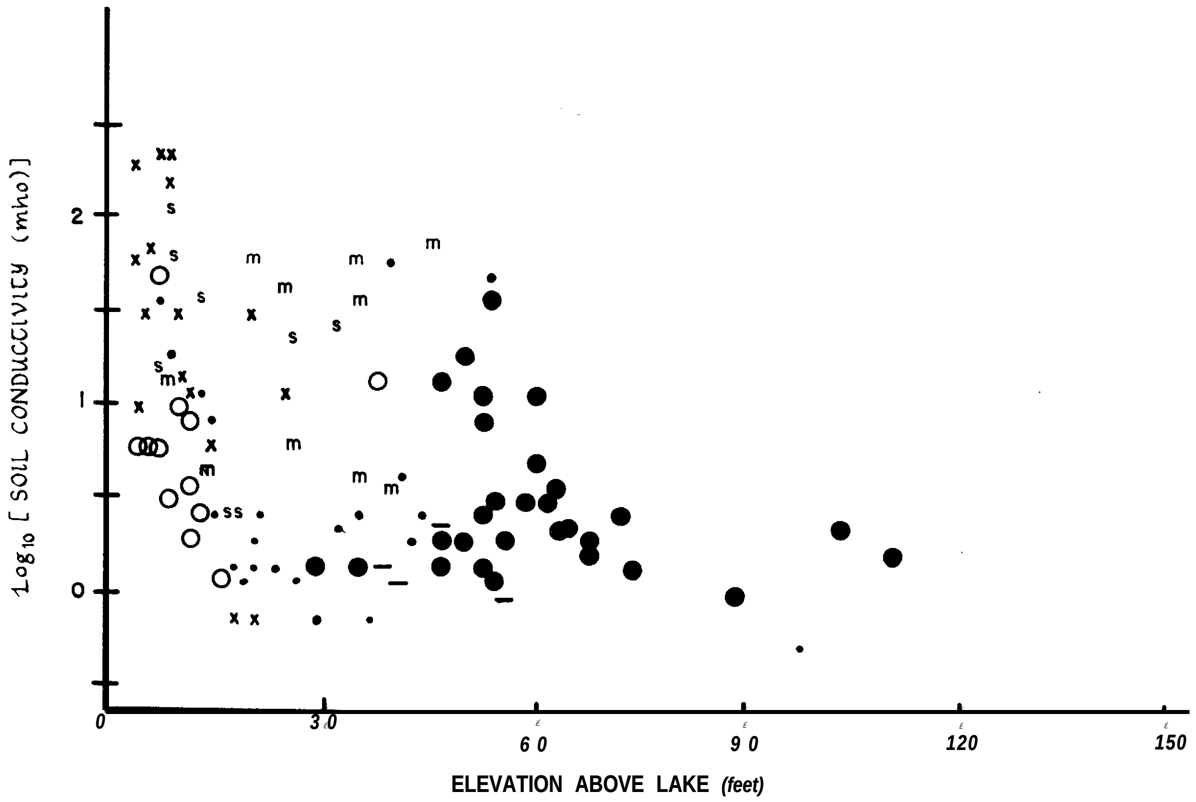

Figure 6-20. ELEVATION ABOVE THE LAKE vs Log_{10} OF SOIL CONDUCTIVITY, GROUPED BY ASSOCIATION TYPES. Codes as in Figure 6-17.

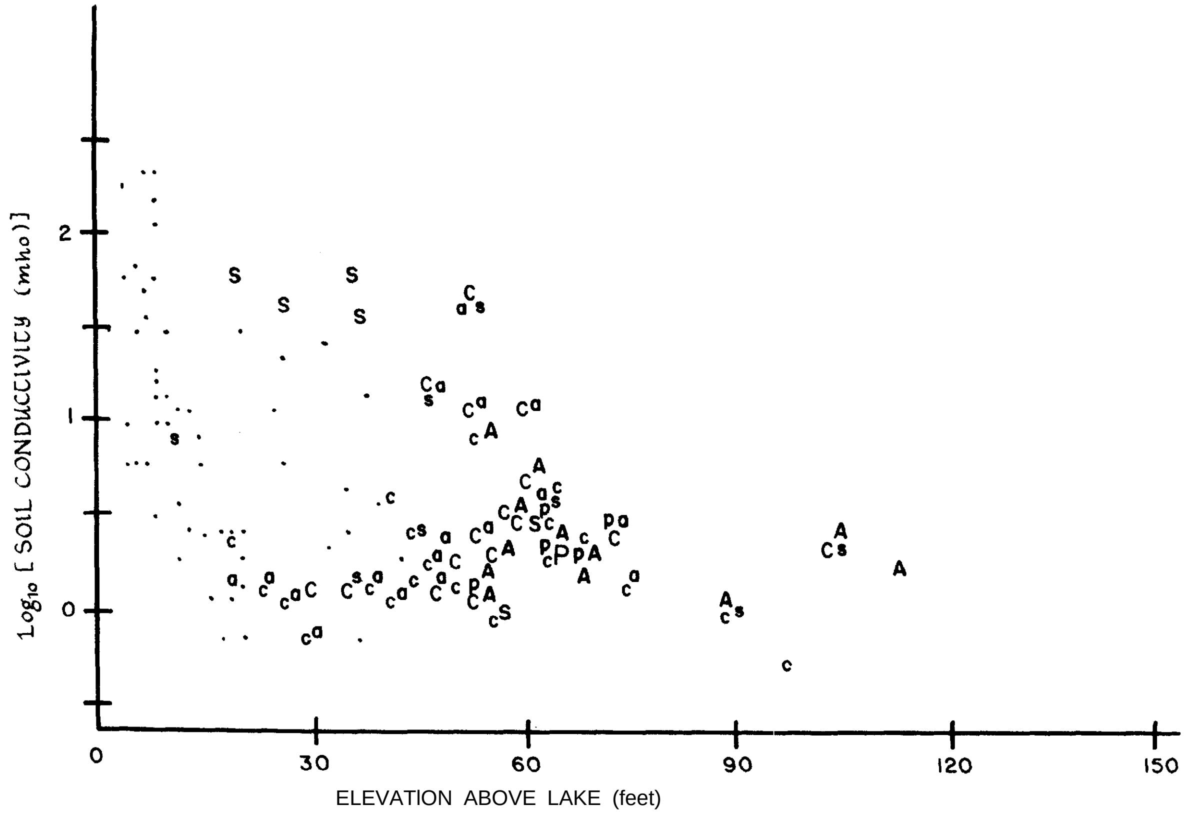

Figure 6-21. ELEVATION ABOVE THE LAKE vs Log_{10} OF SOIL CONDUCTIVITY, DISTRIBUTION OF FOUR SHRUB SPECIES. Species and codes as in Figure 6-18.

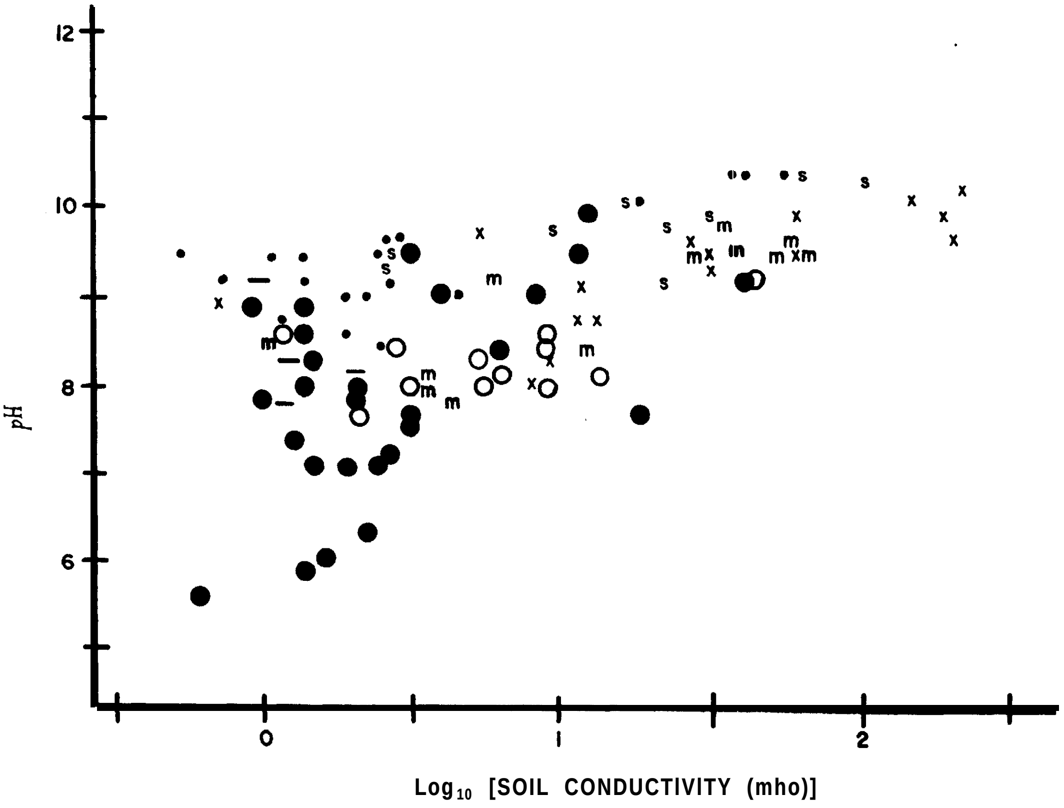

Figure 6-22. Log_{10} OF SOIL CONDUCTIVITY vs SOIL pH, GROUPED BY ASSOCIATION TYPES. Codes as in Figure 6-17.

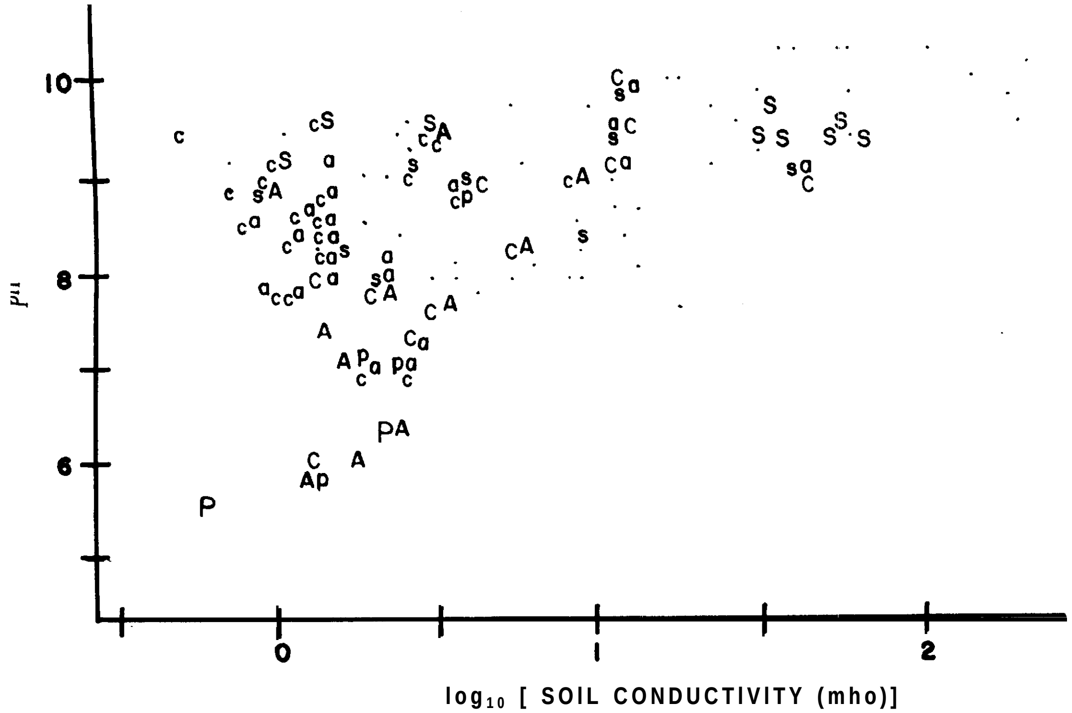

Figure 6-23. Log_{10} OF SOIL CONDUCTIVITY vs SOIL pH, DISTRIBUTION OF FOUR SHRUB SPECIES. Species and codes as in Figure 6-18.

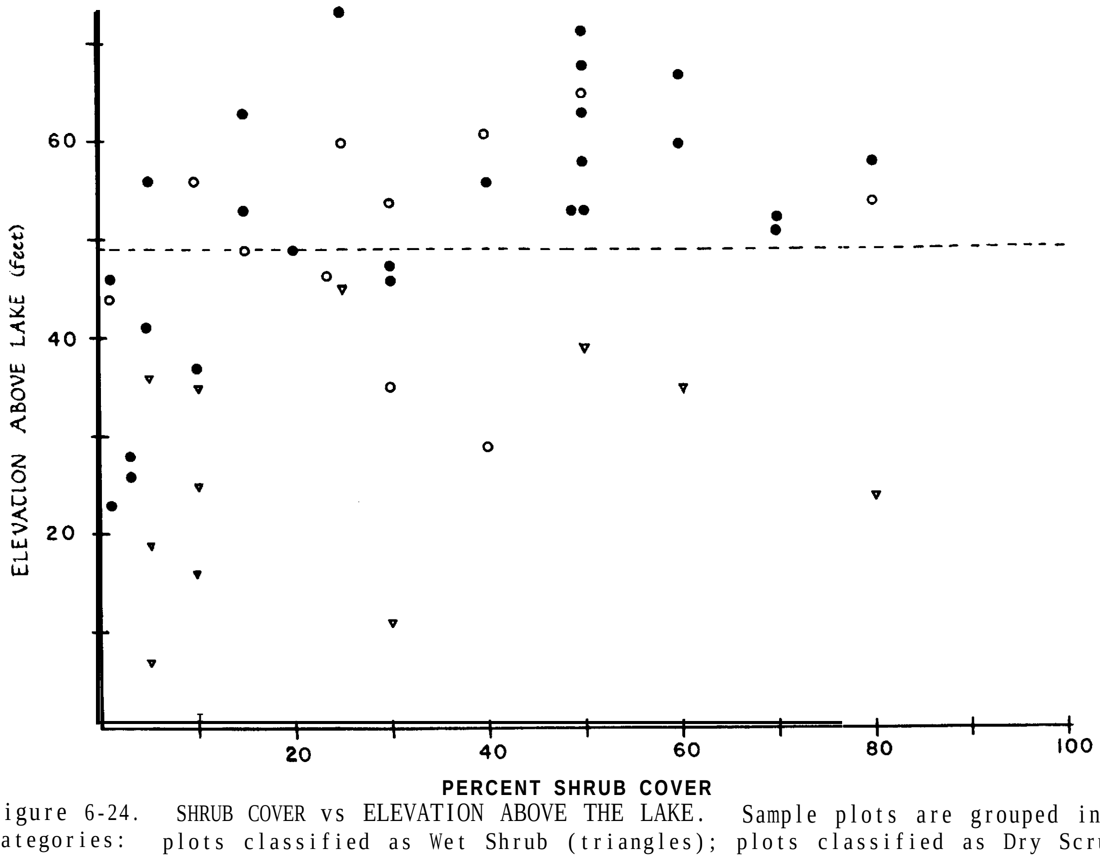

Figure 6-24. SHRUB COVER vs ELEVATION ABOVE THE LAKE. Sample plots are grouped into three categories: plots classified as Wet Shrub (triangles); plots classified as Dry Scrub in sites having near shore marshy areas; sites 7, 8, 9, 11, and 12 (open circles); plots classified as Dry Scrub in sites not having near shore marsh areas; sites 1, 2, 3, 4, 5, 6, and 10 (solid circles). Dashed horizontal line indicates highest point of recent lake fluctuation during 1919; see Figure 6-16.

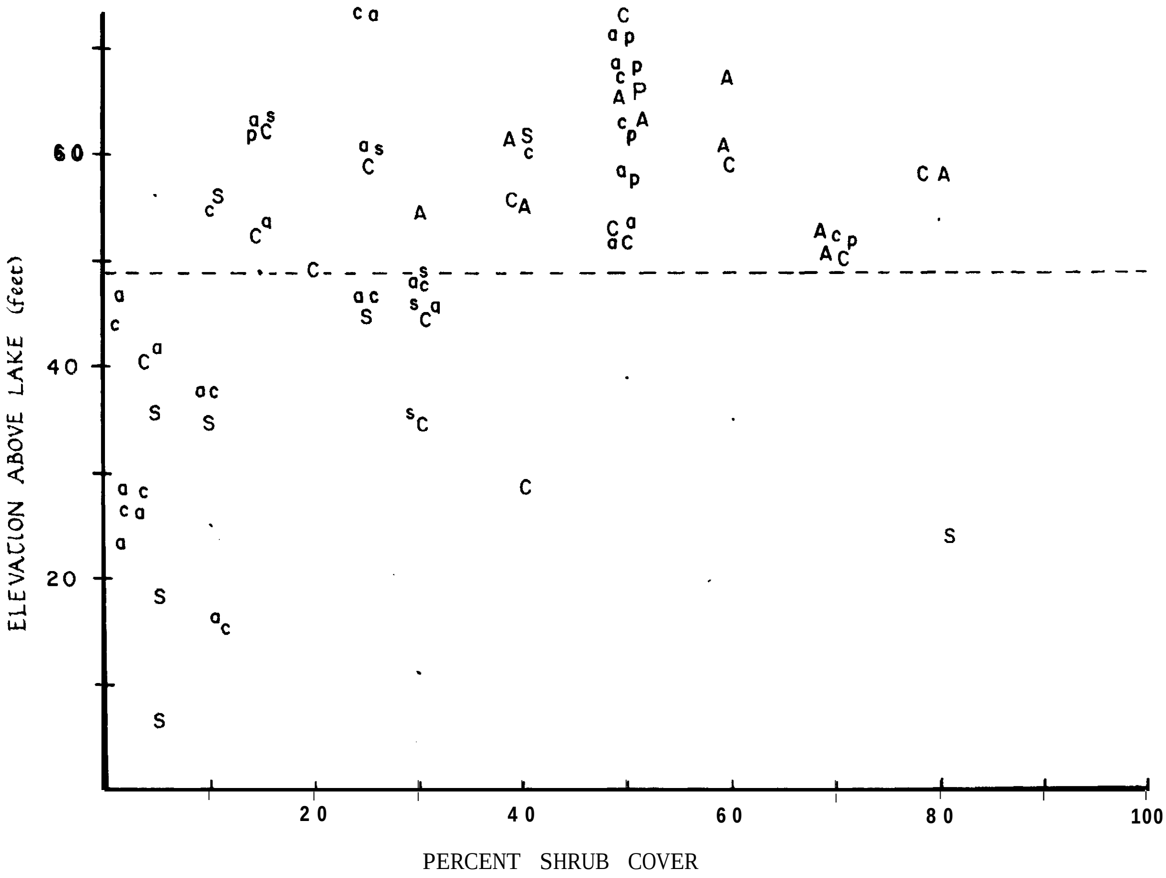

Figure 6-25. SHRUB COVER vs ELEVATION ABOVE THE LAKE, DISTRIBUTION OF FOUR SHRUB SPECIES. Species and codes as in Figure 6-18.

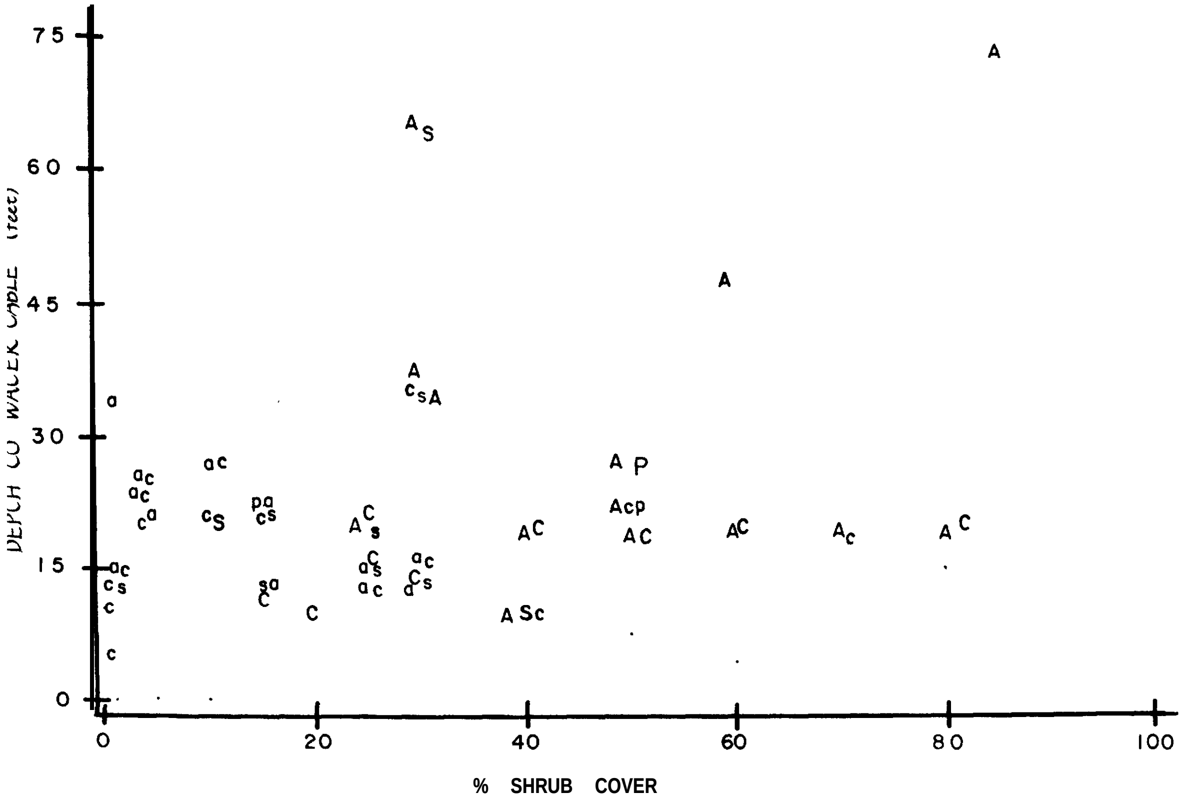

Figure 6-26. SHRUB COVER vs DEPTH TO WATER TABLE, DISTRIBUTION OF FOUR SHRUB SPECIES. Species and codes as in Figure 6-18.

is supported that the abundant water in the marsh leeches the salts and dilutes, creating a more favorable environment. This, in turn, could allow the lush growths of vegetation found in the marsh.

The dense vegetation of the scrub areas is efficient in minimizing dust. Graphs of elevation above the lake versus percent shrub cover of the study plots (i.e. the total percent of the ground covered by all shrub species) give an indication of the rate of shrub cover succession or the rate of soil stability (Fiqures 6-24 and 6-25). In wet areas, shrub succession composed of S. *vermiculatus* and Salix *hindsiana* is relatively fast, on the order of 15 to 20 years. In the dry areas, except for two points from Simmon's Springs with occurrences of C. *nauseosus*, the rate of shrub succession is slow. In Figure 6-24, few dry area points fall below the high water level of 1919, and those that do have very low percent shrub cover values. For practical purposes, the sharp shrub border discussed in the General Vegetation Description section represents this high water level. We are not sure what minimum level of percent shrub cover is needed to stabilize the soil to prevent dust. Note that dry areas dominated by S. *vermiculatus* usually have lower percent shrub cover values (Figure 6-25) and are mainly of fine-textured lake sediments. These shrub areas are commonly quite dusty. Probably a minimum of 30 percent shrub cover is needed for stabilization. Except for Simmon's Springs, no differences in the rate of dry shrub succession was noted in areas preceeded by marsh compared to those that were not. If leeching does occur as the marsh moves down following the lakeshore, the milder soils have little effect on dry shrub succession.

Figure 6-26 depicts the relationship of percent shrub cover versus depth to the water-table. Here our intention, assuming a healthy growth form indicates unlimited water, was to describe how deep shrub species could go to reach groundwater. With a dropping lake level, a (less drastic) lowering of the water table is expected and this could affect the vegetation in the Mono area. This question also is relevant to groundwater pumping in the Owens Valley. Water table data was collected only at half the study sites (sites 2, 5, 6, 7, 9, and 10) and is not conclusive.

PREDICTIONS AND CONCLUSIONS

Given the hydrological projections of Chapter 2 (as illustrated in Figure 2-22), large areas of lake bottom will be exposed during the next hundred years. The scrub border around most of the lake shore represents the high water level of 1919 (see Figure 6-24). With this level as a baseline (lake area of 56,500 acres), the exposed areas of 1976 (lake area of 41,200 acres) represent 15,300 acres, and at the stabilization level (lake area of 22,100 acres) the exposed areas will represent 34,400 acres, a 2.3-fold increase. This increase serves as a conservative approximation of the increase in the dust problem in the future.

Shrub colonization of exposed areas will be slow. From the historical lake level records, we have a forcasting range of 57 years (1919 to 1976). Shrub colonization will certainly take longer than this, but how much longer is not known (see Figure 6-16). The exposed areas will have a soil composition of lake sediments and wind-blown sands. In addition, these soils will be alkaline and saline (with high pH and conductivity values). The future exposed areas are expected to have a physical environment similar to those on Paoha Island and on the east side of the lake. If shrub colonization ever occurs on the exposed lake bottom, the shrub community will resemble those areas which are dominated by *Sarcobatus vermiculatus* (see General Vegetation Description section and Figures 6-18, 6-21, and 6-23).

The future of the marsh areas depends on the groundwater. With the dropping lake level and receding shoreline, the area of seepage of groundwater onto the exposed surface will follow the shoreline and will move inward towards the lake's center. The subsurface geological structure (see Figure 2-3) changes along this path, and the aquifer which transmits the groundwater eventually will be replaced by impermeable lake sediments. When this replacement occurs, the movement of the wet zone will stop.

Marsh species undergo rapid succession and will follow the movements of the wet zone (see Figures 6-17, 6-20, and 6-22). As the marsh moves, each area in the marsh will undergo the progression from extremely wet to drier conditions discussed in the General Vegetation Description section. The drier portion of the marsh will merge into the *Distichlis spicata* matted regions characteristic of the near lake non-vegetated areas. In fact, these mats occur above the marshes at Sites 7 and 8 and suggest the trend from marsh to dry. After the movement of the wet zone stops, the movement of the marshes will also stop.

Unless groundwater pumping reduces groundwater flows and thus jeopardizes the marshes, the marshes should continue to exist. With further drops in lake level, the new areas exposed between marsh and lake will have sparse vegetation cover and will resemble the rest of the lake shore. The final locations of groundwater seepage and marsh are unknown.

Most of the future exposed areas will resemble the near lake non-vegetated areas with their vast open alkaline mud and sand flats. The sparse vegetation does little to stabilize the fine-textured soils in these areas. The increasing dust storms resulting from this condition will affect areas both in and out of the Mono Basin. The effects of the alkaline dust storms originating from the dry Owens Lake bed south of Mono are seen over a wide range. Additional research is needed on the effects of this caustic and alkaline dust on vegetation.

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ACKNOWLEDGMENTS

To accomplish an ecological study of this magnitude in only three months of field work, we needed the help of many people. We especially thank the National Science Foundation for the opportunity to do this student-originated study (grant number 76-07730). We also thank our faculty advisor, Harold A. Mooney, and the members of our faculty review committee, Peter J. Richerson and Irwin Remson, for their support, advice, and knowledge. We are grateful for the efforts of Val Mallin and Virginia Hoffmeister in maintaining our standing with the Stanford administration. We are indebted to the Biology Department of Stanford University for the use of laboratory equipment. We especially thank Sydney Burkhart, Assistant Dean for Research, Stanford, for her help in obtaining computer funding and Geoffrey Wandesforde-Smith and the Institute of Ecology, U. C. Davis, for publishing this report. We thank Wanda Greene for typing the manuscript.

H. Craig Heller's comments and encouragement during the grant writing phase were invaluable. We are grateful for the support and interest, over the course of the summer, of the people who live in Mono Basin. We thank Enid A. Larson, Andrea Lawrence, Sarah Geisen, Derham Guiliani, Mary DeDecker, and Tom Heindel. We are indebted to Charlie Simis for his support and for the use of his laboratory facilities at Lee Vining High School, and to Richard Hubbell for his transportation to the hard-to-reach east side of Mono Lake. We also thank Grady Burch, Jamie Grodsky, and David Gaines for assistance in our field operations.

We especially thank the Los Angeles Department of Water and Power. Their long-term measurements provided most of the raw data upon which the hydrologic model is based. In addition, members of the Department, Mr. Mel Blevins and Mr. Duane Georgeson, freely gave their time in answering technical questions. Mr. Ken Lajoie gave much needed advice concerning the geology of the basin. We also thank Professor Irwin Remson, advisor for the project, and the Stanford Department of Geophysics for the use of the Bison Seismograph. Keenan Lee generously supplied the data from his thesis on the Basin. Cyrano Heathcliff provided much needed transportation to those of our group working on the geology and hydrology of the basin.

We are indebted to Warwick Vincent for providing advice, assistance, and encouragement. We found discussions with Rod Hoffman, Bruce Kimmel, Tim Kittel Rick Gersberg, Garth Redfield and Rich Axler concerning field and laboratory techniques helpful. We appreciate Matilde Lopez' advice on the taxonomy of phytoplankton species. Tim Hansen, Dale Steele, and Grady Burch assisted us in the more mechanical aspects of the field work. We appreciate the advice offered by Evelyne de Amazaga on matters concerning Carbon-14 and the time Don Payne and Sherry1 Paulson spent in analyzing the C filters. We thank Dr. Peter J. Richerson for his suggestions and support throughout the project and for the use of various pieces of equipment. We are extremely grateful to the following people and institutions:

> John Gebel of Jungle Laboratories for allowing us to use the brine shrimp dock and for helping us when our motor chose not to work.
>
> Daniel Veroujean and The Departments of Wildlife and Fisheries (U.C. Davis) for the use of their motor.
>
> The Zoology Department (U.C. Berkeley) and Sagehen Creek Field Station for the use of their boat.
>
> Virginia Hoffmeister of the Biology Department at Stanford University for her efforts to order our equipment.
>
> The Division of Environmental Studies (U.C. Davis) for the use of lab facilities and equipment.
>
> The Institute of Marine Biology (U.C. Santa Barbara) for the use of the Sierra Nevada Aquatic Research Laboratory, with special thanks to Bill Seale.

Dr. A. A. Grigarick of the U.C. Davis Department of Entomology for assistance and use of microscopes in the identification of insect specimens.

We are indebted to the following people for lending us valuable equipment: the Weigens, Gaines', and Toni Fratzke. We would especially like to thank Jan Simis who allowed us to set up our summer camp on her land and Pat Kelly who played an important part of introducing us to the waters of Mono.

Among the many who helped us conduct all-lake censuses we thank Grady Burch, Dave Gaines, Richard Hubbell (USFS), Dale Steele, and Gary Colliver and the biologists from Slate Creek.

We would not have been able to complete the censuses if it had not been for the canoes that Steve Strand and David Gaines lent us.

Conversations with Richard Stallcup and Gary Page served as a continuous source of encouragement and information. Ronald M. Jurek (California Department of Fish and Game) and Tom Heindel provided essential data and advice.

We thank Dr. Ned K. Johnson, at the Museum of Vertebrate Zoology, University of California, Berkeley, and Dr. Marshall A. Howe and Dr. Roger Clapp, at the U. S. National Museum of Natural History, Washington, D.C. for making available to us all the materials under their care.

We thank D. W. Taylor for suggestions he made during the initial stages of the field portion of the study, for allowing us to use his dissecting scope, and for helping us identify species. We also thank Mary DeDecker and R. S. Ferrus for their work in checking and correcting species identifications. We are indebted to Dr. John H. Thomas for the final review of species identifications and for the inclusion of our collection in the Dudley Herbarium at the California Academy of Sciences.

This study was funded in full by the Student Originated Studies Program of the National Science Foundation.

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APPENDIX 2-1

A WATER BUDGET AND ENERGY BUDGET FOR MONO LAKE

by: H. Keith Otsuki

INTRODUCTION

One of the processes that any model for the stabilization of a non-steady state lake must deal with is evaporation. It is not easy to determine at what rate the water is evaporating. There are numerous different methods for calculating evaporation from a variety of different types of data. Each of these methods have both advantages and weaknesses. The most common method used has been a water budget with simplifying assumptions. Most of the values calculated in this manner have been about 1 m/year (39-in/year). Another method used was the energy balance. Mason used an energy balance method to calculate an evaporation rate of about 2 m/year (78 in/year)[8], and with a mass flux calculated he arrived at a rate of 1.3 m/year (51 in/year). A calculation using evaporation pan data from Grant Lake (LADW&P) calculated a value of 1.2 m/year (47 in/year).

Clearly, the range of values is quite large. Since Mono Lake is a closed basin, evaporation is one of the major terms of the water budget. Because the stabilization model is based on the water budget, the choice of evaporation rate is important.

The relative strengths and weaknesses of the various methods is an important consideration in choosing between the results of the different calculations. The use of evaporation pan data measures evaporation directly; however, the pan evaporation must be related to evaporation from the lake by pan coefficients. These coefficients are functions of the lake's size, altitude, and the frequency and strength of the wind. The coefficients must be calculated with empirical formulas. The theory behind energy budgets is very strong, and no major assumptions are required, but the number of different measurements needed tends to create large errors. The mass flux method requires very few types of data, but it is a relatively new method and is empirical in nature. The water budget's strength lies in its requirements for few measurements and its past reliability. Its major problem is that assumptions must be made to account for inflows of water which cannot be measured.

The evaporation rate will be calculated here using three of the methods mentioned above: the water budget, the energy budget, and the mass flux method. (The paper will roughly be organized in the following manner:

1) the procedures used in making the measurements,
2) the data,
3) the energy budget and calculations,
4) the water budget and calculations,
5) the mass flux and calculations,
6) the discussion.)

METHODS

Air Temperature and Wind Speed

The wind and temperature data were both taken at the same elevation, about 2 meters above the mean water level. The station was located on a small flat island just west of Paoha Island. The reasons for choosing this particular island were its very low profile and its proximity to open water to the south and west. The low profile disrupts the wind patterns (predominantly from the southwest) the least The station was set up so that the wet and dry bulb temperatures were recorded on one chart and the wind speed on another. The temperatures were read off the charts with the use of a HP model 981OA calculator and model 9864A digitizing table, while the wind speed data were counted by hand. The temperature data is accurate to about 0.5°C (about the thickness of the pen lines). The accuracy of the wind data (ca. 5%) was limited only by the accuracy of the clock and the eye of the person counting the chart. The wind and temperature values that will be used in the calculations were time-averaged from the 29 days of available data.

The humidity e_a, was calculated from the wet and dry bulb temperatures using the equations in Hess[3]. The surface humidity, e_s, was taken to be the equilibrium vapor pressure at the surface temperature.

Lake Level Variations

The variations in the water level of the lake were measured from a measuring stick placed in the lake by the Los Angeles Department of Water & Power. Measurements were taken on calm mornings with a spotting scope from shore.

Thermal Data- Lake

Water temperatures in the lake were taken at one meter intervals regularly throughout the summer. Temperatures were taken on samples collected with a Van Dorn water bottle. Six stations were used in order to get a reasonable representation of the lake. The measurements from these stations were averaged. The temperature difference over time was then integrated with respect to volume using a hypsographic curve of the lake and a trapezoidal approximation. The remaining volume of the lake was taken to have a 2°C temperature difference.

Surface Inflows

Surface inflows were measured by the time it took for a floating object in the stream to travel a given distance. The distance traveled per unit time by the object was taken to be the average velocity of the stream. Cross-sectional area was also measured. The locations for making the measurements were chosen by the following criteria:

1) stream lines were relatively straight,
2) the velocity appeared constant over the entire region,
3) the creek width was constant,
4) the creek depth was fairly uniform and constant.

The length of the object's timed run was measured along with the width and average depth at both the beginning and the end. Average depth was found by measuring the depth at constant intervals across the creek at both ends of the object's timed run. Measurements were made 3-7 times depending on the width of the stream. The accuracy of the flow measurements was taken to be 15% due to errors in the measurements and our inability to measure the flows more than once during the summer.

Radiation

The radiation can be divided into three different types: solar radiation (shortwave), grey-body radiation (long wave), and back radiation (long wave). The solar radiation was measured directly using a bimetallic pyranograph (pyroheliograph). The pyranograph was calibrated at U. C. Davis before its use, but instruments of this type are typically only accurate to 5-10 percent. Ten percent accuracy will be used in all calculations. The strip charts were read with the use of an HP model 9810A calculator and model 9864A digitizing table.

Both the grey-body and the back radiation values were calculated. The equation used to calculate the grey-body radiation is one which has been used commonly in the past with good results:

$$Q_b = E\sigma T^4$$

where T is the absolute temperature, is the Stefan-Boltzmann constant (1.17×10^{-7} cal/cm^2 day°K^4), and E is the emmissivity of water (0.97). The back radiation was calculated using both the Angstrom equation and the Brunt equation. E, σ, and T for these equations are the same as those used for the grey-body radiation. The "e" found in these equations is the absolute humidity (e_a).

DATA

Wind and Temperature

wet bulb: $T_w = 19 \pm 0.5°C$

dry bulb: $T_a = 21 \pm 0.5°C$

water surface temperature: $T_s = 22 \pm 1°C$

wind speed: u = 9.4 mi./hr. = 4.2 m/sec.

pressure: P = 800 mb. = 600 mm Hg

e_a = 20.7 mb. = 15.5 ± 1 mm Hg

e_s = 26.8 mb. = 20.1 ± 1 mm Hg

data taken 2 m. above the mean lake level

Lake Level

H_1 = 6378.15 ft. June 24, 1976

H_2 = 6376.48 ft. September 3, 1976

At = 70 days

Δs_w = 0.286 in./day = 0.727 cm./day

Inflows

known spring source: I_s = 576 l/sec. = $4.98X10^4$ m^3/day

creek source: I_c = 77 l/sec. = $6.65X10^3$ m^3/day

total measured: I_t = $5.65X10^4$ m^3/day

rainfall: I_r = 5 cm. = 0.07 cm./day

Thermal Data - Lake

T_1 : data taken July 7, 1976

T_2 : data taken September 1, 1976

At = 56 days

remaining volume = $2.65X10^8$ m^3

assume $\Delta T = 2°C$

AS = 59.2 cal/cm^2day

DATA - Thermal Data - Lake

z (m)	T_1 (°C)	T_2 (°C)	ΔT (°C)	Δz (m)	A (10^7 m^2)
0	19.6	22.4	2.8	0.5	16.9
1	18.7	20.6	1.9	1.0	16.7
2	18.6	19.8	1.2	1.0	16.3
3	18.6	19.0	0.4	1.0	15.3
4	18.4	18.4	0.0	1.0	14.9
5	18.2	17.9	-0.3	1.0	14.1
6	18.0	17.6	-0.4	1.0	13.5
7	17.4	17.4	0.0	1.0	12.8
8	17.1	17.2	0.1	1.0	12.5
9	16.5	16.9	0.4	1.0	12.2
10	16.0	16.6	0.6	1.0	11.7
11	15.0	16.3	1.3	1.0	11.5
12	13.8	16.2	2.4	1.0	11.1
13	12.0	16.0	4.0	1.0	10.8
14	11.1	15.8	4.7	1.0	10.3
15	9.8	15.6	5.8	1.0	9.87
16	9.7	14.8	5.1	1.0	9.39
17	8.6	13.4	4.8	1.0	8.94
18	8.3	12.0	3.7	1.0	8.42
19	8.0	11.0	3.0	1.0	7.93
20	7.5	10.7	3.2	1.0	7.45
21	7.3	10.3	3.0	1.0	6.64
22	7.3	9.8	2.5	1.0	6.35
23	7.3	9.7	2.4	1.0	5.95
24	7.3	9.7	2.4	1.0	5.26

DATA - calculations

Radiation

$Q_s = 900 \pm 90$ cal/cm^{2}day

$Q_b = \Sigma\sigma T^4$

$= 886$ cal/cm^{2}day

Angstrom Equation

$Q_a = \Sigma\sigma T^4(A-B\ \exp(-2.3\ C\ e)$

$A = 0.820$

$B = 0.250$

$c = 0.094$

$Q_a = 700$ cal/cm^{2}day

Brunt Equation

$Q_a = \Sigma\sigma T^4(A+B\ e)$

$A = 0.605$

$B = 0.048$

$Q_a = 720$ cal/cm^{2}day

We will use $Q_a = 710$ cal/cm^{2}day

Bowen's Ratio

$$B = 0.49\ \frac{P\ (T_s-T_a)}{760\ (e_w-e_a)}$$

$B = 0.084$

ENERGY BUDGET

Energy budgets are based on the concept that energy is conserved. The terms of the energy budget represent the incoming, outgoing, and net gain or loss of energy. The equation for the energy budget can be written:

$$\Delta s = R + A - H - LE,$$

where S is the change in the energy stored in the lake as heat, R is the net radiation into the lake, A is the advected energy, H is the heat conducted out of the lake, L is the latent heat of vaporization, and E is the evaporation out of the lake.

The advected energy, A, can be expressed as;

$$A = I\ C_v\ \Delta T$$

where I is the flow of water into the lake, C_v is the specific heat of water, and T is the difference in temperature between the inflowing water and the volume average temperature of the lake. If I use order of magnitude comparisons of advection with evaporation (LE), I find that C $\Delta T \ll L$ and so $A \ll LE$ ($I = E$, and $\Delta T \leq 10°C$). Advection can therefore be ignored.

The heat conducted, H, is usually assumed to be related to the evaporation, LE, by Bowen's ratio, B.

$$H = B(LE), \text{ where } B = 0.49\ (P/760)\ (T_s-T_a)/(e_w-e_a).$$

Our calculated Bowen's ratio was B = 0.084.

The radiation term, R, was broken into three terms,

$$R = (1-r)\ (Q_S+Q_a)-Q_b$$

where Q_s is the incoming solar radiation, Q_a is the atmospheric back radiation, Q is the gray-body radiation, and r is the fraction of the incident light that is reflected. The values used for Q_s Q_a , and Q_b are given in the data and explained in the procedures. The value for r that we will use is 0.07.

In order to handle the storage term,, ΔS, I must make certain assumptions, since the absolute amount of energy stored is given by:

$$S = \int C_v T dV$$

The assumptions that we made were:

1) C_v is constant,

2) the integral can be approximated by using a rectangular approximation,

3) the temperature at the midpoint of the rectangle for integration is representative of the whole rectangle.

This yields:

$$S = C_v\ \Sigma\Delta T_i\ \ \Delta V_i$$

Since Vi was kept constant, I can write the change in the heat storage as:

$$S = C_v \Sigma\Delta T_i\ \ \Delta V_i$$

This gives an energy budget equation that looks like:

$$c_v\ \ \Sigma\Delta T_i\ \Delta\ V_i = (1-r)(Q_s+Q_a) - Q_b - (1+B)LE;$$

which yields:

$$E = 0.853 + 0.18 \text{ cm./day}$$

as the average evaporation over the summer.

WATER BUDGET

The water budget is analogous to the energy budget, except I keep track of the amount of water, rather than energy entering, leaving, and remaining in the lake. Because Mono Lake is a closed basin, the equation for the water budget is simply:

$$\Delta S_W = I/A - E$$

where I is the volumetric flow of water into the lake, A is the surface area of the lake, E is the water leaving the lake per unit area through evaporation, and ΔS_W is the change in the volume of the lake divided by the surface area. For small changes in the lake level we can approximate ΔS_W as $\Delta\ h/\Delta t$.

The inflow term, I, was broken into three terms, so that;

$$I = I_t + I_r A + I_n$$

where I_t is the total measured flow of water into the lake, I_r is the water entering the lake as direct precipitation, A is the surface area of the lake, and In is the unmeasured flow of water into the lake. Since In is not known, the water budget cannot be solved directly for evaporation, but by neglecting I, we can calculate a minimum value:

$$\Delta S_w = I_t/A + I_r - (E - I_n/A)$$

The calculation yields.

$$(E - I_n/A) = 0.834 \text{ cm./day}$$

as the minimum amount of evaporation that took place.

MASS FLUX

The mass flux calculation uses an empirical equation relating the evaporation rate to its driving force. The relations used are two-parameter forms of the Dalton Evaporation Equation:

$$E = (A+Bu)\,\Delta e,$$

where A and B are the adjustable parameters, u is the wind speed, and Δe is the absolute humidity difference between the water surface and a height 2 m. above the surface. The driving force for evaporation is represented by Δe.

Air at the surface is assumed to be saturated with water vapor. It is also assumed that the vapor pressure depression due to the presence of salts is negligible. The humidity at 2 m., e_a, was calculated from wet and dry bulb temperatures.

The equation parameters, A and B, vary in value from one data set to another. The values that we will use are summarized in the following chart:

~~Source~~	~~A (10^{-7}cm sec.$^{-1}$mb^{-1})~~	~~B (10^{-9}mb^{-1}~~)
Jackman *	2.70	0.831
Kohler (1954)	0.608	1.42
Meyer (1942)	0.313	0.868

* unpublished

Estimates of evaporation result as follows:

Jackman

$$E = (5.348\ 10^{-2}\text{cm/mb.day})\Delta e$$

$$E = 0.326 \text{ cm./day}$$

Kohler

$$E = (5.678\ 10^{-2}\text{cm/mb.day})\Delta e$$

$$E = 0.346 \text{ cm./day}$$

Meyer

$$E = (3.421\ 10^{-2}\text{cm/mb.day})\Delta e$$

$$E = 0.209 \text{ cm./day}$$

DISCUSSION

From the water balance calculation, the evaporation rate off the lake apparently cannot be less than 0.834 cm/day and is probably not more than about 0.9 cm./day. I will use the former value as the most probable and compare it with my other calculations of evaporation.

The energy balance value compares very well with the water balance value, 0.853 cm./day to 0.834 cm./day. The main problem with this calculation is that the experimental error is so large. In order to make the calculation three or four measurements are required, and the error of each measurement accumulates as it is carried through the calculations.

The third calculation used a mass transfer equation, a form of the Dalton equation. The formula is empirical, and the values calculated by this method are lower than those resulting from the other two calculations based on theory. The reason for this discrepancy may be inaccuracies in the humidity data. The instrument we used to measure the wet bulb temperatures relies on the wind for proper ventilation. During periods of calm, humidity readings were higher than the actual humidity. Our calculated evaporation may therefore be too low.

In order to compare my values with the values in the literature, I must somehow extrapolate our two month's data to an annual evaporation rate. According to Mason's histogram of monthly evaporation, 30% of the evaporation from Mono Lake occurs during the months of July and August. This leads to an annual evaporation rate of about 1.7 m./year. This value is higher than those from most other calculations. The only higher value I have found, 2.0 m./year, is from Mason's heat budget. (Mason discounted this value as being unreasonably high). Most values based on water budgets are around 1.0 m./year (39 in./year). Certainly there are reasons for considering my calculation less than perfect, the major of these being:

1) small data base,

2) data collected during a drought.

Whether these circumstances account for the discrepancy in values is difficult to determine. In view of these considerations my extrapolation seems questionable.

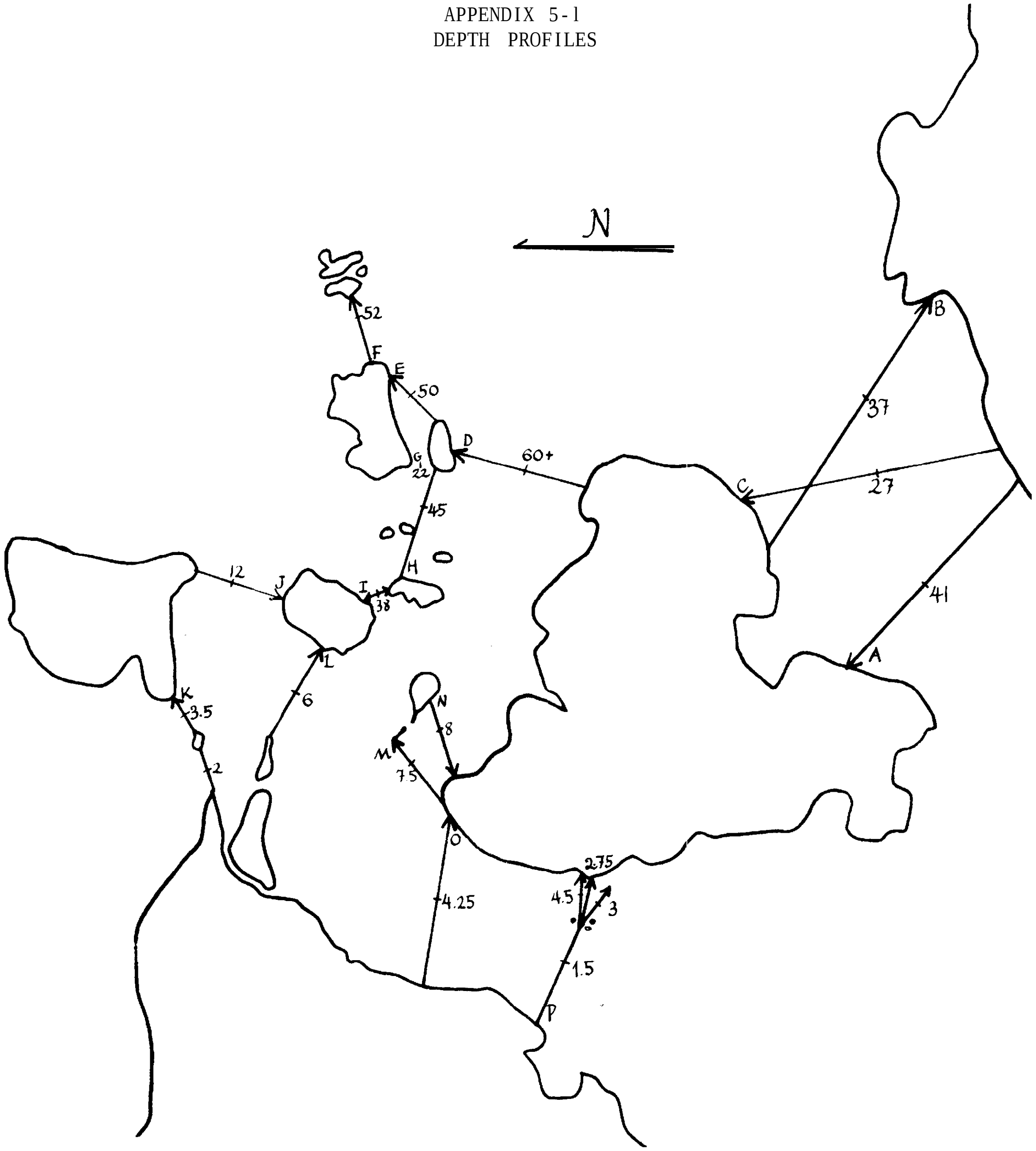
FOOTNOTES

1. S. T. Harding, 1935 Changes in lake levels in the great basin area, Civil Eng., 15:87-92.
2. S. T. Harding, Recent variations in the water supply of the western Great Basin (Water Resources Center Archives, Univ. of Cal., Archives Ser. Rept. No. 16), p. 226.
3. Seymour Hess, 1959 Introduction to Theoretical Meteorology (Holt, Rinehart, & Winston) pp. 59-62.
4. M. A. Kohler, 1954 Lake and pan evaporation, Water-off investigations, Lake Hefner studies, technical report, U. S. Geological Survey Professional Paper 269, pp. 127 - 148.
5. David T. Mason, 1967 Limnology of Mono Lake (Univ. of Cal. Press, P. 19.
6. Ibid p. 24.
7. Ibid p. 26.
8. Ibid p. 54.
9. A. F. Meyer, 1942 Evaporation from lakes and reservoirs, Minnesota Resources Commission Bulletin.

ACKNOWLEDGEMENTS

I would like to thank those people without whose assistance and/or consultation this report would have been more difficult, if not impossible. I would especially like to acknowledge the assistance of Thomas Powell (Division of Environmental Studies, UC Davis) and Alan Jackman (Department of Chemical Engineering, UC Davis). Thanks also go to Jerry Hatfield and L. 0. Myrup (Department of Atmospheric Sciences, UC Davis), Peter Richerson (Division of Environmental Sciences, UC Davis), and the people of Lee Vining, Ca. for their patience and helpfulness.

APPENDIX 5-1
DEPTH PROFILES



To determine the maximum depth of water at any one crossing between the islands and the mainland, imaginary transects were extended across each channel and perpendicular to each shoreline. Depths were taken in feet while proceeding across the channel. Only once did the depths of a channel exceed the limit of our scaled depth line, 60 feet. The transect routes and the deepest depth recorded along each crossing are diagrammed below.

When the shallowest "bridge" across any one channel could not be determined visually from the surface, transect courses were chosen at random. The depth profiles obtained in these cases only represent the shallowest pathways we found between the islands and the mainland. It is entirely possible that shallower "bridges" exist.

APPENDIX 6-1

DETAILS OF FIELD TECHNIQUES FOR PHYSICAL FACTORS IN PLANT STUDY

This appendix provides details of the methods used in gathering the physical data included on the sheet.

1. Gross Physical Factors--

Elevation and distance from shore were measured stepwise (plot by plot) from the shore using a standard surveyor's transit, or (for points quite distant from shore) by estimation from USGS topographic maps. Slope was measured (with the transit) as the change in elevation along the diameter of the plot showing greatest slope. This was then converted to percent slope via the formula:

$$\%\ \text{slope} = \frac{\text{elevation}}{\text{diameter of plot}}$$

Exposure was simply recorded as one of the eight principle compass directions.

2. Substrate--

Soil color was recorded either as a single color or, for mosaics, as a primary and secondary color (Emlen, p. 570.). The texture at the surface was recorded as estimated percentages of silt, sand, gravel (less than 1 cm diameter), pebbles (1-5 cm), cobbles (5-20 cm), boulders (more than 20 cm), and duff (any small, loose organic material). Surface water availability was rated on the following scale:

1--standing water on surface.
2--wet mud: able to squeeze water from soil by hand.
3--surface visibly moist.
4--surface dry, but visible moisture within six inches of surface.
5--dry: no visible moisture.

Water table depths were determined at sites 2, 5, 6, 7, 9 and 10 by methods described in Chapter 2.

3. Lab Analysis of Soils--

In the field, soil samples (of about 100 cc) were collected. The sample for each plot was a composite of ten small samples taken from the surface at randomly selected points within the plot boundaries. The samples were sealed in plastic bags, and were taken to the lab. Hydrogen ion activity (pH) was measured with a standard pH meter using a 50% (by weight) dilution of the soil sample. These measurements were made within 3-5 days of collection.

The remainder of each sample was left to dry until our return to Stanford in mid-September. At that time, electrical conductivity of the samples was measured with a Wheatstone Bridge and standard soil cup, Procedures for both measurements followed those described in Soil Chemical Analysis by Jackson (1958, pp. 234-251).

APPENDIX 6-2

LISTING OF RAW DATA FOR PLANT STUDY

This appendix contains a partial listing of the data used in the plant study. For each of the 116 sample plots, the Braun-Blanquet cover abundance values for the 30 major species and the seven more important physical and physiognomic variables are given. (See Table 6-2 for the key to the Braun-Blanquet code.) The sample plots are grouped into association types and are designated by the site and sample numbers. The site numbers are as indicated on Figure l-l, and the sample numbers are for sample plot identification when consulting the data collection at Stanford University. A field of asterisks for the physical variables indicate missing data.

APPENDIX 6-2

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log10 Soil Conduc. (mho)	Soil pH	Distance From Lake (ft.)	Elev. Above Lake (ft.)	P. trid.	P. and.	M. gut.	C. exil.	S. hinds	R. cymb.	E. aden.	J. eff.	Sit. spp.	H. jub.	E. cin.	P. air.	D. spic.	B. tect.
Wet Marsh																						
7-06	85.	0.	0.	1.	0.96	8.5	2773.	9.														
8-03	60.	0.	0.	1.	0.75	8.0	348.	3.												+		
8-06	90.	0.	0.	1.	0.79	8.1	934.	6.			+			2	+			+		2		
8-07	99.	0.	0.	1.	0.48	7.9	1087.	7.			2			+	1			+		2		
8-09	99.	0.	0.	1.	0.31	7.7	1497.	10.			1	+		1	1			2				
8-10	90.	0.	***	2.	0.07	8.5	1647.	15.			+	+		4	+	1						
9-06	75.	0.	0.	1.	1.65	9.1	420.	6.			+	+		1	+			+		1	+	
9-07	50.	0.	0.	1.	0.96	8.0	584.	9.			+	+		+	+	+				+		
9-08	90.	0.	***	2.	0.40	8.4	693.	12.			+	+			+	+		+				
11-03	99.	1.	***	2.	0.93	8.4	171.	10.										4			2	
11-09	99.	0.	***	2.	1.12	8.1	754.	37.								1		2				
12-02	40.	0.	***	2.	0.74	8.3	95.	4.				+		+	+			1		2	2	
Transition Marsh/Dry																						
5-03	5.	0.	2.	2.	2.26	9.9	144.	3.						+				+		+	+	
5-05	20.	0.	4.	3.	2.34	10.2	301.	6.														
6-04	25.	0.	***	2.	2.17	10.0	936.	8.													2	
6-05	40.	0.	1.	3.	1.50	9.3	1016.	9.												2	2	
7-07	85.	0.	***	2.	1.11	8.7	2803.	9.										R		+	3	
7-08	98.	0.	0.	1.	1.04	9.0	2987.	11.												+	+	
7-09	90.	0.	6.	3.	0.74	9.7	3093.	14.													2	
7-12	25.	0.	4.	2.	1.45	9.6	3653.	20.														
7-15	99.	0.	3.	2.	1.03	8.7	4678.	24.													1	
8-02	95.	0.	0.	1.	0.96	8.3	2980	3.						2				R		2	+	
8-05	5.	0.	***	3.	1.79	9.9	698.	5.												1	+	
8-11	15.	0.	***	4.	-0.12	8.6	1754.	19.										R			1	
8-12	8.	0.	***	4.	-0.12	8.8	1700.	17.				R			+	+		+			1	
9-04	85.	0.	***	3.	1.78	9.4	264.	3.						+				+		2	+	
9-05	80.	0.	***	3.	1.49	9.4	292.	4.				+		+	+			+		2	3	
11-02	50.	0.	***	3.	2.30	9.6	110.	8.										1		+	2	
Near Lake																						
2-07	30.	0.	16.	4.	0.45	9.5	270.	18.								1		R		+	1	R
3-06	50.	0.	***	4.	1.21	10.0	805.	7.												+	3	
3-07	30.	0.	***	4.	0.98	9.7	843.	7.										R		+	1	
5-06	25.	0.	5.	4.	2.04	10.3	428.	7.												R	+	

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc. (mho)	Soil pH	Dist. From Lake (ft.)	Elev. Above Lake (ft.)	Polyp. sp.	O. hym.	M. asper.	S. nev.	S. rob.	S. amer.	P. ann.	C. visc.	C. naus.	A. trid.	C. frem.	S. verm.	S. pest.	B. hys.	C. parv.	Deadwood
Wet Marsh																								
7-06	85.	0.	0.	1.	0.96	8.5	2773.	9.					2	4										
8-03	60.	0.	0.	1.	0.75	8.0	348.	3.					4						+					
8-06	90.	0.	0.	1.	0.79	8.1	934,	6.			+	2	3	3					+					
8-07	99.	0.	0.	1.	0.48	7.9	1087.	7.			+		2	3										
8-09	99.	0.	0.	1.	0.31	7.7	1497.	10.	+		2			4										
8-10	90.	0.	***	2.	0.07	8.5	1647.	15.			+			3										
9-06	75.	0.	0.	1.	1.65	9.1	420.	6.	1		+	3	+	2					R				+	
9-07	50.	0.	0.	1.	0.96	8.0	584.	9.	+			2		3										
9-08	90.	0.	***	2.	0.40	8.4	693.	12.			+	+		5										
11-03	99.	1.	***	2.	0.93	8.4	171.	10.	+				+	3						+				
11-09	99.	0.	***	2.	1.12	8.1	754	37.	+		1			4										
12-02	40.	0.	***	2.	0.74	8.3	95:	4.	2		2			+					1					
Transition Marsh/Dry																								
5-03	5.	0.	2.	2.	2.26	9.9	144.	3.				+							+			+	+	
5-05	20.	0.	4.	3.	2.34	10.2	301.	6.														2	+	
6-04	25.	0.	***	2.	2.17	10.0	936.	8.				1										1		
6-05	40.	0.	1.	3.	1.50	9.3	1016.	9.				1		+								+		
7-07	85.	0.	***	2.	1.11	8.7	2803.	9.				3												
7-08	98.	0.	0.	1.	1.04	9.0	2987.	11.				4		2									+	
7-09	90.	0.	6.	3.	0.74	9.7	3093.	14.				+		4									+	
7-12	25.	0.	4.	2.	1.45	9.6	3653;	20.				+												
7-15	99.	0.	3.	2.	1.03	8.7	4678.	24.				3		3									2	
8-02	95.	0.	0.	1.	0.96	8.3	2980.	3.				1	3									4		
8-05	5.	0.	***	3.	1.79	9.9	698.	5.					1	+					+					
8-11	15.	0.	***	4.	-0.12	8.6	1754.	19.				2												
8-12	8.	0.	***	4.	-0.12	8.8	1700.	17.				+					+							
9-04	85.	0.	***	3.	1.78	9.4	264.	3.	+		+	+	+	2					3				+	
9-05	80.	0.	***	3.	1.49	9.4	292.	4.	1		1	1		1					2				+	
11-02	50.	0.	***	3.	2.30	9.6	110.	8.				+		+					+			3		
Near Lake																								
2-07	30.	0.	16.	4.	0.45	9.5	270.	18.			1	+			+		R				R	+		
3-06	50.	0.	***	4.	1.21	10.0	805.	7.				+										+		
3-07	30.	0.	***	4.	0.98	9.7	843.	7.				R			+							2		
5-06	25.	0.	5.	4.	2.04	10.3	428.	7.											+			2	+	

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail Index	Log10 Soil Conduc. (mho)	Soil pH	Distance From Lake (ft.)	Elev. Above Lake (ft.)	P. trid.	P. and.	M. gut.	C. exil.	S. hinds.	R. cymb.	E. Aden.	J. eff.	Sit. spp.	H. jub.	E. cin.	P. air.	D. spic.	B. tect.
Near Lake, Cont'd.																						
5-07	20.	0.	5.	4.	1.77	10.4	568.	8.												+	2	
5-08	80.	0.	8.	4.	1.51	9.9	833.	12.												+	5	
7-10	85.	0.	4.	4.	0.42	9.3	3246.	17.													5	
7-16	95.	0.	4.	3.	1.35	9.2	5047.	26.										+			2	
7-17	98.	0.	6.	3.	1.37	9.8	5295.									1		3		2	2	
Wet Shrub																						
9-10	99.	10.	***	2.	0.76	9.1	1067.	25.			+		+		+	1						
9-12	90.	60.	4.	3.	0.61	7.8	1216.	35.					+			4						
9-14	60.	50.	8.	4.	0.56	8.0	1245.	39.					2			2						
11-04	99.	5.	***	3.	1.75	9.6	211.	19.													5	
11-05	70.	80.	***	4.	1.59	9.5	312.	24.										+			4	
11-07	99.	10.	***	4.	1.54	9.8	644.	35.										+			4	
11-08	99.	5.	***	3.	1.72	9.5	729.	36.													3	
11-10	50.	25.	***	4.	1.80	9.5	851.	45.										+			3	
12-03	90.	5.	0.	1.	1.09	8.4	161.	7.			+	+	1	+	1							
12-04	65.	30.	***	3.	0.57	8.1	232.	11.				+	2		+	+						
12-05	5.	10.	***	5.	0.04	8.4	272.	16.					1		+							
Dry Open																						
1-10	1.	0.	***	4.	0.91	8.0	1024.	13.														
1-11	3.	0.	***	4.	***	8.8	1255.	18.														
1-12	35.	0.	***	5.	***	8.3	1412.	22.													3	
1-13	7.	0.	***	5.	***	8.3	1646.	29.													+	R
2-09	1.	3.	24.	4.	0.07	8.7	435.	26.								+	R			R	+	+
2-10	5.	3.	25.	5.	-0.11	8.6	665.	28.													+	1
3-08	2.	0.	***	4.	0.42	9.6	943.	13.														
3-09	35.	0.	***	4.	0.44	9.6	998.	13.													3	
3-10	5.	0.	***	4.	0.04	9.4	1148.	18.														
3-13	4.	0.	***	4.	-0.14	9.1	1439.	36.														
4-06	7.	0.	***	4.	1.56	10.4	722.	6.													2	
4-07	4.	0.	***	4.	1.28	10.1	887.	7.													1	
4-11	60.	0.	***	4.	0.28	9.0	1403.	20.													4	
4-16	5.	5.	***	5.	-0.29	9.5	1917.	98.	+													
5-09	30.	0.	11.	4.	0.12	9.1	956.	16.														
5-10	5.	1.	15.	4.	0.13	8.4	1127.	23.								+		+		+	+	+
6-06	50.	0.	2.	3.	1.05	9.2	1076.	12.													3	

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc. (mho)	Soil PH	Dist. From Lake (ft.)	Elev. Above Lake (ft.)	Polyp.sp.	O. hym.	M. asper.	S. nev.	S. rob.	S. amer.	P. ann.	C. visc.	C. naus.	A. trid.	C. frem.	S. verm.	S. pest.	B. hys.	C. parv.	Deadwood
Near Lake, Cont'd.																								
5-07	20.	0.	5.	4.	1.77	10.4	568.	8.														2	+	
5-08	80.	0.	8.	4.	1.51	9.9	833.	12.				1										+		
7-10	85.	0.	4.	4.	0.42	9.3	3246.	17.				+											R	
7-16	95.	0.	4.	3.	1.35	9.2	5047.	26.				4		1									+	
7-17	98.	0.	6.	3.	1.37	9.8	5295.	32.			+	3		1									+	
Wet Shrub																								
9-10	99.	10.	***	2.	0.76	9.1	1067.	25.						2										
9-12	90.	60.	4.	3.	0.61	7.8	1216.	35.			2			+										
9-14	60.	50.	8.	4.	0.56	8.0	1245.	39.			3			+										+
11-04	99.	5.	***	3.	1.75	9.6	211.	19.						+						2				
11-05	70.	80.	***	4.	1.59	9.5	312.	24.												5				
11-07	99.	10.	***	4.	1.54	9.8	644.	35.	+			3		+						2				+
11-08	99.	5.	***	3.	1.72	9.5	729.	36.			3			2						2				2
11-10	50.	25.	***	4.	1.80	9.5	851.	45.			+			1						3				
12-03	90.	5.	0.	1.	1.09	8.4	161.	7.	1		1			4										
12-04	65.	30.	***	3.	0.57	8.1	232.	11.	+		1			3										
12-05	5.	10.	***	5.	0.04	8.4	272.	16.			+						R	+						
Dry Open																								
1-10	1.	0.	***	4.	0.91	8.0	1024.	13.													+			
1-11	3.	0.	***	4.	***	8.8	1255.	18.										R			+			
1-12	35.	0.	***	5.	***	8.3	1412.	22.																
1-13	7.	0.	***	5.	***	8.3	1646.	29.		R					+						R			
2-09	1.	3.	24.	4.	0.07	8.7	435.	26.			+	+			+		1	R			+	R		
2-10	5.	3.	25.	5.	-0.11	8.6	665.	28.			+				+		1	+				+		
3-08	2.	0.	***	4.	0.42	9.6	943.	13.							1									
3-09	35.	0.	***	4.	0.44	9.6	998.	13.							+									2
3-10	5.	0.	***	4.	0.04	9.4	1148.	18.							1									
3-13	4.	0.	***	4.	-0.14	9.1	1439.	36.							+									
4-06	7.	0.	***	4.	1.56	10.4	722.	6.																
4-07	4.	0.	***	4.	1.28	10.1	887.	7.																
4-11	60.	0.	***	4.	0.28	9.0	1403.	20.													+	+		
4-16	5.	5.	***	5.	-0.29	9.5	1917.	98.		R							+							
5-09	30.	0.	11.	4.	0.12	9.1	956.	16.				+						R						
5-10	5.	1.	15.	4.	0.13	8.4	1127.	23.			+	+					+	+						
6-06	50.	0.	2.	3.	1.05	9.2	1076.	12.														+		

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc. (mho)	Soil pH	Distance From Lake (ft.)	Elev. Above Lake (ft.)	P. trid.	P. and.	M. gut.	C. exil.	S. hinds	R. cymb.	E. Aden.	J. eff.	Sit. spp	H. jub.	E. cin.	P. air.	D. spic.	B. tect.
Dry Open, Cont'd.																						
6-08	5.	0.	4.	3.	0.40	9.5	1287.	19.														
6-09	3.	0.	3.	4.	0.15	9.4	1390.	19.														
	15.	0.	8.	3.	0.35	9.0	1918.	31.														2	
6-12	35.	0.	7.	3.	0.40	8.4	2378.	34.														
6-13	30.	0.	14.	3.	0.29	8.6	2606.	42.														2	
6-16	80.	0.	6.	3.	0.64	9.0	3418.	41.														4	
7-19	60.	1.	13.	4.	0.41	9.1	5645.	44.														4	
10-09	5.	0.	9.	5.	1.76	10.3	3222.	39.														2	
10-11	10.	0.	20.	4.	1.62	10.3	3788.	52.														2	
Transition Dry Scrub																						
1-15	40.	5.	***	5.	***	8.0	1884.	41.								+					2	
2-12	70.	5.	21.	5.	0.04	7.8	1176.	41.								+					1	3
5-12	15.	10.	27.	4.	0.14	8.2	1329.	37.					+			+			+		1	+
5-13	20.	1.	34.	4.	0.33	8.1	1458.	46.								1					2	+
7-21	50.	10.	21.	4.	0.01	9.1	5782.	56.											+		3	
Dry Scrub																						
1-18	1.	70.	***	5.	0.15	5.9	2161.	52.	+													
1-19	4.	50.	***	5.	-0.41	5.8	5300.	160.	1													
1-20	1.	40.	***	5.	***	5.4	8000.	280.	3													
1-21	1.	25.	***	5.	-0.20	5.6	10600.	340.	2								+					+
1-22	5.	15.	***	5.	***	5.4	24000.	870.	+								+					
2-13	3.	30.	16.	5.	0.31	7.9	1411.	46.					1								+	+
2-14	15.	50.	19.	5.	0.40	7.2	1636.	53.					+									1
2-16	1.	50.	23.	5.	0.38	7.0	2098.	63.	+	+			+				+					+
2-17	2.	50.	22.	5.	0.27	7.1	2470.	68.	1	2			+				+		+			+
2-18	1.	50.	23.	5.	0.39	7.1	2835.	72.	1	+							R		+		+	R
4-20	1.	50.	***	5.	0.12	8.5	2091.	158.		2												
4-25	1.	40.	***	5.	0.02	7.8	2331.	192.		1												
5-14	30.	30.	38.	5.	0.10	7.4	1606.	54.								+					1	+
5-16	25.	60.	48.	5.	0.21	6.0	1861.	67.								+					+	
6-17	30.	20.	11.	3.	0.31	8.0	3896.	49.													3	
6-19	75.	15.	14.	3.	1.62	9.1	4620.	53.													3	
6-20	5.	40.	19.	4.	0.31	7.8	4836.	56.											R		+	
6-21	5.	80.	20.	3.	0.48	7.7	4950.	58.											1		1	
6-23	5.	15.	23.	3.	0.58	9.0	5330.	63.	R	+											1	

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc.	Soil pH	Dist. From Lake (ft.)	Elev. Above Lake (ft.)	Polyp. sp.	O. hym.	M. asper.	S. nev.	S. rob.	S. amer.	P. ann.	C. visc.	C. naus.	A. trid.	C. frem.	S. verm.	S. pest.	B. hys.	C. parv.	Deadwood
Dry Open, Cont'd.																								
6-08	5.	0.	4.	3.	0.40	9.5	1287.	19.							+						+	1		
6-09	3.	0.	3.	4.	0.15	9.4	1390.	19.							+						+	+		
6-11	15.	0.	8.	3.	0.35	9.0	1918.	31.							+						1	+		
6-12	35.	0.	7.	3.	0.40	8.4	2378.	34.							+						2	1		
6-13	30.	0.	14.	3.	0.29	8.6	2606.	42.							+						1			
6-18	80.	0.	6.	3.	0.64	9.0	3418.	41.				3					R							
7-19	60.	1.	13.	4.	0.41	9.1	5645.	44.									R			+			R	
10-09	5.	0.	9.	5.	1.76	10.3	3222.	39.																
10-11	10.	0.	20.	4.	1.62	10.3	3788.	52.																
Transition Dry Scrub																								
1-15	40.	5.	***	5.	***	8.0	1884.	41.									2	+						
2-12	70.	5.	21.	5.	0.04	7.8	1176.	41.									1	+			+			
5-12	15.	10.	27.	4.	0.14	8.2	1329.	37.			+	+					+	1						
5-13	20.	1.	34.	4.	0.33	8.1	1458.	46.										+			+			
7-21	50.	10.	21.	4.	0.01	9.1	5782.	56.		+						+	+			2				
Dry Scrub																								
1-18	1.	70.	***	5.	0.15	5.9	2161.	52.									2	3						2
1-19	4.	50.	***	5.	-0.41	5.8	5300.	160.										3						1
1-20	1.	40.	***	5.	***	5.4	8000.	280.																1
1-21	1.	25.	***	5.	-0.20	5.6	10600.	340.																1
1-22	5.	15.	***	5.	***	5.4	24000.	870.		+						R		2						2
2-13	3.	30.	16.	5.	0.31	7.9	1411.	46.									1	+			+			2
2-14	15.	50.	19.	5.	0.40	7.2	1636.	53.									2	1			+			2
2-16	1.	50.	23.	5.	0.38	7.0	2098.	63.		R	R						+	2			R			2
2-17	2.	50.	22.	5.	0.27	7.1	2470.	68.		+							1	1						2
2-18	1.	50.	23.	5.	0.39	7.1	2835.	72.		+						+	2	1			+			2
4-20	1.	50.	***	5.	0.12	8.5	2091.	158.		+						+	1	1						
4-25	1.	40.	***	5.	0.02	7.8	2331.	192.		+						1	+	1						
5-14	30.	30.	38.	5.	0.10	7.4	1606.	54.										2			+			
5-16	25.	60.	48.	5.	0.21	6.0	1861.	67.										4						
6-17	30.	20.	11.	3.	0.31	8.0	3896.	49.		+							2							+
6-19	75.	15.	14.	3.	1.62	9.1	4620.	53.				3					2	R		R				
6-20	5.	40.	19.	4.	0.31	7.8	4836.	56.		+	+					+	2	3						
6-21	5.	80.	20.	3.	0.48	7.7	4950.	58.								+	2	2						
6-23	5.	15.	23.	3.	0.58	9.0	5330.	63.		R							1	1		+				

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc. (mho)	Soil pH	Distance From Lake (ft.)	Elev. Above Lake (ft.)	P. trid.	P. and.	M. gut.	C. exil.	S. hinds.	R. cymb.	E. Aden.	J. eff.	Sit. spp.	H. jub.	E. cin.	P. air.	D. spic.	B. tect.
Dry Scrub, Cont'd.																						
7-22	8.	25.	15.	4.	1.05	9.5	6060.	60.											2		+	
7-23	10.	40.	11.	4.	0.50	9.4	6394.	61.													2	
7-26	1.	30.	34.	4.	-0.03	8.8	7305.	88.														
8-14	15.	40.	***	5.	0.14	8.4	2043.	29.								2					+	
8-16	20.	30.	***	4.	0.17	8.2	2302.	35.								2					2	
8-19	30.	15.	***	4.	1.27	7.6	3790.	49.					2			+			+			
9-17	15.	25.	14.	5.	0.14	7.9	1296.	46.					1			+			R			2
9-19	5.	80.	15.	5.	0.50	7.5	1370.	54.					2									1
9-21	30.	50.	27.	5.	0.33	6.3	1459.	65.	2	2							+					3
9-27	1.	85.	74.	5.	0.18	7.0	1773.	111.											+			
10-12	10.	30.	14.	4.	1.10	9.9	4065.	46.													2	
	1.	70.	19.	5.	0.93	9.0	4441.	52.													+	
10-15	15.	50.	19.	4.	1.06	9.1	4683.	53.									+		+		2	
10-18	1.	60.	20.	4.	0.73	8.3	5533.	60.									+		R			
10-24	5.	25.	14.	4.	0.14	8.8	7142.	74.													2	
10-33	15.	25.	19.	4.	0.32	8.0	10163.	103.											+		2	
10-34	2.	30.	64.	4.	-0.41	8.4	19000.	178.														
11-11	0.	40.	***	5.	1.49	9.4	896.	150.														

APPENDIX 6-2, Cont'd.

	% Herb Cover	% Shrub Cover	Water Table Depth (ft.)	Water Avail. Index	Log 10 Soil Conduc. (mho)	Soil pH	Dist. From Lake (ft.)	Elev. Above Lake (ft.)	Polyp.sp.	O. hym.	M. asper.	S. nev.	S. rob.	S. amer.	P. ann.	C. visc.	C. naus.	A. trid.	C. frem.	S. verm.	S. pest.	B. hys.	C. parv.	Deadwood
Dry Scrub, Cont'd.																								
7-22	8.	25.	15.	4.	1.05	9.5	6060.	60.		+					+	1	2	+		+				1
7-23	10.	40.	11.	4.	0.50	9.4	6394.	61.		+						+	1	2		2				
7-26	1.	30.	34.	4.	-0.03	8.8	7305.	88.		+						2	+	2		1				
8-14	15.	40.	***	5.	0.14	8.4	2043.	29.				1					3				R			
8-16	20.	30.	***	4.	0.17	8.2	2302.	35.				+			+		3			R				
8-19	30.	15.	***	4.	1.27	7.6	3790.	49.			+										2			
9-17	15.	25.	14.	5.	0.14	7.9	1296.	46.			1						R	+						2
9-19	5.	80.	15.	5.	0.50	7.5	1370.	54.																3
9-21	30.	50.	27.	5.	0.33	6.3	1459.	65.								+		2						2
9-27	1.	85.	74.	5.	0.18	7.0	1773.	111.										5						1
10-12	10.	30.	14.	4.	1.10	9.9	4065.	46.								+	3	+		1	+			
10-14	1.	70.	19.	5.	0.93	9.0	4441.	52.									+	4						
10-15	15.	50.	19.	4.	1.06	9.1	4683.	53.									2	+						3
10-18	1.	60.	20.	4.	0.73	8.3	5533.	60.									2	3						2
10-24	5.	25.	14.	4.	0.14	8.8	7142.	74.		R						1	1	+						
10-33	15.	25.	19.	4.	0.32	8.0	10163.	103.		+						+	2	2		+				
10-34	2.	30.	64.	4.	-0.41	8.4	19000.	178.		1						1		2		R	R			
11-11	0.	40.	***	5.	1.49	9.4	896.	150.												2				1

APPENDIX 6-3

ABUNDANCE AND DISTRIBUTION DATA FOR PLANT SPECIES

This appendix gives for each species' samples in the data, the number of occurrences in each Braun-Blanquet cover abundancy category and the number of occurrences in each association type. Because in the designation of major species, the criterion of 9 or more total occurrences was used without reference to percent of the ground covered, the histogram across the Braun-Blanquet categories are presented to describe species importance in terms of ground cover. The number of occurrences in each association type serve to describe the entire flora for each association. The summery statistics at the bottom of the table are helpful in comparing the association types.

APPENDIX 6-3

	Braun-Blanquet							Wet	Transition	Near	Wet	Dry	Transition	Dry	
	R	+	1	2	3	4	5	Marsh	Marsh/Dry	Dry	Scrub	Open	Dry/Scrub	Scrub	Total
DEADWOOD		3	6	12	2						3	1		19	23
BORAGINACEAE															
Coldenia nuttallii	3	4										1		6	7
Cryptantha circumscissa		4											1	3	4
Cryptantha confertiflora	1		1									1		1	2
Cryptanta ssp.		1											1		1
Lappula redowskii		1												1	1
Plagiobothrys kingii		7										1		6	7
CAPPARIDACEAE															
Cleome sparsifolia		3	1	1								5			5
Cleomella parviflora	2	11		1				1	7	5		1			14
CHENOPODIACEAE															
Atriplex argentea		1							1						1
Atriplex phyllostegia	1									1					1
Bassia hyssopifolia	1	10	3	4	1	1			6	6		8			20
Chenopodium atrovirens		1									1				1
Chenopodium fremontii	1	6	1	1	1			4	5	1					10
Chenopodium leptophyllum	1													1	1
Grayia spinosa	3				1									4	4
Salsola pestifera	5	13	2	2						1		10	2	9	22
Sarcobatus vermiculatus	3	5	2	6	1		1	1			5	5	1	10	18
Chenopodiaceae spp.	1	4	2	1				1			4	1		2	9
COMPOSITAE															
Artemisia tridentata	4	12	7	9	4	2	1				1	5	4	29	39
Achilles lanulosa		1									1				1
Aster occidentalis		2									2				2
Chrysothamnus nauseosus					3				1	1	1	6	4	25	38
Chrysothamnus viscidiflorous	1	9	4	1									1	14	15
Haplopappus spp.		3	1						1	1	1			1	4
Machaeranthera canescens		1									1				1
Solidago spectabilis	1	6	1					2			6				8
Lygodesmia spinosa	1	3	1									1		4	5
Taraxacum officinale	1	2									1		1	1	3
Cirsium vulgare	1	3						1	1		2				4
Chaenactis spp.	1													1	1

APPENDIX 6-3 - Page 2

	Braun-Blanquet							Wet	Transition	Near	Wet	Dry	Transition	Dry	
	R	+	1	2	3	4	5	Marsh	Marsh/Dry	Dry	Scrub	Open	Dry/Scrub	Scrub	Total
COMPOSITAE, Cont'd.															
Psathyrotes annua		14	2							2		12		2	16
Tetradymia axillaris	1		1	1										3	3
Tetradymia glabrata		1	6	1								1	1	6	8
Compositae spp.		2						2							2
CRUCIFERAE															
Descurainia pinnata		1												1	1
Descurainia sophia	1	4										2		3	5
Descurainia spp.		4	1											5	5
Lepidium lasiocarpum		1									1				1
CUPRESSACEAE															
Juniperus occidentalis	1	2	1											4	4
CYPERACEAE															
Carex diandra		1			1						2				2
Carex douglasii	1	2	2		2								1	6	7
Carex nebrascensis		1	1								2				2
Carex praegracilis		1											1		1
Eleocharis macrostachya		1	1		1	1		4							4
Eleocharis montevidensis		2	1			1		3			1				4
Eleocharis rostellata		1	1					2							2
Scirpus acutus		2	1					3							3
Scirpus americanus		8	4	5	7	5	1	11	8	2	9				30
Scirpus nevadensis	1	15	6	3	7	2		4	14	7	1	4	1	3	34
Scirpus robustus		3	1	2	2	1		6	3						9
ELAEAGNACEAE															
Shepherdia argentea	1	1		3	1						2			4	6
EPHEDRACEA															
Ephedra viridis		1												1	1
GERANIACEAE															
Erodium cicutarium		2												2	2
GRAMINEAE															
Agrostis alba		2	1	1				1			3				4

APPENDIX 6-3 - Page 3

	Braun-Blanquet							Wet	Transition	Near	Wet	Dry	Transition	Dry	
	R	+	1	2	3	4	5	Marsh	Marsh/Dry	Dry	Scrub	Open	Dry/Scrub	Scrub	Total
GRAMINEAE, Cont'd.															
Muhlenbergia asperifolia	1	15	6	3	2			8	2	2	7	3	1	4	27
Muhlenbergia filiformis		1	1					2							2
Oryzopsis hymenoides	5	12	1									2	1	15	18
Polypogon spp.		7	3	1				6	2		3				11
Stipa comata		2												2	2
Holcus mollis		3						1			2				3
Bromus tectorum	3	9	5	1	2					1	1	5	3	10	20
Distichlis spicata		18	11	23	11	5	3	3	14	9	5	17	5	18	71
Poa palustris			1	1							2				2
Puccinellia airoides	2	13	2	8				6	9	7		3			25
Puccinellia lemmonii		2	1	3				3	2	1					6
Elymus cinereus	3	8	1	1									2	11	13
Elymus triticoides		4	1										1	4	5
Hordeum jubatum	5	13	2	2	1	1		8	8	4	3	1			24
Sitanion spp.	2	7										1		8	9
HYDROPHYLLACEAE															
Phacelia bicolor	1	5												6	6
IRIDACEAE															
Iris missouriensis	1													1	1
Sisyrinchium halophilum	1										1				1
JUNCACEAE															
Juncus effusus		13	6	3		1		4	1	2	4	2	4	6	23
Juncus macrandus		2	3					2			3				5
Juncus spp.		2						1			1				2
JUNCAGINACEAE															
Triglochin concinna		5		1				1	4	1					6
LEGUMINOSAE															
Medicago lupulina		4	1					1	1		3				5
Melilotus albus			1	2		1		1			3				4
Trifolium spp.	1	1						1			1				2

APPENDIX 6-3 - Page 4

	Braun-Blanquet							Wet Marsh	Transition Marsh/Dry	Near Dry	Wet Scrub	Dry Open	Transition Dry/Scrub	Dry Scrub	Total
	R	+	1	2	3	4	5								
LILAEACEAE															
Smilacina stellata		1									1				1
LOASACEAE															
Mentzelia albicaulis		1											1		1
Mentzelia laevicaulis	2	2										2		2	4
Mentzelia torreyi	1	3										2		2	4
ONAGRACEAE															
Epilobium adenocaulon		11	3					8	2		4				14
Gayophytum ramosissimun		1												1	1
Oenothera boothii	2	5	1									7	1		8
Onagraceae ssp.		2												2	2
ORCHIDACEAE															
Epipactis gigantea		1									1				1
Habenaria sparsiflora		1									1				1
PAPAVERACEAE															
Argemone munita	1	2											1	2	3
PINACEAE															
Pinus jeffreyi			1		1									2	2
Pinus monophylla		2												2	2
POLEMONIACEAE															
Gilia leptomeria	1	6	1									3	1	4	8
Leptodactylon pungens	3	1	1									1		4	5
POLYGONACEAE															
Eriogonum ampullaceum		5										5			5
Eriogonum spp.	1	2											1	2	3
Oxytheca dendroidea		3												3	3
Rumex crispus	2	3	3					4			3		1		8
Rumex fueginus	2	5	1					5	3						8
Rumex triangulivalvis	1							5	3	1					1

APPENDIX 6-3 - Page 5

	Braun-Blanquet							Wet Marsh	Transition Marsh/Dry	Near Dry	Wet Scrub	Dry Open	Transition Dry/Scrub	Dry Scrub	Total
	R	+	1	2	3	4	5								
RANUNCULACEAE															
Ranunculus cymbalaria		7	2	2		1		7	4		1				12
SALICACEAE															
Populus trichocarpa		1												1	1
Salix hindsiana		6	4	4							6		1	7	14
Salix lutea	1	1	1	4				1			5			1	7
SCROPHULARIACEAE															
Castilleja exilis	1	9						6	2		2				10
Castilleja spp.		3									3				3
Mimulus bigelovii		3												3	3
Mimulus guttatus		7	1	1				7			2				9
Verbascum thapsus		3									2	1			3
Veronica anagallis		3						2	1						3
ROSACEAE															
Cercocarpus ledifolius	2										1			1	2
Prunus andersonii		5	1	3								1		8	9
Purshia tridentata	1	3	3	2	1									10	10
Rosa woodsii		4	3		1						1			7	8
TAMARICACEAE															
Tamarix rasmosissima	1									1					1
TYPHACEAE															
Typha ssp.		2				1		2			1				3
UMBELLIFERAE															
Berula erecta		4						3			1				4
Sphenosciadium capitellatum	1										1				1
URTICACEAE															
Urtica holosericeae		1												1	1
Column Total	91	462	142	134	51	22	6	139	102	56	124	118	43	326	909
Number of Sample Plots								12	16	9	11	26	5	37	116
Number of Species								41	24	20	54	35	26	61	120

APPENDIX 6-4

PLANT SPECIES LIST AND HERBARIUM COLLECTION NUMBERS

Authorities for scientific names are Munz, P. A. (1968),A California Flora with Supplement. Numbers in parentheses are from the collection of the Mono Basin Research Group care of Jeff Robins. These specimens are stored in the Dudley Herbarium at the California Academy of Sciences. Numbers preceded by an asterix are from the collection of D. W. Taylor and are stored in the Univ. Cal. Davis Herbarium. The names listed here (except for the major species, see Table 6-5) are from field identifications and are subject to revision before being stored in the Dudley Herbarium.

BORGAINACEAE

Coldenia nuttallii Hook. (92)
Cryptantha circumscissa (H. & A.) Jtn. (78, 112)
Cryptantha confertiflora (Greene) Pays. (158)
Cryptantha sp. (208)
Heliotropium sp. (237)
Lappula redowskii (Hornem.) Greene. (286)
Plagiobothrys kingii (Wats.) Gray. (83)

CAPPARIDACEAE

Cleome sparsifolia Wats. (183)
Cleomella parviflora Gray. (146, 199, 253)

CARYOPHYLLACEAE

Arenaria plaudicola Rob. (*6076)
Stellaria sp. (70)

CHENOPODIACEAE

Atriplex argentea Nutt. (200)
Atriplex phyllostegia (Torr.) Wats. (152, 202)
Atriplex sp. (152-1/2)
Bassia hyssopifolia (Pall.) Kuntze, (39, 107, 123, 151, 170, 306)
Chenopodium atrovirens Rydb. (299)
Chenopodium fremontii Wats. (149, 213, 243)
Chenopodium leptophyllum Nutt. (138)
Grayia spinosa (Hook.) Moq. (160, 161, 209, 232, 298)
Nitrophilia occidentalis (Nutt.) Moq. (203)
Salsola pestifera Nels. (80, 143, 315)
Sarcobatus vermiculatus (Hook.) Torr. (33, 44, 48, 189, 293, 305)
Chenonodiaceae spp. (207, 236, 290, 300, 313)

COMPOSITAE

TRIBE - ANTHEMIDEAE

Artemisia tridentata Nutt. (93, 110, 320, 324, 329)
Achillea lanulosa Nutt. (319)

TRIBE - ASTERACEAE

Aster frondosus (Nutt.) T. & G. (*6086)
Aster occidentalis (Nutt.) T. & G. (307)
Crysothamnus nauseosus (Pall.) Britt. (s. 1.) (25, 81, 94, 231, 291, 292, 311)
Chrysothamnus viscidiflorous (Hook.) Nutt. (88)
Haplopappus nanus (Nutt.) D.C. Eat. (187)
Haplopappus racemososus (Nutt.) Torr. (205) (*6083)

TRIBE - ASTERACEAE, Cont'd.

Machaeranthera canescens (Pursh) Gray. (312)
Solidago spectabilis (D. C. Eat.) Gray. (258)
Solidago canadensis (Nutt.) Keck. (*6067)

TRIBE - CICHORIEAE

Lygodesmia spinosa Nutt. (95, 159-1/2)
Taraxacum officinale Wiggers. (69)

TRIBE - CYNAREAE

Cirsium vulgare (Savi) Ten. (281, 304)

TRIBE - HELENIEAE

Chaenactis sp. (340)

TRIBE - SENECIONEAE

Psathyrotes annua (Nutt.) Gray. (23, 109, 145)
Senecio hydrophilis (Nutt. (*6075)
Tetradymia axillaris Nels. (159)
Tetradvmia alabrata Grav. (157)
Tetradymia canescens DC: (238)'
Compositae Sp.

CONVOLVULACEAE

Cressa truxillensis HBK. (125, 133, 147)

CRUCIFERAE

Descurainia pin*nata* (Walt.) Britton. (84)
Descurainia sophia (L.) Webb. (106, 132, 233)
Descurainia sp. (85)
Lepidium lasiocarpum Nutt. (310)

CUPRESSACEAE

Juniperus occidentalis Hook. (190, 210

CYPERACEAE

Carex diandra Schrank. (269)
Carex douglasii Boott. (178)
Carex nebrascensis Dewey. (268, 285)
Carex praegracilis W. Boott. (174)
Carex subfusca W. Boott. (*6069)
Eleocharis macrostachya Britton. (219)
Eleocharis montevidensis Grant. (267)
Eleocharis rostellata (orr.) Torr. (257)
Scirpus acutus Muhl. (51, 225, 302)
Scirpus americanus Pers. (5, 148. 180, 198, 230)
Scirpus nevadensis Wats. (28, 42, 128, 168, 171, 186, 195)
Scirpus robustus Pursh. (2, 182, 194, 220, 244)

ELAEAGNACEAE

Shepherdia argentea Nutt. (191, 283)

EPHEDRACEAE

Ephedra viridis Cov. (327)

GERANIACEAE

Erodium circutarium (L.) L'Her (101, 322)

GRAMINEAE

TRIBE-AGROSTIDEAE

Agrostis alba L. (259, 274)
Muhlenbergia asperifolia (Nees & Meys.) Parodi. (124, 247)
Muhlenbergia filiformis (Thurb.) Rydb. (254)
Oryzopsis hymenoides (R. & S.) Ricker. (87)
Polypogon interruptus HBK. (252, 303)
Polypogon monspeliensis (L.) Desf. (8, 250, 251)
Stipa comata Trin. & Rupr. (119, 289)

TRIBE-AVENEAE

Deschampsia caespitosa (L.) Beauv. (271)
Holcus mollis L. (261)
Trisetum cernuum Trin. (275)

TRIBE-FESTUCEAE

Bromus tectorum L. (10)
Bromus spp. (82)
Distichlis spicata (L.) Greene (11, 21, 96 240)
Poa Palustris L. or Poa *pratensis* L. (62, 67, 266, 280)
Poa sandbergii Vasey. (272)
Puccinellia airoides (Nutt.) Wats. & Coult. (127, 167, 169, 212)
Puccinellia lemmonii (Vasey) Scribn. (166,"204, 262)

TRIBE-HORDEAE

Elymus cinereus Scrbn. & Merr. (did not collect)
Elymus tritcoides Buckl. (134, 235, 287, 294)
Hordeum jubatum L. (29, 73, 153)
Sitanion jubatum Sm. (9, 104)
Sitanion hystrix (Nutt.) Sm. (103)

HYDROPHYLLACEAE

Phacelia bicolor Torr. ex Wats. (144)

IRIDACEAE

Iris *missouriensis* Nutt. (341)
Sisyrinchium halophilum Greene. (263)

JUNCACEAE

Juncus effusus L. (98, 206, 228)
Juncus macrandus Cov. (255, 308, 309)
Juncus spp. (256)

JUNCAGINACEAE

Triglochin concinna Davy. (179, 196)
Triglochin maritma L. (*6082)

LEGUMINOSAE

Lumpinus duranii Eastw. (31)
Medicago lupulina L. (72)
Melilotus albus Desr. (260)
Trifolium sp. (325)

LILAEACEAE

Smilacina stellata (L.) Desf. (326)

LOASACEAE

Mentzelia albicaulis Dougl. ex Hook. (111)
Mentzelia laevicaulis (Dougl.) T. & G. (154)
Mentzelia torreyi Gray. (155)

ONAGRACEAE

Epilobium adenocaulon Haussku (s. 1,) (4, 58 , 222, 246:)
Gayophytum- ramosissimun T. & G. (117)
Oenothera Boothii Dougl. ex Hook. (27, 108, 156, 185)
Oenothera alyssoides (H. & A.) Wats. (*6090)
Onagraceae sp. (114)

ORCHIDACEAE

Epipactis gigantea Dougl. ex Hook. (284)
Habernaria sparsiflora Wats. (265)

PAPAVERACEAE

Argemone munita Dur. & Hilg. (135, 139)

PINACEAE

Pinus jeffreyi Grev. & Balf. (35)
Pinus monophylla Torr. & Frem. (34)

POLEMONIACEAE

Gilia leptomeria Gray. (77, 105, 116)
Leptodactylon pungens (Torr.) Rydb. (162)

POLYGONACEAE

Eriogonum ampullaceum Howell (131, 184)
Eriogonum microthecum Nutt. (165)
Eriogonum spp. (79, 176)
Oxytheca dendroidea Nutt. (115)
Rumex crispus L. (227)
Rumex fueginus Phil. (214, 241)
Rumex triangulivalvis. (Danser) Rech. (129)

RANUNCULACEAE

Ranunculus cymbalaria Pursh. (2, 3)

ROSACEAE

Cercocarpus ledifolius Nutt, (172, 288)
Prunus *andersonii* Gray. (323, 328)
Purshia tridentata (Pursh) DC. (17, 140)
Rosa woodsii Lindl. (137, 177, 282)

RUBIACEAE

Galium multiflorum Kell. (*6087)

SALICACEAE

Populus trichocarpa T. & G. (142)
Salix *hindsiana* Benth. (76, 136)
Salix lutea Nutt. (75)
Salix sp. (264)

SCROPHULARIACEAE

Castilleja exilis Nels. (226
Castilleja (273, 277, 278, 279)
Mimulus Bigelovii (Gray) Greene (18, 118)
Mimulus guttatus Fisch. ex DC. (221)
Verbascum thapsus L. (173)
Veronica anagallis-aquatica L. (1, 248)

TAMARICACEAE

Tamarix ramosissima (130)

TYPHACEAE

Typha sp. (223)

UMBELLIFERAE

Berula *erecta* (huds.) Cov. (229)
Cicuta douglasii (DC.) Coult. & Rose. (*6068)
Sphenosciadium capitellatum Gray. (270)

URTICACEAE

Urtica holosericeae Nutt. (234)

UNDETERMINED SPECIES

(175, 188, 314, 211, 245, 301, 197, 216, 215)

The following species occur in the Mono Basin according to maps prepared by the California Native Plant Society, U. C. Davis Arboretum, and are classified as rare and endangered by the *Inventory of Rare and Endangered Vascular Plants of California* by the California Native Plant Society. The designation to the right of each name will be the status of the plants in the *Report on Endangered and Threatened Plant Species of the United States* by the Smithsonian Institution to be published (personal communication, Dr. Robert DeFilipps, Smithsonian Institution, 1/21/77). If the species are represented in our collection, the collection numbers are given in parentheses.

Listed as VERY RARE, RARE, and ENDANGERED

Astragalus monoensis Barneby	ENDANGERED
Eriogonum ampullaceum Howell (131, 184)	THREATENED
Eriogonum beatleyea Reveal	THREATENED
Eriogonum Kearneyi Tidestra. var. Kearneyi	NOT LISTED

Listed as RARE and NOT ENDANGERED

Lupinus duranii Eastw. (31)	THREATENED
Lupinus motigenus Heller	NOT LISTED
Puccinellia lemmonii (Vasey) Scribn. (166, 204, 262)	NOT LISTED

AN ECOLOGICAL STUDY OF MONO LAKE, CALIFORNIA

Update for the Mono Lake Committee Reprinting-
1 January, 1980

An Ecological Study of Mono Lake, California firmly established Mono Lake's importance as a biological and scientific resource. It has served as the principal factual basis for subsequent political and legal efforts to secure protection for this unique and highly productive ecosystem.

Since the study was conducted in the summer of 1976, the level of Mono Lake has fallen from 6,378.18 feet (17 June, 1976) to 6,372.62 feet (December 7, 1979). As a result, its volume has decreased by about 10 percent, its salinity has increased accordingly, and a landbridge has emerged between Negit Island and the mainland. In 1979, as predicted in the *Ecological Study,* mainland predators crossed this landbridge and forced the abandonment of the island's California Gull nesting colony.

This update briefly reviews this and other developments, on-going research, and recent publications.

I. Water diversion rates, lake levels, and current shoreline configuration

Los Angeles Department of Water and Power diversion rates, Mono Lake surface elevations, and approximate lake volumes for the period 1976-1979 are given in Table U-l. Diversion rates reached record levels during the wet years of 1978 and 1979. Run-off was above normal in 1978, and during early summer about 25,000 acre-feet of water flowed down Rush and Leevining Creeks into Mono Lake. The shoreline configuration of Mono Lake in September, 1979 is depicted in Figure U-l.

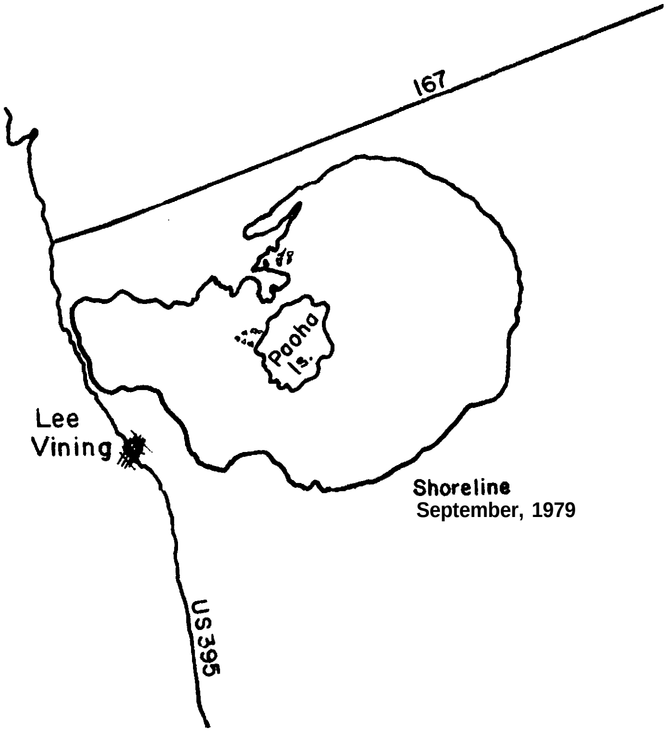


FIGURE U-1. *Shoreline configuration of Mono Lake in September, 1979.. Note that Negit Island has become a peninsula, and that small islets have appeared west of Paoha Island. To appreciate the magnitude of the changes, compare this figure with the map on p. 5 of the Ecological Study.*

TABLE U-1. *Diversion rates, lake levels and approximate volumes of Mono Lake, 1976-1979 (Sources: Los* Angeles *Department* of Water *and Power; Harding, S. T., notes in Calif. State Water Resources Center Archives, Univ. of Calif., Berkeley).*

Year	Lake Level (Feet-Dec.)	Lake Level Change (Ft)	Approx Volume (Acre-Feet)	Approx Volume Change (A-F)	LADWP Diversion (Acre-Feet)
1976	6376.75 (12/7)		2,280,000		68,297
1977	6374.95 (12/30)	-1.80	2,200,000	-80,000	41,083
1978	6374.32 (12/14)	-0.63	2,160,000	-40,000	140,511
1979	6372.62 (12/7)	-1.70	2,100,000	-60,000	125,000 (approx.)

TABLE U-2. *Recent data on Mono Lake water chemistry (Sources: D. B. Herbst and J.* Melack, *pers. communications).*

	Year	Datum	Source
TDS (Total Dissolved Solids)	1979	94.6+ g/l	Herbst
pH	1978	9.95	Herbst
	1979	10.15	Melack
Specific Gravity	1978	1.080	Herbst
	1979	1.084	Melack
Cl^-	1978	21.3 g/l	Herbst

TABLE U-3. *Estimated numbers of California Gulls breeding at Mono Lake, 1976-1979 (Source: Censuses conducted by David Winkler, pers. comm.).*

	Number of Breeding Adults	
Location	1976-78	1979
I. Negit Island*	38,480	0
II. Islets Northeast of Negit Island		
Twain	3,781	3,332
Little Tahiti	1,059	1,526
Pancake*	1,045	0
Little Norway	726	299
Steamboat	624	225
Java	613	625
Spot	184	401
Tie	160	281
Krakatoa	132	167
Hat	37	63
La Paz**	--	142
Geographic**	--	53
Muir**	--	30
TOTALS	8,361	7,144
III. Islets West of Paoha Island**	--	4,000
IV. Paoha Island	0	0
TOTALS	46,841	11,144

"Connected to mainland in 1979. ***Newly emergent in 1979.*

II. Changes in salinity and water chemistry

Recent data on Mono Lake water chemistry are summarized in Table U-2. These update the figures cited in Section 3.1 of the *Ecological Study* (pp. 40-42).

III. Effects of the Negit Island landbridge on the reproductive success of the California Gull colonies

In spring, 1979 the last of three attempts by the California Department of Fish and Game and the Bureau of Land Management to blast a viable water barrier between the mainland and Negit Island failed. By May, coyotes had reached the island, causing the abandonment of the island's most productive north plateau nesting area. By June even the less productive peripheral nesting areas had been visited by predators. As a result of these depredations, no California Gull chicks were successfully raised on Negit Island in 1979. This abandonment represents a reduction of the total successful Mono Lake nesting population from approximately 50,000 in the period 1976-1978 to approximately 15,000 in 1979 (Table U-3).

IV. Revision of the 1857-1883 lake levels

In a 1965 publication, S. T. Harding defended H. B. Lynch's conclusion that Mono Lake stood at an elevation of 6,376 feet in 1857. This figure was uncritically accepted and cited in many subsequent scientific and popular articles-- including the *Ecological Study (see* p. 13). It is drastically in error.

The scholarly research of Scott Stine (Department of Geography, University of California, Berkeley 94720) has proven that the 1857 lake stood at 6,407 ± 1 feet. His conclusion derives from the survey notes and maps of Colonel Alexis Waldemer Von Schmidt, who surveyed, or "meandered," nearly the entire shoreline of Mono Lake between 1855 and 1857. Using details in shoreline topography, such as the inlet shown in Figure U-2, Stine was able to pinpoint the 1857 lake surface elevation to within one foot.

Stine then extrapolated from 1857 to 1883, the first date for which a definite lake elevation is known. In November of that year, Willard D. Johnson, Israel Russell's topographer, etched a mark at waterline on Negit Island, enabling subsequent researchers to derive a lake elevation of 6,410 feet. Stine determined the intervening lake levels from historical accounts and precipitation records.

The results of Stine's research are depicted on the graph in Figure U-3. They indicate that Mono Lake's surface elevation and correspondingly its volume and salinity did not fluctuate nearly so drastically as Harding and Lynch believed. The surface elevation of the lake did not fall below 6,405 feet until it was artificially lowered by the Los Angeles water diversions. For the past two decades, rather than only the past two years as previously supposed, the water diversions have lowered the lake below its lowest level in historical times.

Figure U-4 depicts fluctuations in the salinity of Mono Lake in light of Stine's research.

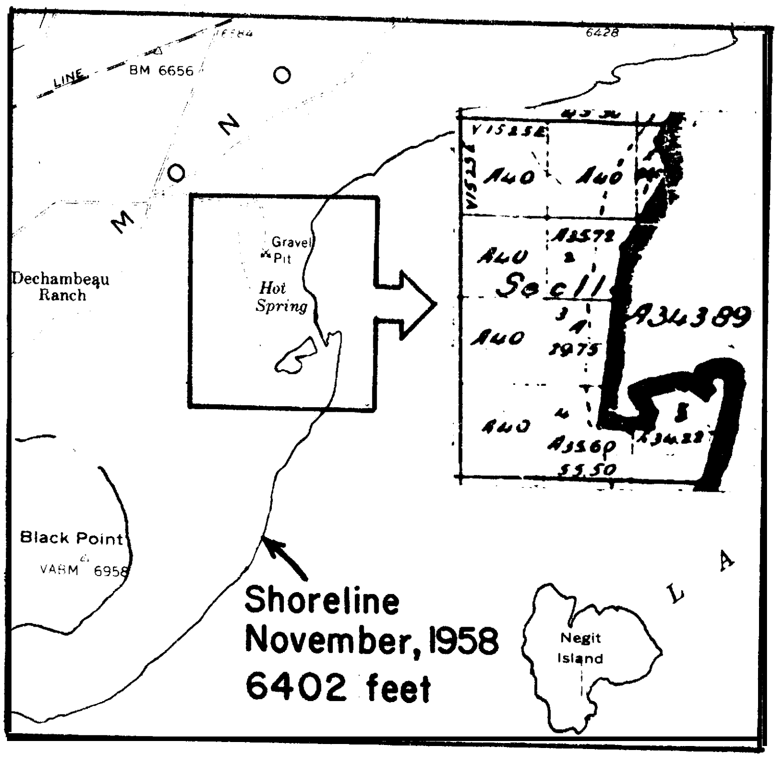


FIGURE U-2. *By comparing Von Schmidt's original survey plats with recent U.S.G.S. maps, Stine derived an 1857 Mono Lake surface elevation of 6,407 ± 1 feet. This figure compares Section 11 (T2N, R26E) as depicted on the 1958 Bodie quadrangle and on Von Schmidt's original plat (insert). The reader will note that when the lake's level stands at 6,402 feet, the pond and small inlet east of Dechambeau Ranch are separated by a low bar. Von Schmidt's plat indicates that in 1857 this bar was submerged. If, as Harding and Lynch supposed, the lake had stood at 6,376 feet in that year, the shoreline would have been more than one mile east*

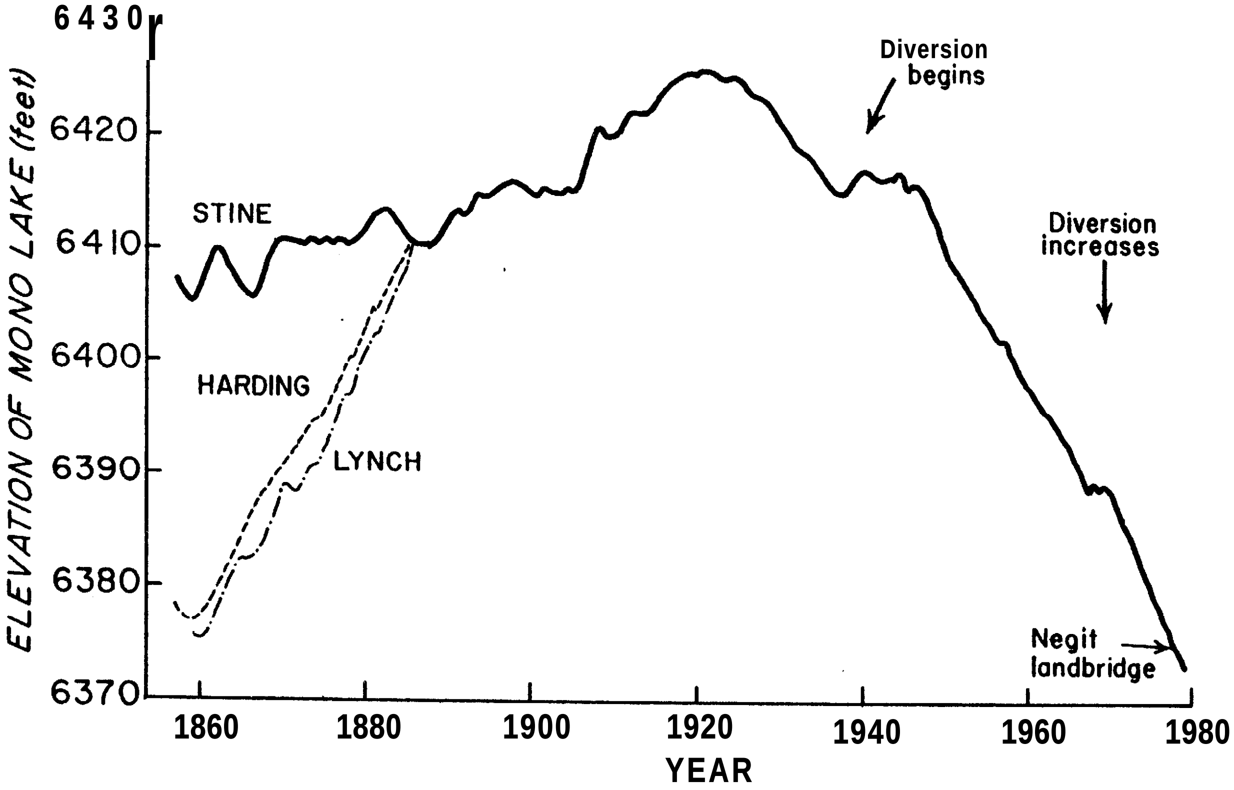


FIGURE U-3. *Surface elevations of Mono Lake, 1857-1979.*

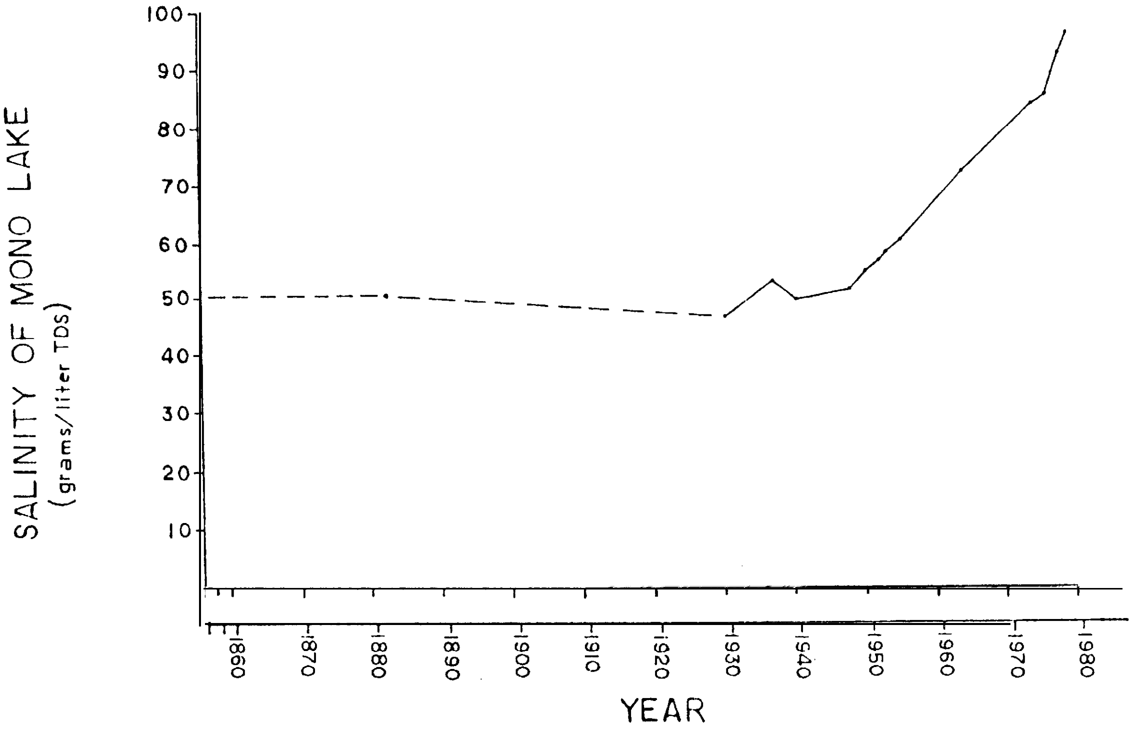


FIGURE U-4. *Fluctuations in the salinity of Mono bake, 1857-1979 (compiled by David Herbst, per. comm.).*

V. Recent publications and on-going research

1. In 1978 Dr. John Melack (Department of Biological Sciences, University of California, Santa Barbara 93106) initiated an on-going investigation of Mono Lake's plankton. His research focuses on (1) the growth rates and nutrient needs of the phytoplankton, (2) the reproductive, grazing and nutrient excretion rates of the brine shrimp, (3) the influence of salinity increases on the reproductive success of the biota, and (4) the seasonal dynamics of the plankton populations. Results have yet to be published.

2. In 1978 Petra Lenz (Department of Biological Sciences, University of California, Santa Barbara 93106) began an in-depth demographic and life history study of the Mono Lake brine shrimp. Many of her findings are summarized in *Ecology of an Alkali-adapted Variety of Artemia from Mono Lake,* a paper she presented at the International Symposium on the Brine Shrimp, Corpus Christi, Texas, August 20-23, 1979.

3. Dr. Sarane T. Bowen (Department of Biological Sciences, San Francisco State University, 1600 Holloway Ave., San Francisco, CA 94132) and her colleagues have been investigating the genetics of brine shrimp populations for many years. Their studies indicate that the population at Mono Lake should not be considered conspecific with the cosmopolitan *Artemia salina,* but should be recognized as a distinct, reproductively isolated species, *Artemia monica.* This important conclusion, which was anticipated in the *Ecological Study* (p. 57), further documents the genetic uniqueness of the Mono Lake ecosystem. The interested reader is referred to the following papers: (a) Bowen, S. T., J. P. Durkin, G. Sterling and L. S. Clark, 1978. *Artemia hemoglobins: Genetic Variation in Parthenogenetic and Zygogenetic Populations.* Biol. Bull. 155: 273-287; (b) Bowen, S. T., M. L. Davis, S. R. Fenster and G. A. Lindwall. *Sibling Species of Artemia.* Paper presented at: Internatl. Symp. on the Brine Shrimp, Corpus Christi, Texas, Aug. 20-23, 1979.

4. David B. Herbst (Department of Zoology, Oregon State University, Corvallis 97331) has been pursuing comparative physiological and life history investigations of brine fly and brine shrimp populations at Mono Lake and Abert Lake (Oregon). In addition to field observations, Herbst has been conducting laboratory studies on salt content of body fluids, salinity-dependent changes in metabolism, effects of increasing lake-water salinity on survival, respiratory rates and internal solute regulation, and, in the case of the brine fly, the influence of photoperiod and temperature on the duration of pupation. In an important set of experiments, mortality of Mono Lake brine shrimp exposed to increasingly concentrated lakewater closely approximated the results reported in the *Ecological Study* (pp. 63-69); these results are reported in *Environmental Physiology of Salt Tolerance in an Alkali-Adapted Variety of Artemia from Mono Lake, California," a* paper by Herbst and Gayle L. Dana presented at the International Symposium on the Brine Shrimp, Corpus Christi, Texas, August 20-23, 1979. Herbst's brine fly studies have yet to be published.

5. In 1978 and 1979, Gary Page, Lynne Stenzel and their colleagues (Point Reyes Bird Observatory, Box 321, Bolinas, CA 94924) studied the habitat requirements and reproductive success of the Snowy Plover at Mono Lake. They found at least 384 adult birds, far more than reported in the Ecological *Study* (p. 98), and about 10 percent of the entire California breeding population. The results of the 1978 research are summarized in a U. S. Fish and Wildlife Service report entitled The Breeding *Biology* of the *Snowy* Plover at Mono Lake, California.

6. In 1979 David Winkler (Museum of Vertebrate Zoology, University of California, Berkeley, CA 94720) began a long-term study on the nesting ecology of the California Gull at Mono Lake. His research focuses on the interplay between the gulls' food supply, nesting environment and reproductive effort as they relate to the realized reproductive success of the gulls. The results of his research have yet to be published.