Chapter 3E. Environmental Setting, Impacts, and Mitigation Measures - Aquatic Productivity of Mono Lake

This chapter concerns biological production within the Mono Lake aquatic ecosystem. A glossary of technical terms is presented in Table 3E-1.

GENERAL DESCRIPTION OF THE MONO LAKE AQUATIC ECOSYSTEM

Introduction

Mono Lake has few species, which is typical of highly saline waters. The lake's most important primary producers (see glossary) are coccoid chlorophytes, coccoid cyanobacteria, and diatoms (Jellison and Melack 1992). In near-shore areas of the lake (littoral zone), where sufficient light reaches the lake bottom, benthic algae are important primary producers, and the Mono Lake alkali fly (*Ephydra hians*) is the dominant consumer species. Other insects, such as the deer fly (*Chrysops* sp.), the long-legged fly (*Hydrophorus plumbeus*), and the biting midge (*Cuciloides occidentalis*), also occupy the littoral zone, but these species are much less abundant than the alkali fly. In open water areas (pelagic zone), the Mono Lake brine shrimp (*Artemia monica*) feeds on phytoplankton and is the only significant consumer (NAS 1987).

The alkali fly and brine shrimp are the major food source of the lake's large bird populations (Winkler 1977). Therefore, this assessment of aquatic productivity in Mono Lake focuses on production of these species.

Sources of Information

The aquatic ecosystem of Mono Lake has been well studied during the past three decades, particularly since about 1980. Mason (1967) documented the physical, chemical, and biological characteristics (limnology) of Mono Lake in the mid-1960s, including brief descriptions of plankton community dynamics and production. Mason's account also provides information on abundance and life history of the brine shrimp but does not discuss the alkali fly. During the summer and early autumn of 1976, a group of scientists conducted a multidisciplinary study of Mono Lake (Winkler 1977) that examined phytoplankton production rates, nutrient limitation, salinity tolerance, and distribution; brine shrimp distribution, abundance, and salinity tolerance; and alkali fly distribution, life history, and salinity tolerance.

Since 1979, the limnology of Mono Lake has been studied intensively by a group of scientists under direction of John Melack of the University of California (UC), Santa Barbara and with funding from LADWP. Lenz (1982, 1984) studied the brine shrimp population from 1979 to 1981, sampling at 1-3 week intervals from late May through July or October, and occasionally in winter and spring. She used ten widely spaced stations in the lake, but occasionally sampled additional stations. Lenz provided detailed accounts of the life history dynamics, temporal and spatial patterns of abundance, and food-web relationships of the brine shrimp.

In 1982, the UC Santa Barbara group began a much broader sampling effort on Mono Lake, which is ongoing. Lakewide surveys are conducted biweekly from March to August and monthly during the remainder of the year, except that winter months were not sampled in 1982-1984 (Jellison et al. 1990). Brine shrimp, water temperature, and dissolved oxygen are sampled on every survey; light penetration, electrical conductivity (a measure of salinity), concentrations of ammonium and chlorophyll *a*, and photosynthetic uptake rates are measured once a month. Two, three, or ten stations are sampled, depending on the parameter. Dana et al. (1990a) presents a detailed description of the sampling and analysis methods.

The UC Santa Barbara group has produced a collection of documents that detail many features of ecosystem structure and function in Mono Lake (Melack 1983, 1985; Jellison et al. 1986, 1989a, 1989b, 1990; Lenz et al. 1986; Jellison 1987; Jellison and Melack 1988, 1991, 1992; Jellison, Dana, and Melack 1991; Jellison, Dana, Romero, and Melack 1991). The group has also provided detailed accounts of the life history, development, growth, grazing rates, production, and salinity tolerance of brine shrimp (Dana and Lenz 1986; Jellison 1987; Dana et al. 1988; Dana et al. 1990b, 1992; Jellison et al. 1989a, 1989b, 1992). Estimates of the numerical abundance of brine shrimp in Mono Lake are presented in Jellison (1987), Jellison et al. (1989a, 1989b, 1990), and Jellison, Dana, Romero, and Melack (1991).

LADWP has carried out limited surveys of phytoplankton and brine shrimp in Mono Lake since 1974 (Thun and Starrett 1982) and has studied factors affecting hatching success of overwintering brine shrimp cysts (Drinkwater and Crowe 1986, Thun and Starrett 1986).

Herbst (1986, 1988, 1990b) studied the alkali fly populations of Mono Lake and Abert Lake, Oregon, from April 1983 to September 1984 and provided detailed accounts of the natural history, physiological ecology, and community ecology of both populations. Herbst and Bradley (1990) used SCUBA at six stations in August and September 1989 to examine how alkali fly abundance in Mono Lake varied with depth. In 1991, Herbst (1992) conducted an intensive study of the Mono Lake alkali fly, sampling different substrates at six stations every 2 or 3 weeks from late April to mid-October and sampling pupae and adults floating on the water surface (drift) biweekly from May through October. He also carried out a series of microcosm experiments to test salinity effects on alkali fly productivity. Herbst (1990a, 1990b), Little et al. (1989), and Stine (1992) described the distribution of the alkali fly and the different types of alkali fly habitat in Mono Lake. Herbst (1992) and Little et al. (1989) provided estimates of numerical abundance of the alkali fly on different substrate types.

The following description of the aquatic ecosystem in Mono Lake is based on a review of the sources discussed above.

Important Features of the Aquatic Ecosystem

Because Mono Lake lies in a closed basin, its water surface elevation naturally fluctuates considerably, ranging from an estimated low of 6,404 feet in 1862 (Vorster 1985) to a high of 6,428 feet in 1919 before diversions began (Figure 1-7). Several physical features of the Mono Lake ecosystem directly related to lake level, such as lake area (Figure 3A-1), volume (Figure 3A-2), and salinity (Figures 3B-1), strongly affect productivity of the alkali fly and brine shrimp populations. Lake area and volume determine the extent of available habitat for the brine shrimp and alkali fly. The high salinity (currently about 90 grams per liter [g/l] of total dissolved solids) and alkalinity (currently 35 g/l of carbonate and bicarbonate ions) of Mono Lake have direct physiological effects on the alkali fly and brine shrimp and influence other important physical and biological features of their habitats, such as patterns of lake mixing, production and species composition of algae, and population levels of potential predators and competitors.

Salinity and alkalinity change seasonally relatively little, decreasing in the spring when large influxes of fresh water enter the lake, and increasing in the summer when water evaporates from the lake surface (Herbst 1986). Year-to-year salinity and alkalinity fluctuations are much greater because lake volume, which determines salt concentrations, varies more over several years than over one season (Figure 3B-1). Although many lakes support insect and brine shrimp populations at salinities higher than those found in Mono Lake, none are as alkaline (NAS 1987).

Salinity, freshwater inflows, and seasonal winds and temperature variations control the circulation patterns of Mono Lake. Large freshwater inflows may lead to periods of chemical stratification (meromixis) that are irregular in frequency and duration. (Meromixis occurs because freshwater is less dense than the lake's saline water. The fresher water layer, or "mixolimnion", floats on top of the more saline water, or "monimolimnion", and resists being mixed with it. The chemical gradient between the two water layers is termed the "chemocline".) A prolonged period of meromixis was observed by UC Santa Barbara researchers from 1983 to 1988 (Figure 3E-1) (Jellison, Dana, Romero, and Melack 1991), but this was the first recorded instance of meromixis in Mono Lake.

Regular seasonal temperature variations in Mono Lake (Figure 3E-2) each year produce one period of thermal stratification (in summer) and one period of lake mixing (in winter). (Thermal stratification occurs because warm water is less dense than cold water. The upper layer, or epilimnion, which is well mixed and generally euphotic from sunlight, is separated from the lower layer, or hypolimnion, by a temperature gradient known as the "thermocline".) When the lake is meromictic, seasonal mixing occurs in the mixolimnion only. When the lake is not meromictic, the entire water column mixes during the mixing season. A circulation pattern with one period of complete mixing and one period of thermal stratification each year is termed "monomixis". Both meromixis, which occurs irregularly, and seasonal thermal stratification, which is predictable, affect habitat conditions in the lake, particularly in the pelagic zone.

The alkali fly and brine shrimp are among the few species that can tolerate conditions of salinity and alkalinity as extreme as those of Mono Lake. Birds are the main predators of the fly and shrimp populations; no fish inhabit the lake. Neither the alkali fly nor brine shrimp has important competitors under present conditions in Mono Lake. Both populations are highly productive (Herbst 1988, Dana et al. 1992).

Because species diversity in Mono Lake is so low, food webs are relatively simple (Mason 1967, Lenz 1982, NAS 1987). The food webs of the pelagic and littoral zones in Mono Lake are largely independent: the alkali fly is the primary consumer of the littoral food web and the brine shrimp is the primary consumer of the pelagic food web. These populations have little effect on each other and therefore can be investigated independently.

Littoral Habitat Zone and Alkali Fly Life History

The littoral habitat zone is the narrow band at the periphery of Mono Lake where sufficient light reaches the bottom to allow growth of benthic algae. Light penetration is dependent on the water's transparency. In Mono Lake, the photosynthetically active zone varies seasonally from about 10 feet vertical depth in winter to almost 60 feet in summer (NAS 1987). Benthic algae have not been sampled quantitatively but have been observed throughout the euphotic littoral zone (Herbst 1990a). The alkali fly is by far the most abundant animal in benthic-littoral habitats.

The alkali fly has a typical insect life cycle, developing from egg to larva before pupating and metamorphosing into a reproducing adult insect (Figure 3E-3). Eggs are laid in mats of benthic algae and hatch in 1-3 days (Herbst 1986). The larvae undergo three distinct development phases (first, second, and third instars). Details of the life history of the alkali fly are given in Appendix I, "Natural History of the Mono Lake Alkali Fly".

Larvae develop in 4 weeks to more than 5 months, depending on temperature, salinity, and food quantity and quality. Laboratory studies show that growth and development at 20°C usually require 4 days for the first instars, 7 days for the second instars, and 36 days for the third instars (Herbst pers. comm.) (Figure 3E-4). Water temperatures at Mono Lake are often lower than 20°C, so larvae may actually develop more slowly. Dry weight increases from 0.02 mg for first instars to 2.85 mg for third instars.

Emerging adults, however, weigh only 1.31 mg because pupation and metamorphosis consume much energy (Herbst 1990a).

When the adult Mono Lake alkali fly emerges from the puparium, it ascends to the water surface. It spends the remainder of its life along the lake shore grazing on algal and detrital food sources and reproducing (Herbst 1986). Normal adult life span is 10-14 days, but overwintering adults may survive for months. Food is essential to successful reproduction, and adult flies are capable of submerging to gain access to high quality benthic algae. Mating of the densely aggregated adults seems to be random with no precopulatory behavioral displays (Herbst 1986). The females submerge to deposit their eggs in the benthic algal mats, thus completing the life cycle.

Submerged alkali fly larvae have few predators or competitors. Numbers are limited mainly by food availability and physical habitat constraints. The larvae and pupae use clawed prolegs to cling to hard surfaces; most deaths probably occur when larvae and pupae are dislodged by waves and currents and swept to the middle of the lake or the shore, where they are exposed to starvation, predation, or parasitism (Herbst 1986).

The alkali fly population is the only important link between the bird populations and the substantial food resources of the littoral zone of Mono Lake. Birds prey chiefly on pupae and third instars, which are the most nutritious and accessible life stages, averaging 11.2 and 12.4 calories per individual, respectively, whereas adults contain only 7.2 calories (Herbst 1986). The third instars and pupae are easy prey for birds because they are continually dislodged by waves and either swept out to the middle of the lake by wind and currents, where they collect as drift, or washed ashore in windrows (Herbst 1986). Drift and windrows are important feeding areas for birds, although the distribution of the drift in the lake is patchy (Herbst 1992).

Eggs and young larvae are too small to attract birds. Adult flies congregated on the shore sometimes are eaten by birds (Herbst 1986).

Though birds feed heavily on dislodged larvae and pupae, the impact of predation on the alkali fly population is probably minor (Dana and Herbst 1977). The alkali fly population is regulated mainly by environmental constraints such as temperature, salinity, food, and availability of hard substrate for attachment and shelter.

Temperature Requirements

Temperature strongly affects temporal and spatial patterns of alkali fly abundance. In winter, low ambient temperatures slow metabolic processes of the alkali fly and increase development time and mortality. If temperatures drop below a certain threshold, development ceases (Herbst 1988).

Alkali fly in inactive, nonfeeding life stages, such as pupae and eggs, are especially sensitive to low temperatures. Pupae cannot develop or survive long at water temperatures at or below 5°C (Figure 3E-5)

(Herbst 1988). Because winter temperatures in Mono Lake regularly drop below 5°C, pupae presumably suffer high winter mortalities. Eggs also perish in very cold water, but eggs generally are not exposed to severe cold because adult flies do not produce eggs during winter. Larvae can survive the near zero temperatures, however, and overwintering populations consist mainly of slowly growing larvae in the second and third instar phases (Herbst 1988, 1990a).

Increasing water temperatures in spring (March-April) cause rapid growth and development of the overwintering larvae and increase rates of development and survival of the pupae. As a result, the alkali fly population increases exponentially during spring (Figure 3E-6) (Herbst 1986). The population remains abundant through summer, until shorter days and declining temperatures in autumn cause adult flies to cease egg laying (Herbst 1988, Herbst pers. comm.). Pupal densities are highest in early autumn (August-September) probably because, as development rates slow down when temperatures cool, longer periods are spent in this lifestage. Population density drops rapidly in October when cooling temperatures cause high mortalities of all life stages.

The growing season available to the Mono Lake alkali fly is short due to the lake's high-altitude location and cool ambient temperature. However, the fly develops and reproduces rapidly, normally producing 1-3 generations in a season (Herbst 1988).

Water temperatures in Mono Lake also influence the spatial distribution of the alkali fly. Alkali fly larvae and pupae are most abundant in water less than 10 feet deep (Figure 3E-7), and generally are not found below the thermocline, where temperatures are too cold for growth and development (Herbst and Bradley 1990). Littoral temperatures exhibit greater extremes than pelagic temperatures. Selected littoral-benthic areas may freeze in winter and warm to 40°C in summer (Herbst 1986, Herbst pers. comm.). Areas that are sheltered from wind and waves, such as Black Point tufa shoals, have warm water temperatures and a long growing season.

Salinity and Alkalinity Requirements

The alkali fly is well adapted to high salinities, but the energy expended to regulate internal salinity reduces the energy available for growth and development (Herbst 1986). Increasing salinities have a marked negative effect on hatching success, larval growth and development rates, larval survivorship, pupation success, pupal weight, and successful adult emergence of the alkali fly (Bradley 1991). At salinities above 150 g/l (which would correspond to a lake surface elevation of about 6,350 feet), the detrimental effects of osmotic stress become insurmountable (Herbst 1986). Larvae in the early instar phases are particularly sensitive to high salinities (Herbst 1990b).

Increased salinity further harms the alkali fly by reducing food quantity and, possibly, quality (see "Food Requirements" below) (Herbst 1992). As food availability declines, alkali fly growth and development rates decrease correspondingly, resulting in smaller pupae and adults, higher mortality, and less reproductive success (Herbst 1986, 1992). Increased energy must be spent on foraging, so it becomes more difficult for the larvae to counter the physiological effects of high salinity (Herbst 1990b).

The total alkalinity of Mono Lake water is about 40% of the total dissolved solids. Alkalinity in Mono Lake is caused primarily by large concentrations of carbonate and bicarbonate ions (Herbst 1986).

Although lakes exist worldwide supporting insect communities at salinities much higher than those found at Mono Lake, none is as alkaline (NAS 1987). Most species have difficulty adapting to high salinity and high alkalinity, yet Mono Lake alkali fly larvae survive better in alkaline salt water than in nonalkaline water of the same salinity (Herbst 1986). The larvae have a special gland, the lime gland, for removing carbonate ions from the blood.

Benefits of high salinity and alkalinity in Mono Lake include less interspecies competition, less predatory pressure, and less parasitism and diseases, because very few organisms can tolerate such high levels.

Substrate Requirements

Storm-generated waves and undertows in Mono Lake sweep away alkali fly larvae and pupae not firmly attached to or sheltered by rocks. Once adrift in the lake or cast ashore, the larvae and pupae are vulnerable to predation, desiccation, and parasitism. Wave action also shifts benthic sands and silts, potentially burying larvae and pupae. The alkali fly, therefore, must have access to rocky surfaces or vegetation, especially during pupation, to which it can cling.

The benthic-littoral habitat consists of both soft and hard substrates (Table 3E-2, Figure 3E-8). Sands, gravels, and especially muds make up the soft substrates. Littoral sands and occasional gravels encircle Mono Lake above elevations of approximately 6,365 feet (Stine 1992). Tributary creeks are the main sources of littoral deposits of silts, sands, and gravels, but shoreline erosion also contributes some material. Soft substrates are of limited use to the alkali fly because they offer no shelter from waves and no firm attachment sites for larvae and pupae.

Hard substrates consist of mudstone, free-standing tufa, tufa-covered pumice blocks, bedrock, beachrock, and vegetation. Mudstone is the most extensive of the hard substrates in terms of total acreage (Table 3E-2), but is considered a poor habitat because its surface is relatively soft and does not contain small crevices for shelter (Herbst pers. comm.).

Tufa-covered pumice blocks are the second most extensive hard substrate. Tufa-covered blocks constitute a good habitat for the Mono Lake alkali fly because their coarse-textured surfaces provide a foothold and shelter for the larvae and pupae. Most pumice blocks are more than 3 feet across. They are found up to an elevation of 6,390 feet in concentrations mainly near the northern and western shorelines of the lake where they floated after volcanic ejection (Figure 3E-8) (Stine 1992).

Scattered solitary tufa towers, continuous tufa bulwarks, and other free-standing tufa types constitute a very small yet important hard substrate type. Free-standing tufa occurs primarily on the southern portion of the lake at elevations ranging from 6,300 to 6,400 feet, and consists of calcite and aragonite (two forms of calcium carbonate) and other mineral deposits precipitated where fresh spring water from lake bottom orifices mixed with saline lake water (Stine 1992). Some tufa originates from the mineral gaylussite (Herbst and Bradley 1990).

Tufa of all types is the most suitable alkali fly habitat. Field studies found third instar larvae and pupae in far greater densities on tufa than on any other hard or soft substrate (Little et al. 1989).

The alkali fly's preference for tufa has several likely explanations. Tufa provides superior attachment sites because its surface is rough and the towers have deep crevices that shelter larvae and pupae from waves and predation by birds (Little et al. 1989). Towers are elevated above the lake bottom, protecting flies in early life stages from burial or abrasion by shifting bottom sands (Little et al. 1989). Tufa also serves as a good growth site for diatoms and algae. Finally, the freshwater springs associated with tufa groves locally may lower salinities, thereby increasing algal abundance and larval growth and development (Little et al. 1989).

Bedrock of volcanic origin is found on the Negit islets, on several points on Paoha Island, and along earthquake faults on the lake floor (Stine 1992). It is the third most abundant type of hard substrate habitat in terms of total acreage and provides good habitat for the alkali fly. Due to the steepness of the bedrock areas, only a small portion of the bedrock in the lake is within the littoral zone (CORI 1988). Generally, bedrock is coated with tufa deposits.

Beachrock is a rare hard substrate consisting of tufa-cemented sands, gravels, and cobbles, found mainly on the deltas of Mill and Lee Vining Creeks and other smaller tributaries. Beachrock forms when freshwater containing calcium mixes with carbonate- rich lake water and the resulting calcium carbonate cements rocks and gravels together. Today, much of the beachrock habitat is covered with littoral sands. Although beachrock provides good habitat for the Mono Lake alkali fly, it is of relatively little importance because of its limited extent (Little et al. 1989).

Submerged vegetation also provides good attachment sites for larvae and pupae. Density of larvae and pupae in areas of submerged vegetation is about half of that on tufa (Herbst 1990a). Studies show that inundated terrestrial vegetation can persist for up to 10 years before deteriorating. At present, this type of habitat is not extensive because soils near much of the lake are highly alkaline.

Changes in the surface elevation of Mono Lake that affect the availability of different substrates in near-surface waters would affect alkali fly abundance. As noted earlier, alkali fly abundance is strongly influenced by depth, with most of the biomass found in water less than 10 feet deep (Figure 3E-7).

Food Requirements

Benthic algae and algal detritus on the lake bottom are the principal sources of food for alkali fly, but detrital bacteria and protozoa may also be important (NAS 1987). On preferred habitats where larval densities are high, such as tufa, grazing may significantly reduce algal biomass. The reduction in food supply may be partly responsible for an observed decline in the mean body sizes of pupae and adults from spring through autumn (Herbst 1986).

Physical factors affecting food availability are salinity, substrate type, nutrients, and depth. Biomass of benthic algae may decrease as salinity increases (Herbst 1986, 1992). Areas near freshwater inflows have high algal production. Soft substrates have good algal food supplies for young larvae, but algal mats on tufa seem to be the preferred food source. Biomass of benthic algae decreases with depth, so shallow waters have better food availability for the alkali fly.

Pelagic Habitat Zone and Brine Shrimp Life History

The brine shrimp is the only animal that presently inhabits the pelagic zone of Mono Lake. Several bird species feed heavily on adult brine shrimp. The brine shrimp population links the bird populations to the large food resources of the pelagic zone of Mono Lake.

Phytoplankton of the pelagic zone is the only known source of food for the brine shrimp population (NAS 1987). Bacteria may also be an important food, but the Mono Lake bacteria have not been studied. Phytoplankton abundance in Mono Lake is determined by temperature, light, nutrient supply, and the level of brine shrimp grazing (Jellison and Melack 1992). Nitrogen is the limiting nutrient in the pelagic zone and is available to algae primarily in the form of ammonium (NH_4+). During the winter mixing period, ammonium originates from the sediments and, if the lake is meromictic, from the monimolimnion. When the lake stratifies in early spring, the epilimnion is largely cut off from the sediments or monimolimnion. Increasing temperature and sunlight lead to rapid growth of algae. The growth of algae depletes the ammonium in the epilimnion and the high biomass reduces light penetration so that by April or May algal growth is limited (Jellison and Melack 1992).

Increasing temperature in spring leads to growth of the brine shrimp population and increased grazing (Jellison and Melack 1992). Although grazing on the phytoplankton increases during spring, it is never sufficient to suppress algal biomass because the brine shrimp population cannot grow fast enough to keep pace with the algae. Therefore, peak algal abundance is not affected by brine shrimp grazing. Shortly after algal biomass peaks, however, grazing pressure begins to reduce the algae, allowing penetration of light. This clearing phase occurs over a period of 2-3 weeks in late spring and is accompanied by an increase in epilimnetic ammonium concentrations because the brine shrimp excrete ammonium. By early summer, therefore, brine shrimp grazing, not light or ammonium supply, probably limits phytoplankton abundance. Algal biomass increases again in autumn as the brine shrimp population declines.

The spatial distribution of the brine shrimp population across Mono Lake varies seasonally, but it has been fairly consistent during the years for which it has been reported (1980, 1981, and 1990). In early autumn 1980 and 1981, brine shrimp were more abundant in the western sector of Mono Lake than in the eastern sector, but later in the autumn they were more abundant in the eastern sector or the abundances in the two sectors were not significantly different (Lenz et al. 1986). In summer and early autumn 1990, brine shrimp were fairly evenly distributed around Mono Lake, but in early spring and again in late autumn they were more abundant in the eastern sector of the lake (Jellison, Dana, Romero, and Melack 1991).

A commercial fishery on Mono Lake harvests and markets brine shrimp as fish food. The fishery has an annual take of about 500,000 pounds (dry weight) (Dana and Herbst 1977). Estimated peak total numbers of brine shrimp in Mono Lake in 1982 and 1983 were 12,683 billion and 14,458 billion, respectively (Conte et al. 1988). Assuming a dry weight per individual of 0.55 mg (mean dry weight of adults) (Jellison, Melack, Dana 1992), the fishery's annual harvest is only about 3% of peak abundance.

The life cycle of the Mono Lake brine shrimp is complex (Figure 3E-9). Development proceeds through seven naupliar (larval) instar phases, four juvenile instar phases, and one or more adult instar phases. Generally, two generations develop annually: a spring generation originating from overwintering cysts produced during the previous summer and autumn and a summer generation originating ovoviviparously (by live birth) from adults of the spring generation. In some years, a small third generation appears in autumn (Jellison et al. 1989a; Jellison, Dana, Romero, and Melack 1991).

Hatching of the spring generation occurs from January to May and the first adults usually appear in May (Lenz 1984). The females reproduce ovoviviparously for about a month, giving rise to the second generation. In June, adult females of the first generation begin producing cysts (diapause eggs), which settle to the lake bottom until the following year (Jellison et al. 1989b). The second generation matures in July and August and primarily reproduces oviparously (by producing eggs or cysts) (Lenz 1984). The development period, which is strongly affected by temperature, is about 2 days at 20°C for each of the preadult instar phases (Jellison et al. 1989a).

Salinity affects survival, growth, reproduction, and cyst hatching of Mono Lake brine shrimp (Starrett and Perry 1985, Dana and Lenz 1986). In bioassay experiments, increasing salinity had direct negative effects on the shrimp; these effects were continuous over the entire range of salinities tested (76-192 g/l total dissolved solids) (Starrett and Perry 1985, Dana and Lenz 1986). The effect of salinity on cyst hatching may be the most important effect with respect to survival of the Mono Lake population. The percentage of cysts hatched dropped steadily with increasing salinity and no cysts hatched at a salinity of 160 g/l (Dana et al. 1992).

Details of the life history of the brine shrimp and the effects of salinity, temperature, dissolved oxygen concentration, and food supply on brine shrimp production are given in Appendix J, "Natural History of the Mono Lake Brine Shrimp".

Habitat conditions for plankton in Mono Lake, including the brine shrimp, are different during monomictic and meromictic years. The following sections provide descriptions of the pelagic habitat and brine shrimp population under both types of mixing regimes.

Monomictic Mixing Regime

Before 1982, Mono Lake was probably monomictic in all years since the start of water diversions (Jellison and Melack 1991). The lake was again monomictic after 1988.

Under monomictic conditions, complete mixing (holomixis) of the lake occurs in November when water temperature is about 9°C (Jellison, Dana, Romero, and Melack 1991). Mixing reoxygenates the hypolimnion and resupplies nutrients to the epilimnion. The influx of nutrients, particularly ammonium nitrogen, leads to a winter-spring algal bloom. Despite the abundance of algae, brine shrimp numbers are low in the winter (Jellison, Dana, Romero, and Melack 1991).

Temperature of Mono lake is uniform at all depths through winter, but the lake begins stratifying in March (NAS 1987). Because of its high salinity, Mono Lake does not freeze. Once the lake becomes thermally stratified, mixing is restricted to upper depths, where light and temperature conditions are most favorable for growth of algae. High algal production, however, depletes nutrients in the epilimnion and primary production is nitrogen-limited in spring (Jellison, Dana, Romero, and Melack 1991).

Brine shrimp hatch from cysts in late winter and early spring. Cysts are produced in the previous year and require about 3 months of exposure to cold water temperatures for hatching (Dana 1981, Thun and Starrett 1986). The late-winter, early-spring hatch is the first of two or three generations of brine shrimp that are produced each year. The first generation has a superabundant food supply, but it matures slowly because of low water temperatures. Adults first appear in May.

Heavy grazing by the growing brine shrimp population leads to a sharp reduction in algal biomass in May and June. Grazing pressure limits algal abundance at this time; nitrogen requirements are probably satisfied by excretion of ammonium by the brine shrimp. Water transparency increases greatly as the algae are removed. Dissolved oxygen levels in summer are low (2-4 mg/l) because of high respiratory consumption by the shrimp and low production by algae. Dissolved oxygen concentrations lower than 2 mg/l may lead to increased mortality (Dana et al. 1992).

The second generation of brine shrimp is produced ovoviviparously in May and June and matures rapidly (about 3 weeks) because of warm water temperatures. Production of brine shrimp is limited at this time of year by the low biomass of algae, which causes lower fecundity of the first generation and reduced growth and survival of the second generation. Both generations begin producing cysts in summer, when the food supply is low. Settling of cysts and fecal pellets of the brine shrimp, and sinking of algae, removes nitrogen from the epilimnion and enriches the hypolimnion. Decomposition of these materials depletes dissolved oxygen, so the hypolimnion becomes anoxic and unfit for brine shrimp habitation.

In autumn, brine shrimp abundance declines. A third generation, whose origin (i.e., cysts or live births) is uncertain, appears in autumn in some years, but is never abundant (Jellison et al. 1989b; Jellison, Dana, Romero, and Melack 1991). The reason for the autumn decline in brine shrimp abundance is unknown, but predation by grebes, aging of adults, and reduction in birth and survival of nauplii have been suggested as possible causes (Cooper et al. 1984, Jellison et al. 1992, Lenz 1982). The decline causes reduced grazing pressure on the algae, so algal biomass increases and the algae become nitrogen-limited again. The principal source of nitrogen in autumn is ammonium nitrogen from the hypolimnion, which is entrained as thermal stratification weakens and the surface mixed layer deepens. The increase in ammonium leads to further increases in algal biomass.

Meromictic Mixing Regime

Mono Lake was meromictic from 1982 to November 1988. No evidence exists of meromixis at any other time in the lake's recent history (Jellison and Melack 1991).

Habitat conditions and brine shrimp population dynamics during meromictic years differ in several respects from those during monomictic years. Most important of all, autumn mixing reaches only to the chemocline; the monimolimnion is unaffected. Less nitrogen is transported upward to the epilimnion, and algal production is reduced (Jellison and Melack 1992).

If meromixis is not maintained by additional freshwater inflows, the mixolimnion becomes increasingly saline because of evaporative concentration, which weakens the chemical stratification (Figure 3E-1). At the same time, ammonium becomes increasingly concentrated in the monimolimnion (Figure 3E-10). As a result of these processes, the amount of nitrogen entrained by autumn mixing increases as meromixis weakens, and increased nitrogen results in increased primary production.

In Mono Lake, algal biomass in the mixed layer, measured as chlorophyll *a* concentration, increased each year during the meromictic period except 1986, when high freshwater inflow reinforced the chemical stratification (Figures 3E-11 and 3E-1) (Jellison and Melack 1992).

The reduction of primary production as a result of meromixis might be expected to lower productivity of brine shrimp (combined spring and summer generation peaks), but this was not generally borne out by the results of sampling. Brine shrimp abundance was relatively low during some of the meromictic years (e.g., 1983 and 1985), but it was also low in some of the monomictic years (e.g., 1980 and 1990) (Figure 3E-12) (Jellison, Dana, Romero, and Melack 1991). As noted previously, algal biomass peaks in spring before brine shrimp numbers and water temperatures are high enough for the brine shrimp population to exploit the algae effectively. Only a portion of annual primary production influences brine shrimp production, and effects of meromixis on algal production are not necessarily propagated up the food chain to the brine shrimp population.

The ratio of abundance of the spring generation of brine shrimp to that of the summer generation has varied considerably from year to year (Figure 3E-12). The cause of these variations is only partially understood. The size of the spring generation is probably determined by the number of cysts produced in the previous year, the hatching success of these cysts, and rates of development and survival of the nauplii and juveniles. For example, the spring generation in 1988 was unusually abundant (Figure 3E-12). Cyst production was high in 1987, oxygenation of the cysts was good, and spring food supply was relatively high. In contrast, the spring generation in 1989 was low, probably because survival of nauplii was low (Jellison et al. 1990). The breakdown of meromixis occurred late in 1988, so in early spring 1989 oxygen levels and temperatures were low and the concentration of toxic compounds, such as hydrogen sulfide or gaseous ammonia, may have been high (Jellison et al. 1990; Jellison, Dana, and Melack 1991). Hydrogen sulfide and ammonia often accumulate to high concentrations in anoxic water layers.

The size of the summer brine shrimp generation is inversely related to the size of the spring generation. When the spring generation is abundant, it quickly reduces the food supply. At low food levels, fecundity of the adult females and survival of the summer generation nauplii are reduced, leading to relatively low abundance of summer generation adults (Jellison, Dana, Romero, and Melack 1991). When the spring generation is small, however, food remains plentiful and abundance of the summer generation is high. Thus, the size of the summer generation was much larger in 1989 than in 1988 (Figure 3E-12).

The ratio of abundance of the spring and summer generations may have important ecological consequences. Cyst production is higher in years with a large summer generation, and high cyst production should result in a large spring generation in the following year (Figure 3E-12). A large summer generation, however, was not necessarily followed by a large spring generation, perhaps because other factors were more important (Jellison et al. 1989a). The relative sizes of the spring and summer generations could have important effects on eared grebe populations. The grebes feed heavily on Mono Lake brine shrimp, but do not arrive at the lake until late summer or early autumn (Winkler 1977).

PREDIVERSION CONDITIONS

Sources of Information

Observations of some early visitors to Mono Lake, such as J. R. Browne, Mark Twain, I. C. Russel, J. M. Aldrich, W. H. Brewer, and W. K. Fisher provide a general, though limited, picture of the biota and habitat conditions of the lake before LADWP began diverting water from the basin in 1941

(Fisher 1902, Mason 1967, Winkler 1977, Herbst and Bradley 1990). Mason's (1967) study, the earliest limnological account of Mono Lake, includes quantitative descriptions of the plankton. According to LADWP projections, salinity of Mono Lake, which was about 53 g/l in 1941, had increased to about 70 g/l by 1964 when Mason sampled the lake (Mason 1967, NAS 1987). The littoral zone community was not well studied until recently (Dana and Herbst 1977).

Prediversion habitat conditions of Mono Lake may be partially surmised by examining conditions in lakes with similar salinities. Wurtsbaugh and Berry (1990) described species composition of the plankton and abundance of a brine shrimp, *A. franciscana*, in the south arm of the Great Salt Lake in 1987, when salinity was similar to that in Mono Lake in 1941 (although alkalinity and pH were much lower).

Littoral Zone Productivity

Early visitors to Mono Lake noted the presence of many alkali flies (Fisher 1902, Herbst and Bradley 1990). Fisher's (1902) account includes a photograph showing a dense shoreline concentration of alkali flies that, according to Fisher, surrounded the lake. Wallis McPherson (pers. comm.), a resident of Mono Basin since 1917, has stated that the flies were much more abundant during the prediversion period than today. Historical accounts also described windrows of pupae and larvae that may have been larger than those presently found at Mono Lake (Herbst 1990b). Windrowed and nearshore pupae were traditionally harvested by Kuzedika Paiute Indians in early summer and late autumn and constituted an important part of their diet.

Salinities in the prediversion period were lower than today, and productivity of the alkali fly may have been higher. Although the alkali fly is well adapted to high salinities, the additional metabolic energy required to regulate these high salt levels is great and reduces the total energy available for growth and development, thus reducing productivity (Herbst 1986). On the other hand, productivity of the alkali fly might have been lower when the lake was less saline because interspecific competition, predatory pressure, parasitism, and diseases increase at lower salinities. Abert Lake in Oregon, which has a salinity of about 30 g/l, has about twice as many benthic macroinvertebrate species as Mono Lake (Herbst 1986). During 1983-1984, when salt concentrations were reduced 5-10 g/l by large freshwater inflows in both Mono Lake and Abert Lake, species diversity increased in both lakes (Herbst 1986). Despite the increase in species diversity at lower salinities, however, prediversion salinities at Mono Lake were probably too high for potential predators and competitors to survive well enough to affect productivity of the alkali fly (Herbst pers. comm.).

The surface area of Mono Lake was greater during the prediversion period because of the higher lake levels, but suitable habitat for the alkali fly was not necessarily more prevalent. Stine (1987, 1992) estimates most of the hard substrates were well below depths inhabited by the alkali fly during the prediversion period (Table 3E-2, Figures 3E-7 and 3E-8). However, the relative value to alkali fly productivity of hard substrate versus soft substrate may have been less under prediversion conditions than under current conditions. Furthermore, a leafy algae may have been present (McPherson pers. comm.), or submerged vegetation that was drowned during a rise in lake level in the late 19th century or in 1938 after a short lowstand period may have persisted until 1941 to provide additional suitable substrate during the prediversion period.

Pelagic Zone Productivity

Early accounts of Mono Lake suggest that brine shrimp were abundant in the lake long before LADWP began diverting water from the basin, but quantitative information is lacking (Mason 1967, Winkler 1977). As described in Appendix J, increasing salinity has negative effects on survival, growth, and reproduction of brine shrimp, which would tend to reduce brine shrimp productivity. Therefore, brine shrimp productivity was probably higher under prediversion conditions than under current conditions. However, as noted above for the alkali fly, the postdiversion increases in salinity may have reduced levels of predation and competition.

Nothing is known about what species other than brine shrimp inhabited the pelagic zone in prediversion Mono Lake. Though brine shrimp are the only zooplankton in the lake at present, Mason (1967) found two planktonic rotifers (*Brachionus plicatilus* and *Hexarthra jenkinae*) between 1959 and 1963, when salinity was 70 g/l or lower. The rotifers were abundant only in December 1959, when few brine shrimp were present; however, at the lower salinities of the prediversion period, rotifers, as well as other potential competitors, also may have been abundant in summer.

Pelagic zone predators also may have been present in prediversion Mono Lake. Wurtsbaugh and Berry (1990) attributed a decline in abundance of *A. franciscana* in the south arm of the Great Salt Lake to predation by the insect *Trichocorixa verticalis* that invaded the lake between 1963 and 1987 when salinity dropped from 250 g/l to 50 g/l. Potential competitors of the zooplankton also invaded the lake when the salinity dropped. *T. verticalis* cannot live in highly alkaline water and thus would not have been present in Mono Lake, but other predators would be able to live under prediversion conditions (Dana et al. 1992).

The volume and surface area of Mono Lake were greater under prediversion conditions than at present, so more brine shrimp habitat would have been available (NAS 1987). However, lake level changes could affect habitat quality and thus brine shrimp production. Hurlbert (1991), for instance, observing that shallow lakes tend to be more productive than deep lakes (because more of the water receives sunlight and is close to sediments), showed that, for a period after water diversions began, total production may have increased in Mono Lake as lake elevation dropped. Total production would have increased if gains in productivity caused by reduced depth outweighed losses resulting from smaller habitat area.

ENVIRONMENTAL SETTING

Sources of Information

Conditions in the pelagic zone of Mono Lake in 1989 are described in Jellison et al. (1990). Little information is available on the littoral zone in 1989, but descriptions are given in Little et al. (1989) and Herbst (1992) of the littoral zone in 1988 and 1991, respectively.

Estimates of productivity of the Mono Lake brine shrimp population in 1989 are not available, but Jellison et al. (1990) provided graphs of numerical densities in 1989. The graphs show density of brine shrimp adults, juveniles, and nauplii in each month of 1989. Similar graphs for 1988 and 1990 are presented in Jellison et al. (1989b) and Jellison, Dana, Romero, and Melack (1991).

No estimates of productivity or abundance of the Mono Lake alkali fly population in 1989 are available. However, Little et al. (1989) and Herbst (1992) provided information on mean densities of alkali fly larvae and pupae on different substrate types in 1988 and 1991.

Little et al. (1989) sampled the substrates in April, June, and August 1988 at 15 near-shore stations spaced 3 km apart. All stations were in water 30 cm deep. In June and August, the authors also measured surface areas of the different substrate types at each station along 50-m transects. The transects included areas between water depths of 20 and 40 cm. Little et al. (1989) presented tables of mean density of the three larval instars and pupae on each substrate type in June and August. Estimates of mean densities on all hard substrates and all soft substrates can be derived from estimates of the mean densities and relative surface areas of the individual substrate types.

Herbst (1992) sampled the hard and soft substrates every 2-3 weeks from late April to mid-October 1991 at six stations. The stations were widely distributed around Mono Lake, but were located in areas where tufa was abundant. Sampling depths were between 25 and 50 cm. Herbst (1992) provided graphs of mean densities of the three larval instars and pupae on each sampling date.

Lake Condition

The large range in annual precipitation and changes in water diversion schedules during recent years at Mono Lake has resulted in highly variable habitat conditions in the lake. Most important of all, high freshwater inflows in 1982 and 1983 resulted in chemical stratification, which was sustained, with the help of additional inflows in 1986, until November 1988 (Figure 3E-1) (Jellison and Melack 1991). Before and after this period of meromixis, the lake was monomictic, mixing completely during the winter. Salinity in August 1989 was about 89 g/l (Figure 3B-1), and total alkalinity was about 34 g/l.

The breakdown of chemical stratification in November 1988 produced highly unusual conditions in Mono Lake in 1989, the point of reference, which may have affected productivity of the brine shrimp and alkali fly populations. The hatching brine shrimp suffered total mortality in early 1989 as a result of the low water temperatures and low oxygen concentrations caused by upwelling monimolimnetic water (Jellison, Dana, Romero, and Melack 1991). On the other hand, the upwelling water was rich in ammonium, so nutrient and algae concentrations in 1989 were high (Figures 3E-10 and 3E-11). There is no evidence that the alkali fly population experienced unusually high mortality in 1989, but mortality of the alkali fly may have escaped detection because the population was not sampled in early 1989.

Littoral Zone Productivity

The surface area of the benthic-littoral zone of Mono Lake has declined with the reduction in lake surface area, but the amount of high-quality hard substrate habitat for the alkali fly has probably increased because the fall in lake level has brought more tufa and pumice into the near-surface water layer (Figure 3E-8). In 1989, when the lake level was about 6,376 feet, there was about 523 acres of hard substrate in the top 10 feet of lake (Table 3E-2). Although this area is large compared to that at most other lake levels, the hard substrate area would be even larger if the lake level were 5 or 10 feet higher. As has been described, however, available substrate is only one of a number of factors potentially affecting alkali fly production that may be affected by lake level changes. A complete analysis of the effect of lake surface elevation on amount of usable substrate is presented in Appendix L, "Alkali Fly Productivity Model", and in the impact section of this chapter.

Estimates of alkali fly productivity are not available for the August 1989 point of reference, but densities can be estimated for August 1988 and August 1991 from information provided in Little et al. (1989) and Herbst (1992) (Table 3E-3). Mono Lake was meromictic in 1988 and was monomictic in 1991. Estimates of densities of pupae in August were similar in the two studies. In both years, the pupae occupied hard substrates almost exclusively.

Estimates of larval density were consistently higher in the 1991 study than in the 1988 study (Table 3E-3). The differences in estimates between the studies may reflect real differences in densities of alkali fly between 1988 and 1991 or may reflect differences in how the two studies were conducted. For instance, the density estimates for soft substrates, which were higher by an order of magnitude or more in the 1991 study, in part reflect differences in sampling. As noted above, Herbst (1992) sampled soft substrates only in areas where tufa was abundant, whereas Little et al. (1989) sampled soft substrates without regard to the distribution of tufa. Little et al. (1989) found that densities on soft substrates were significantly higher at stations in tufa-rich areas than at stations far removed from tufa.

Pelagic Zone Productivity

Density of Mono Lake brine shrimp adults was about 70,000 individuals per square meter in August 1989 and reached more than 90,000 per square meter in September 1989 (Figure 3E-13). These densities were the highest that the population had achieved since 1982 (Figure 3E-12). On the other hand, densities in the spring of 1989 were unusually low (Figure 3E-12). Densities of nauplii and juveniles also were very low in the spring (Figure 3E-13). Mixing of monimolimnetic water produced unusually low water temperatures and low oxygen concentrations in spring 1989 that caused high mortality of brine shrimp nauplii (Jellison et al. 1990).

The low abundances of brine shrimp in spring and the high abundances in autumn resulted from the breakdown of meromixis at the end of 1988 (Jellison, Dana, Romero, and Melack 1991). High autumn abundances resulted from good feeding conditions because the deep mixing replenished ammonium in the epilimnion (Figure 3E-10), stimulating growth of algae, and because grazing pressure on the algae was low during spring and early summer.

Because conditions in 1989 were so unusual, abundances of brine shrimp in 1989 were compared with abundances in 1988, a meromictic year, and 1990, a monomictic year (Figures 3E-13, 3E-14, and 3E-15). In August 1988, density of adults was about 35,000 individuals per square meter, but in June 1988 the density reached over 70,000 per square meter. In August 1990, density was between 30,000 and 35,000 per square meter, which was the peak abundance for the year.

The breakdown of meromixis in Mono Lake in the autumn of 1988 produced unusual conditions in 1989, leading to very low abundances of brine shrimp in spring and very high abundances in autumn. For the year as a whole, however, abundance of the brine shrimp population in 1989 appears not to have differed greatly from abundances in other recent years (Figure 3E-12).

IMPACT ASSESSMENT METHODOLOGY

Impact Prediction Methodology

Alkali Fly Productivity Model

Introduction. The effects of the alternatives on alkali fly production in Mono Lake were assessed based on results of the field and laboratory studies described above under "Environmental Setting" and in Appendix I. These studies suggest that the most important effects of different lake levels are changes in salinity and area of high-quality habitat (effective habitat area); therefore, this assessment focused on these impacts. Temperature, which controls seasonal patterns of alkali fly biomass and production, also was considered.

The alkali fly productivity model, described in detail in Appendix L, predicts the effects of various lake surface elevations on the alkali fly population at Mono Lake. Using available lake bathymetry and alkali fly field and experimental data for model input and calibration, this population model estimates the relative seasonal abundance of alkali fly aquatic lifestages for various lake levels. The model estimates monthly alkali fly average biomass and cumulative production at environmental conditions corresponding to lake elevations from 6,350 to 6,420 feet. The model also simulates effects of salinity and effective habitat surface area of different lake levels on the alkali fly population. Salinity influences mean density, biomass, and production per unit area of substrate; effective habitat surface area affects lakewide total biomass and production.

Figure 3E-16 presents a diagram of the alkali fly assessment model calculations and indicates the necessary input data and assumptions. Figure 3E-17 shows the locations of sampling stations that provided density data used in the model. The model computes daily mean density of individuals per unit area of available high-quality hard substrate for each alkali fly lifestage. These densities are then applied for each lake elevation to the effective habitat area that reflects the relative value of hard and soft substrates and the decrease in habitat usability with depth. Depth-weighting for both hard and soft substrates is based on empirical equations developed from sample counts at various depths. Soft substrate areas are weighted at 5% or 10% (depending on distance from hard substrate) of their actual areas because mean fly densities observed on soft substrates are much lower than on hard substrates. No allowance is made for the effects of submerged vegetation. An important assumption of the model is that the relative densities of alkali fly on hard and soft substrates do not change with changes in lake level. The validity of this assumption is unknown.

The model calculates mean daily density, biomass, and production for the May 1 and October 31 growing season. The 1991 field data were collected during this period; temperatures are too cold for significant growth in other months.

Egg Pattern. The model estimates of egg density on high-quality hard substrates use an empirically derived relationship with temperature that closely matches the observed average hard substrate egg density pattern during 1991. The number of eggs hatching each day to become first instars is determined from the egg density divided by the egg development time multiplied by percent hatching success. Egg hatching success is assumed to decrease linearly with increasing salinity. The model assumes that adult densities and fecundity are not affected by salinity; thus, the same empirical egg pattern is used for all lake levels.

Development Time. Development times of alkali fly in the model depend on temperature and salinity (Appendix L). Daily temperatures are used to estimate development times for each lifestage, and development is considered to halt at temperatures below 10°C. Above 10°C, development time decreases with temperatures. At 20°C, development times are assumed to be 3 days for eggs, 4 days for first instars, 7 days for second instars, 15 days for third instars, and 15 days for pupae. Development times for larval instars are assumed to lengthen with increasing salinity, whereas development times for eggs and pupae are assumed to be unaffected by salinity.

Density Estimates. Daily first instar density is calculated as the previous day's density, plus the eggs that hatch, minus the first instars that develop into second instars, and minus the first instars lost to mortality. An initial first instar density was obtained from selected field data on April 31. Second, third, and pupal densities are calculated similarly. Actual data are unavailable, but mortality is assumed to increase from 1% per day at 50 g/l salinity to 10% per day at 150 g/l salinity for the larval lifestages. Pupal mortality is not affected by salinity and for modeling purposes is assumed to be 0% for all salinities. Temperature does not affect mortality rates in the model.

Biomass Estimates. Daily biomass for each lifestage is estimated as the product of population density (individuals per square meter) and the estimated mean dry weight of that lifestage. The mean weight of larvae was assumed to be 50% of the weight of the fully developed life stage. Pupal weight was assumed constant. No direct measurements of biomass from the 1991 field data exist for calibration of daily modeled biomass.

Production Estimates. Production at each life stage is estimated as the product of the mean weight of the fully developed life stage and the development rate of that life stage. The production usable by foraging birds is estimated from third instar production. The model calculates the seasonal total production for each lake level by summing daily production values.

The model estimates the proportion of third instar population that remains attached to the substrate as pupae and the fraction that is lost from the substrate to become open water drift or is windrowed ashore. The model specifies separate loss fractions for hard substrate (10%) and soft substrate (90%). The great majority of dislodged third instars and pupae are blown ashore as windrows; an unknown fraction becomes drift available to water birds.

Brine Shrimp Productivity Model

Introduction. Assessing effects of the alternatives on production of Mono Lake brine shrimp is based on results of the field and laboratory studies described above under "Environmental Setting" and in Appendix J. These studies suggest that the most important effects of different lake levels are changes in food production (planktonic algae), salinity, and total habitat area (lake surface area); therefore, this assessment focused on these impacts. Temperature and dissolved oxygen concentration, factors important in brine shrimp population dynamics, also were considered.

The brine shrimp productivity model predicts the effects of various lake surface elevations on the brine shrimp population at Mono Lake. The model includes separate physical and biological limnology models to simulate temperature, light level, vertical mixing, and salinity changes and their effects on algae and brine shrimp production. A complete description of the brine shrimp productivity model is presented in Appendix M, supported by reports from the UC Santa Barbara research group (especially Jellison, Dana, Romero, and Melack [1991]). The UC Santa Barbara research and assessment models are largely directed toward understanding possible effects of increasing salinity; lower salinity conditions have not been as intensively studied.

Physical Limnology Model. Vertical temperature, salinity, and mixing patterns in Mono Lake were simulated with a computer model, Dynamic Reservoir Simulation Model (DYRESM) (Jellison, Dana, Romero, Melack 1991). DYRESM models the lake as a vertical stack of horizontal layers of uniform temperature and salinity (as conductivity). The model uses mass balance equations to calculate changes in the volume, temperature, and salinity of each layer. The layers fluctuate vertically with changes in volume caused by inflows, rainfall, and evaporation.

DYRESM simulations for each lake level alternative were run for a 50-year period beginning with the point-of-reference elevation of 6,376.3 feet. Inflows and lake level fluctuations simulated with LAAMP (Jones & Stokes Associates 1993) were used as input for the DYRESM model. Daily meteorological data for 1990 were used for all 50 years of simulation.

Simulated years with vertical salinity differences that persisted through the mixing season were considered meromictic years. The frequency of meromictic years during the 50-year simulations estimates the probability of producing meromictic conditions in the lake under each alternative. Conditions during the period of transition from the point of reference to the final equilibrium conditions for each lake level alternative were simulated; thus, the simulations estimate the probability of meromixis (meromictic conditions) under a combination of transition and final conditions. The probability of meromixis under final conditions was estimated as the frequency of meromictic years during the final decade of the DYRESM simulations. Use of the final decade overestimates the probability of meromixis because the hydrologic inputs used for the final decade are the actual hydrologic conditions that produced the long meromictic period of the 1980s.

The DYRESM model algorithms are described in the model documentation (Imberger and Patterson 1981), the UC Santa Barbara application to Mono Lake (Jellison et al. 1991; Dana, Jellison, Romero, and Melack 1992), and Appendix M.

Biological Limnology Model. The biological limnology model contains two linked submodels: a nitrogen submodel that simulates the movement of nitrogen in Mono Lake and a brine shrimp submodel that simulates brine shrimp population dynamics (Appendix M). The biological model simulated only 1 year, representing the final condition of each lake level alternative, but the year was simulated for both monomictic and meromictic conditions. The DYRESM final decade results were then consulted to determine whether monomixis or meromixis would be more likely under the final equilibrium conditions for that alternative.

Nitrogen Balance Submodel. The nitrogen balance submodel simulates nitrogen movement among pools representing the sediments, the hypolimnion, the epilimnion, the planktonic algae, and the brine shrimp population (Figure 3E-18). Nitrogen in the hypolimnetic and epilimnetic pools is present almost entirely as ammonium (NH_4^+), while that in the algae and brine shrimp is bound up in tissues, feces, or other particulate forms. Only the ammonium nitrogen, which is dissolved, is immediately available to algae (see Appendix M, Table M-2, for nitrogen [N] equivalence formulas).

The submodel assumes a constant areal rate of ammonium release from the sediments. When Mono Lake is holomictic (not stratified), the released ammonium moves directly into the combined epilimnetic and hypolimnetic pool. When the lake is stratified, the ammonium is added to the hypolimnetic and epilimnetic pools separately, based on the area of sediments within each layer. Vertical movement of ammonium between the hypolimnion and epilimnion is modeled by moving slabs of water with the ammonium they contain back and forth between the water layers as the epilimnetic depth changes. Movement of nitrogen from ammonium to the algae (nitrogen assimilation) is modeled as a photosynthetic growth process. The submodel assumes algal growth rate is regulated by temperature, light, ammonium concentration, and salinity in the epilimnion.

Nitrogen is removed from the algal pool through grazing by brine shrimp and by sedimentation (the settling of algae out of the epilimnion). The maximum grazing rate of a brine shrimp is dependent on its weight and the water temperature. When the grazing rate is below maximum (because algal biomass is below the upper limit), the rate is dependent on algal biomass, as well as the weight class and temperature. Total daily transfer of nitrogen from the algal pool to the brine shrimp pool is the sum over all weight classes of the weight class grazing rate times the number of brine shrimp in the weight class.

Nitrogen leaves the brine shrimp pool by excretion, defecation, cyst production, and mortality. Excreted nitrogen (ammonium) is immediately available for reuse by the algae, but the other processes result in particulate nitrogen that settles to the lake bottom. Nitrogen excretion and defecation rates are assumed equal to that portion of nitrogen from ingested algae not used for growth or production of cysts or nauplii (i.e., grazing minus production).

Brine Shrimp Submodel. The brine shrimp submodel simulates hatching of cysts, grazing, growth, development, naupliar production, cyst production, excretion, defecation, and mortality of a population of brine shrimp (Jellison, Melack, Dana 1992). Growth of the brine shrimp is modeled by incrementing their weight by a fixed proportion (growth efficiency) of the weight of the grazed algae (i.e., that not lost to feces and excretion). Grazing and growth are computed in terms of nitrogen content (i.e., weight of nitrogen consumed and nitrogen weight added to body tissue). The model assumes no growth occurs in the adult stage and that, for ovigerous females, a fixed proportion (reproductive efficiency) of grazed algae is devoted to production of nauplii (ovoviviparity) or cysts (oviparity). Division of the total number of nauplii and cysts produced depends on the time of year, water temperature, algal biomass, and the number of broods previously produced. The initial size of the brine shrimp population is held constant to simplify comparisons of the different lake levels.

Brine shrimp mortality was modeled by removing from the population each day a proportion (mortality rate) of the individuals in each age class. Separate mortality rates were estimated for nauplii, juveniles, and adults.

The effect of salinity on the brine shrimp population is incorporated into the submodel by adjusting model parameters. Growth efficiency, reproductive efficiency, percent ovigerity (i.e., percent ovigerous females), cyst hatching success, and maximum rate of algal growth increase in the model as salinity declines, whereas mortality of juveniles and adults, the peak day of cysts hatching, and percent ovoviviparity (i.e., percent of broods containing nauplii rather than cysts) decrease. All the changes in model parameters, except percent ovoviviparity, cause higher brine shrimp production at lower salinities. However, the ovoviviparity results are suspect because percent ovoviviparity in the bioassays was consistently much lower than from field observations (Jellison, Melack, Dana 1992).

Because of trophic interactions, brine shrimp productivity would probably be much less affected by salinity increases than the direct effects of salinity on the brine shrimp suggest. For instance, because brine shrimp are food limited much of the year, reductions in brine shrimp growth efficiency because of higher salinity would mean more ammonium excretion and algal growth, thereby allowing higher brine shrimp grazing and growth rates. The effects of salinity cannot be properly understood in isolation from the other factors that affect brine shrimp production.

Factors Not Included in the Models

Competition and Predation. One possible impact on the alkali fly and brine shrimp that could not be simulated is competition or predation from new species invading Mono Lake at lower salinities. David Mason (1967) found rotifers in Mono Lake between 1959 and 1963 when the salinity was about 62 to 70 g/l, but numbers were generally too low to affect the brine shrimp population. Dana et al. 1992 speculate that the brine shrimp population could experience competition and predation in Mono Lake only at salinities below about 50 g/l. At prediversion salinities, which were about 50 g/l, predation and competition would probably not have had much effect on alkali fly productivity (Herbst pers. comm.).

SubmergedVegetation. Lakeshore submerged vegetation may be important habitat for the alkali fly. Normal fluctuations in lake level cause periodic flooding of shoreline vegetation and may persist under water for up to 10 years and support high densities of alkali larvae and pupae (Herbst 1990a, 1990b). Submerged vegetation is likely to be a less important habitat at low lake levels than at high lake levels because alkalinity of most near-lake soils at low lake levels is too high to sustain plants, while salt grasses and other plants are relatively abundant at higher elevations. The alkali fly productivity model does not incorporate submerged vegetation into effective habitat area because too little is known about its importance; consequently the existing model may underestimate productivity at the higher lake level alternatives.

Changes in Relative Value of Substrate Types with Lake Level. As noted earlier, the alkali fly model assumes that densities of alkali fly on soft substrates are 5% or 10% (depending on distance from hard substrate) of estimated densities on hard substrates. Although processes may exist that would lead to changes in relative densities of alkali fly on hard and soft substrates with changes in lake level, the overall effect of these processes cannot be quantified. Therefore, the model assumes that the relative densities remain constant for all alternative lake levels. If, however, relative density on soft substrate increases at higher lake levels, then the model underestimates alkali fly productivity at higher lake levels.

Vertical Mixing Regime. The alkali fly model does not consider the vertical mixing regime of Mono Lake (monomixis versus meromixis), but the mixing regime probably has much less influence on the littoral zone than on the pelagic zone and therefore is unlikely to significantly affect alkali fly productivity.

Determination of Point-of-Reference and Prediversion Conditions

Point-of-Reference Condition. Model simulations of the point-of-reference scenario were used to describe point-of-reference conditions for the alkali fly and the brine shrimp populations. The simulated point-of-reference values were derived in the same way that predictions for the alternatives were derived and therefore provide relatively consistent comparisons. Recent field data are presumably more accurate, but were unavailable for 1989 and would provide less consistency if used as point-of-reference conditions and compared to model simulation results.

The simulations of the alkali fly productivity model, the physical limnology model (DYRESM), and biological limnology model for brine shrimp productivity used different elements of the point of reference. DYRESM used streamflows at the point of reference, while the alkali fly model and the biological limnology model used the lake level at the point of reference (6,376 feet).

DYRESM simulations of the first 50 years follow the LAAMP simulated surface elevations and releases to Mono Lake shown in Chapter 2 for the point of reference. These DYRESM simulations of the point-of-reference streamflows indicate that about 20 of the next 50 years would be meromictic, including all years of the final decade. However, the DYRESM simulation for the 6,377-Ft Alternative, which has a target lake level only 1 foot higher than the point-of-reference lake level, indicates that only 1 year of the final decade is meromictic (Figure 3E-19). The final equilibrium conditions simulated by DYRESM for the 6,377-Ft Alternative were considered more representative of the point-of-reference lake level conditions than the final equilibrium conditions of the point-of-reference simulations, and the probability of meromixis at the point-of-reference lake level was considered low. Therefore, predictions for the brine shrimp impact assessment variables under the different lake level alternatives were compared with point-of-reference values that assumed monomictic conditions. The alkali fly impact assessment variables were not affected by the mixing regime (i.e., monomixis versus meromixis).

Alkali Fly. The alkali fly model simulation of point-of-reference conditions generally matches observed conditions fairly closely. Simulated and observed values are close for density of eggs, first and third instar larvae, and pupae (Appendix L, Figures L-23, L-24, L-26, and L-27). The match is not as good for second instar larvae and drift (Appendix L, Figures L-25 and L-28).

Brine Shrimp. Simulations of the brine shrimp model for a lake surface elevation of 6,375 feet, just 1 foot less than the point-of-reference lake elevation, were also used to describe point-of-reference conditions in the brine shrimp impact analyses. The simulated point-of-reference values were determined for both monomictic and meromictic conditions; each variable thus has two point-of-reference values. However, as noted earlier, monomictic conditions were considered to be more representative of typical point-of-reference conditions than meromictic conditions, and predictions for the different alternatives were compared only with the point-of-reference values for monomictic conditions. Comparisons with the point-of-reference values for meromictic conditions can be made by consulting Table 3E-4 and Figures 3E-20 through 3E-22. The match between the simulated point-of-reference values and means of estimates derived from field data for meromictic (1983-1988) and monomictic (1989-1990) years is poor in some cases (see Appendix M).

Prediversion Condition. Prediversion conditions in Mono Lake are largely unknown, so cumulative impact assessments are necessarily speculative. Simulation results for the No-Diversion Alternative should most closely match prediversion conditions. The DYRESM simulations indicated that the probability of meromixis is very low under final equilibrium conditions above 6,390 feet (Figure 3E-19), and monomictic conditions were assumed at the prediversion lake level for the cumulative impact assessment. DYRESM simulations were not actually made for the prediversion conditions.

Alkali Fly. The alkali fly model results for the No-Diversion Alternative (6,420 feet lake level) should most closely match prediversion conditions. These results, however, show a substantial decrease in productivity from the point-of-reference level, contradicting many historical accounts of very high prediversion abundances of alkali flies (see "Prediversion Conditions" section). This difference could not be resolved, but the simulation results should be interpreted cautiously, particularly when projecting well beyond observed conditions, because potentially important factors (e.g., submerged vegetation habitat area) that may be missing from the model could lead to substantial prediction errors.

Brine Shrimp. The No-Diversion and 6,410-Ft Alternatives, which presumably would most closely match prediversion conditions, were not simulated with the biological model. Therefore, simulation results for the 6,390-Ft Alternative, the highest lake level simulated, were used as a proxy for the prediversion conditions. Representing prediversion conditions with the 6,390-Ft Alternative probably underestimates the cumulative impacts of most alternatives because brine shrimp and cyst production are presumed to increase at lake levels above 6,390 feet (see impacts and mitigation measures for 6,410-Ft and No-Diversion Alternatives). Furthermore, cumulative impacts of the 6,390-Ft, 6,410-Ft, and No-Diversion Alternatives cannot be estimated, but it is assumed that they would be less than significant.

Criteria for Determining Impact Significance

Several impact assessment variables were selected to evaluate the impact of lake levels changes on the alkali fly and brine shrimp populations, particularly as they affect feeding conditions for birds. Criteria for determining impact significance for each variable are discussed below.

Project Impacts

Alkali Fly. Variables selected to evaluate predicted changes in the overall abundance of alkali flies and their availability to birds were lakewide total annual (May-October) production of pupating third instar larvae (MT/lake), areal mean drift (dislodged third instar larvae) density (ind/m^2), and lakewide total annual production of drift (MT/lake). Actual drift densities are expected to be about 10 times smaller than predicted drift estimates. Alternatives were considered to have significant effects if third instar larvae, drift production, or drift density is predicted to differ by more than 10% from point-of-reference estimates. This was considered to be the threshold for measurement of differences in these alkali fly productivity variables.

Brine Shrimp. Brine shrimp biomass density (mg N/m^3), areal mean (g N/m^2) and lakewide total annual brine shrimp production (MT N/lake), and areal mean and lakewide total cyst production (numbers of cysts) were used to evaluate effects of alternatives on brine shrimp availability to birds. Brine shrimp biomass and production directly estimate feeding conditions for birds, whereas cyst production affects the long-term survival potential of the brine shrimp population. The biomass density of brine shrimp is useful for analyzing bird food availability because food density, not simply total amount of food, may be important for birds feeding on small prey such as brine shrimp. Birds must expend more energy feeding on small prey that are widely dispersed.

Annual brine shrimp production determines the capacity of the pelagic zone to support bird populations because production represents not simply the amount (biomass) of food present, but also the rate at which the food is produced. Areal mean production estimates indicate how much food is produced each year in a given area, and the lakewide totals indicate how much food is produced each year in the entire lake. The lakewide totals reflect effects of alternatives on the total surface area of habitat available and the effects on food density, salinity, nitrogen cycling, and other factors, while the areal means reflect the effects on food density, salinity, nitrogen cycling, and other factors only. Annual production estimates are expressed in terms of nitrogen to facilitate comparisons with ammonium concentrations and primary production. Annual cyst production represents the maximum potential size of the following year's population. Conversion to dry weight of biomass can be made by assuming nitrogen is about 7% of biomass (Appendix M).

Determining impact significance for brine shrimp is difficult because almost nothing is known about how declines in the brine shrimp population might threaten the population's survival or how changes in brine shrimp density, biomass, or production may affect bird populations using shrimp as food. For determining significance, the range of values in the 1983-1988 biological model simulation (Table 3E-5) was used to represent natural variability of the variables during meromictic point-of-reference conditions and the range of values in the 1989-1990 simulation was used to represent natural variability during monomictic point-of-reference conditions. However, 1989-1990 is too short a period to estimate variability reliably, so natural variability for monomictic conditions was estimated as the range of values during meromictic conditions scaled to the value of the monomictic point of reference (i.e., monomictic range = meromictic range times [monomictic point of reference divided by meromictic point of reference]). Natural variability for lakewide totals (monomictic and meromictic) was estimated as the range of the areal means scaled to the point-of-reference values for lakewide totals.

For the impact analyses, predicted values of the impact assessment variables for lake level alternatives that exceeded point-of-reference values by more than 25% of the estimated range of natural variability were considered to represent significant beneficial effects; those that fell below point-of-reference values by more than 25% of the range were considered to represent significant adverse impacts. Predicted values that were within 25% of the estimated range were determined to have no significant effect (termed "point-of-reference range for no impacts"). Point-of-reference ranges for no impact for the impact assessment variables were used to evaluate impacts of the alternatives (Table 3E-4). Point-of-reference estimates for monomictic conditions were used for impact assessments, but estimates for meromictic conditions are also presented (Table 3E-4, Figures 3E-20 through 3E-22) because, as noted earlier, the point-of-reference equilibrium lake level condition has an estimated 10% probability of meromictic conditions.

Significant impacts on alkali fly are judged based on 10% change from the point-of-reference mean estimate, while impacts on brine shrimp are judged based on 25% of the estimated natural variation.

Cumulative Impacts

Alkali Fly. An alternative lake level was considered to have a significant adverse impact on alkali fly if the value of any of the alkali fly impact assessment variables (lakewide total third instar annual production, areal mean drift density, and lakewide total annual drift production) was more than 10% below the projected No-Diversion Alternative value.

Brine Shrimp. The impact assessment criteria used for determining significance of cumulative impacts are the same as those used for the point-of-reference impacts (brine shrimp biomass, mean areal annual production, total lakewide annual production, mean areal annual cyst production, and lakewide total annual cyst production), but the no-impact ranges of natural variation between years were scaled to the estimated prediversion values (6,390-Ft Alternative) (Table 3E-4).

SUMMARY COMPARISON OF THE IMPACTS AND BENEFITS OF THE ALTERNATIVE

Effects of the alternatives on the alkali fly and brine shrimp populations are listed below and in Tables 3E-6 and 3E-7. Impacts on and benefits to alkali fly are based on predicted changes in annual production of third instar larvae, and annual production and density of drift (dislodged third instar larvae), while impacts on and benefits to brine shrimp are based on predicted changes in brine shrimp biomass and annual production of brine shrimp and cysts.

OVERVIEW OF MODEL PREDICTIONS

Alkali Fly Effects

Alkali fly impact assessment results are summarized in Table 3E-8. Predicted monthly and annual (May-October) lakewide alkali fly production estimates for third instar larvae and drift over a range of lake levels (6,350-6,420 feet) are shown in Figures 3E-23 and 3E-24. Production is minimized at the lowest evaluated lake level because of high salinity and reduced habitat area. Maximum values occur at intermediate lake elevations of 6,380-6,390 feet where the effective habitat area is greatest and salinity is decreased. At higher elevations, salinity impacts are further reduced, but the effective habitat also is smaller and drift density and productivity decline. As noted earlier, effective habitat may be underestimated at the higher elevations because submerged vegetation is not modeled and because relative densities of alkali fly on hard and soft substrates may change with changes in lake elevation.

The effects of changing salinity within the evaluated elevation range of 6,350 feet (147 g/l salinity) to 6,420 feet (46.5 g/l salinity) without the influence of effective habitat area are indicated by changes in areal mean density and production estimates. Third instar densities increased from 8,000 to 60,000 ind/m^2 as salinity decreased from 147 to 46.5 g/l, primarily due to reduced mortalities. Pupating third instar productivity increased from 1.6 to 9 g/m^2/day within the identical range of salinities, due to increased densities, decreased development times, and higher mean weights.

To evaluate the effects of changing effective habitat area without simultaneously affecting salinity, the assessment model was run for the evaluated elevation range with salinity fixed at 46.5 g/l (the lowest salinity within the range of evaluated elevations). Total production of pupating third instars reached a maximum of 2,700 MT/lake in the elevation range of 6,375-6,395 feet, which is twice that produced when salinity effects are incorporated (Figure 3E-23). At higher lake elevations, habitat-influenced production approaches levels shown in Figure 3E-23 (700 MT/lake at 6,420 feet elevation) because the actual salinity approaches the modeled constant salinity of 46.5 g/l. At lower elevations when salinity is highest at 147 g/l, habitat-influenced production (900 MT/lake at 6,350 feet elevation) is more than six times the production anticipated when salinity impacts are included. Drift production follows a similar pattern to production of pupating third instars, with 90% on soft substrate and 10% on hard substrate assumed to become drift.

Brine Shrimp Effects

Table 3E-9 summarizes predicted values for several brine shrimp variables at different Mono Lake surface elevations. The lowest lake level, 6,360 feet, corresponds approximately to the lake level under the No-Restriction Alternative, and the highest lake level, 6,390 feet, is lower than the 6,410-Ft and No-Diversion Alternatives. The predictions are derived from 1-year simulations of the biological limnology model using 1984 and 1990 observed daily temperature and salinity profiles as inputs to represent meromictic and monomictic conditions, respectively.

Areal primary production (i.e., primary production per unit area of the lake) would vary little among the different lake levels, regardless of whether monomictic or meromictic conditions are assumed, but total lakewide production would increase 50% from the lowest (6,360 feet) to highest (6,390 feet) simulated lake levels. Total lakewide primary production would probably continue to increase at higher lake levels. These increases of total production largely reflect the increased habitat area available at higher lake levels. Predicted primary production was much lower for meromictic conditions than for monomictic conditions. This difference may result more from the particular years 1984 and 1990 having been selected for input data than from any consistent difference in primary production attributable to the mixing regime.

Predicted brine shrimp production differed greatly among lake levels on both an areal and total lakewide basis (Table 3E-9). The predictions for monomictic and meromictic conditions differed much less than did the primary production predictions.

Three major factors would affect brine shrimp production at the alternative lake levels: nitrogen availability for growth of algae, salinity, and lake surface area. Lake surface area and salinity are relatively constant at a given lake level, while nitrogen availability is highly variable. Therefore, at a given lake level, salinity and lake surface area limit maximum rates of algae and brine shrimp production, but nitrogen availability determines the realized rates within these limits.

Nitrogen Availability and Mixing Regime Impacts

Model simulations of annual growth patterns of algae in a meromictic year (1984) and a monomictic year (1990) demonstrate the importance of nitrogen availability (Figure 3E-25). The simulations show potential growth rates of algae as controlled by temperature alone, light level alone, and epilimnetic dissolved nitrogen (ammonium) concentration alone. Temperature variations alone would produce a threefold to fivefold increase in algal growth rate from winter to summer. However, the growth rates based on temperature were never realized because, at all times, light level or ammonium concentration held growth rates below those determined by temperature alone. In 1984, ammonium concentrations limited growth at all times except during summer, when the brine shrimp excrete large amounts of ammonium. In 1990, light conditions limited growth in winter, early spring, and perhaps in late summer, but ammonium concentrations limited growth most of the year. These patterns of growth limitation are consistent with findings of other research conducted at Mono Lake (Jellison, Dana, Romero, Melack 1991; Jellison and Melack 1992).

The UC Santa Barbara field studies found that year-to-year variations in epilimnetic ammonium concentrations in Mono Lake were strongly influenced by the vertical mixing regime (i.e., whether the lake was monomictic or meromictic) (Jellison, Dana, Romero, and Melack 1991; Jellison, Dana, and Melack 1991). Much less of the ammonium released from the sediments reached the mixed layer early in the 1983-1988 meromictic period than during monomictic years because the chemocline limits ammonium transport. However, as ammonium concentrations in the monimolimnion increased and the chemocline deepened later in the meromictic period, mixed layer ammonium concentrations increased (Figure 3E-10), leading to increases in algal biomass (Figure 3E-11). The most dramatic increase in epilimnetic ammonium concentration occurred in 1989, following breakdown of meromixis.

Although ammonium availability and algal production were clearly suppressed immediately after meromixis became established in 1982-1983, elevated levels later in the meromictic period and immediately after meromixis broke down may have produced long-term averages that are no lower than those occurring under equilibrium monomictic conditions. The field studies provided no multiyear record of monomictic conditions with which to test this possibility. Nonetheless, meromixis does change the nitrogen balance of Mono Lake, but it may not affect long-term productivity because reduced production early in the meromictic period may be balanced by elevated production late in the period and immediately after meromixis breaks down.

Meromixis in Mono Lake clearly influenced algal biomass, which was relatively low in 1983 through 1987 and high in 1988 through 1990 (Figure 3E-11), but had little effect on brine shrimp production. Peak abundances of brine shrimp showed no consistent relationship to presence or absence of meromixis (Figure 3E-12). In most years, algal biomass peaked in early spring before brine shrimp were present in sufficient numbers to exploit it effectively, so only a portion of annual primary production influenced brine shrimp production. Therefore, effects of meromixis on algae were not necessarily propagated up the food chain to the brine shrimp population.

Meromixis reduces the proportion of Mono Lake sediments that receive dissolved oxygen during the winter mixing period and this factor, too, could be expected to inhibit brine shrimp production because brine shrimp cysts do not hatch in anoxic sediments. However, even under meromictic conditions, the number of cysts in oxygenated sediments is more than sufficient to replenish the population.

Many, but not all, of the effects of meromixis observed in the field were successfully simulated by the computer models. The 1983-1990 simulations (Table 3E-5) successfully simulated year-to-year increases in summer epilimnetic ammonium concentrations during meromixis, but failed to simulate the large increase observed in 1989 (Figure 3E-10). As noted earlier, the model simulations for 1984 representing early meromictic conditions overestimated summer epilimnetic ammonium concentrations. Despite these problems, the model accurately simulated brine shrimp biomass for both 1984 and 1990 and was consistent with field observations in indicating that mixing regime (i.e., meromixis versus monomixis) had little influence on brine shrimp production.

Salinity Impacts

Salinity in Mono Lake would decrease from about 120 g/l at a lake level of 6,360 feet to 71 g/l at 6,390 feet. Most of the difference in predicted brine shrimp areal production among the simulated lake levels (Table 3E-9) results from salinity effects. Salinity would cause even greater differences if not for interactions of brine shrimp with the other nitrogen pools (i.e., algae and ammonium). Predicted areal brine shrimp production varied more than 1,000% between lake levels of 6,360 and 6,390 feet when simulations did not include nitrogen exchanges among the brine shrimp, algae, and ammonium (Table 3E-10). When these interactions were included, predicted production increased less than 100% between 6,360 and 6,390 feet (Table 3E-9).

The nitrogen interactions ameliorate the influence of salinity on brine shrimp production by improving growth conditions for the shrimp as production decreases. For example, the reduction in shrimp production at higher salinities results partly from reduced growth efficiency (Appendix M). Reduced growth efficiency increases ammonium excretion per shrimp (because less of the grazed algae is used for growth and more is directed to excretion and defecation), which increases algal production. Reduced shrimp production reduces grazing, which also increases algal production.

Lake Surface Area Impacts

The effect on total primary and brine shrimp production from changes in Mono Lake surface area was simulated by multiplying the predicted mean areal estimates of production by the projected surface areas. Because differences in surface area between alternatives were considerable (Table 3E-8), the surface area effect was substantial. Total primary production increased about 50% as lake level rose from 6,360 feet to 6,390 feet and, as noted earlier, nearly all this difference was caused by the surface area effect alone (Table 3E-9). Total brine shrimp production increased about 250% between lake levels of 6,360 and 6,390 feet (Table 3E-9), but approximately half of this increase was caused by the surface area effect and half by the salinity effect. At higher lake levels, total brine shrimp production would probably continue to increase considerably.

IMPACTS AND MITIGATION MEASURES FOR THE NO-RESTRICTION ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

LAAMP model results (Jones & Stokes Associates 1993) show that lake levels under the No-Restriction Alternative would eventually stabilize at about 6,350 feet, 26 feet below the lake level point of reference. As a result, lake surface area would drop from 40,724 acres to 29,650 acres, and effective habitat area for the alkali fly would decrease by more than half from 981 acres to 410 acres. Salinity would increase from 90.8 g/l to 147 g/l.

DYRESM simulations of the No-Restriction Alternative were not made because UC Santa Barbara staff determined that the lake salinity would increase beyond the observed range of values so that several assumed "equations of state" and the relationship between salinity and conductivity would exceed the applicable range. However, because of increased lake salinity, it is reasonable to assume that freshwater inflows would have a strong effect on salinity stratification and that meromictic events would occur more frequently and persist for longer periods of time than the point-of-reference simulations indicated. Therefore, predictions for this alternative assuming meromictic conditions were used to assess impacts.

Alkali Fly Effects. The No-Restriction Alternative was simulated with the alkali fly model based on a lake level of 6,350 feet, the dynamic equilibrium lake level predicted for this alternative by LAAMP (Jones & Stokes Associates 1993).

Third instar lakewide productivity would decrease 84% from 919 metric tons (MT) to 146 MT (Table 3E-8, Figure 3E-23). This reduction is greater than 10% and therefore is considered a significant adverse impact on third instar productivity.

Seasonal lakewide drift production would decrease 80% from 409 MT to 82 MT. Drift densities would be reduced 66% to 5.6 ind/m^2 (Table 3E-8, Figure 3E-24). Both reductions are significant adverse impacts.

Brine Shrimp Effects. The No-Restriction Alternative was simulated with the biological submodel by assuming a lake level of 6,360 feet, though the lake would decline to 6,350 feet under this alternative. Therefore, the 6,360 foot simulations may underestimate the impacts of this alternative.

Predicted brine shrimp biomass, areal mean production, and lakewide total production are below point-of-reference values (Table 3E-9) and are below the point-of-reference ranges for no impacts (Figures 3E-20 and 3E-21). Predicted areal mean and lakewide total cyst production for the 6,360-Ft Alternative are also below the point-of-reference ranges for no impacts (Figure 3E-22). The reductions in brine shrimp biomass, production, and cyst production are considered significant adverse impacts because the predicted values are below the point-of-reference ranges for no impacts.

Differences between meromictic and monomictic conditions had little effect on the brine shrimp (Table 3E-9, Figures 3E-20 and 3E-21) and contributed little to the differences between the predicted values and the point-of-reference range for no impact. The principal cause of the adverse impact of the 6,360-Ft Alternative on the brine shrimp population was increased salinity, though decreased surface area also affected the lakewide totals.

Near-Term Changes

The alkali fly and brine shrimp models are designed to evaluate conditions at a fixed lake level and are not well suited for assessing near-term impacts during the period of transition to the alternative. Furthermore, it is difficult to generalize about near-term impacts because the transition to the alternative lake level would be gradual and continuous. Generally, near-term conditions for alkali fly and brine shrimp are expected to be intermediate between point-of-reference conditions and final equilibrium conditions under the No-Restriction Alternative. Frequency of meromictic events might be somewhat reduced early in the transition period because of reduced freshwater inflows but would later increase above point-of-reference values.

Drought Effects

Under the No-Restriction Alternative, a drought would not substantially increase salinity of Mono Lake (Chapter 2) and would therefore not reduce alkali fly and brine shrimp production below the levels predicted for the No-Restriction Alternative. Probability of meromixis would increase following a period of drought, but impacts on alkali fly and brine shrimp production from meromixis are uncertain.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (No-Restriction Alternative)

- # Significantly decreases lakewide alkali fly production, lakewide drift production, and drift density by 84%, 80%, and 66%, respectively.

Mitigation Measures. Herbst measured alkali fly density on artificial (concrete) substrates and found densities similar to those on tufa (1992). In theory, therefore, impacts of the No-Restriction Alternative on the alkali fly population could be mitigated by placing many concrete blocks in the littoral zone of the lake. However, this measure would have a substantial adverse visual impact if the lake level decreased and exposed the blocks (as might occur during drought). Also, the measure would probably be incompatible with the Mono Basin National Forest Scenic Area Management Plan and be expensive to implement.

- # Significantly decreases brine shrimp biomass, areal mean and lakewide production, and areal mean and lakewide cyst production by 40%, 32%, 44%, 52%, and 60%, respectively.

Mitigation Measures. None are available because there are no practical methods to manage the brine shrimp populations in Mono Lake.

IMPACTS AND MITIGATION MEASURES FOR THE 6,372-FT ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

Lake levels under the 6,372-Ft Alternative would reach a dynamic equilibrium at about 6,375 feet, about 1 foot below the point-of-reference elevation. Lake surface area, effective alkali fly habitat area, and salinity would therefore change only slightly from the point-of-reference condition (Table 3E-8). LAAMP simulations of lake level fluctuations under the 6,372-Ft Alternative indicate that the lake level would vary between 6,372 feet and 6,379 feet.

Meromictic conditions are predicted by DYRESM model for a few years (1956, 1969, and 1982-1986), but the salinity differences between the surface and bottom layers were relatively small (2-8 g/l); the meromictic conditions did not persist for many years. A total of 6 years (out of 50) are predicted to be meromictic under the 6,372-Ft Alternative, but 4 of these years would occur in the final decade

(Figure 3E-19). Because both monomictic and meromictic conditions appear to be likely under this alternative, predictions were made for both conditions.

Alkali Fly Effects. The 6,372-Ft Alternative was simulated with the alkali fly model by assuming a lake level of 6,375 feet, the dynamic equilibrium lake level predicted for this alternative by LAAMP.

Third instar lakewide productivity would decrease 9%, from 919 MT to 832 MT (Table 3E-8). This reduction is considered a less-than-significant impact.

Seasonal lakewide drift production would fall 9%, from 409 MT to 373 MT (Table 3E-8). Drift densities would decrease 6%, to 15.5 ind/m^2. Both reductions are less than 10% and therefore are less than significant.

Brine Shrimp Effects. Regardless of whether monomictic or meromictic conditions are assumed for this alternative, the predicted values of brine shrimp biomass, areal mean production, and lakewide total production for the 6,372-Ft Alternative fall within the point-of-reference ranges for no impacts (Figures 3E-20 and 3E-21), and thus impacts on brine shrimp productivity are considered to be less than significant.

Predicted areal mean and lakewide total brine shrimp cyst production for the 6,372-Ft Alternative under monomictic conditions are 86% and 79% of the point-of-reference values (Table 3E-9) and are below the point-of-reference ranges for no impacts. The predicted values for cyst production under meromictic conditions are within the no-impact ranges (Figure 3E-22). Under monomictic conditions, implementation of the 6,372-Ft Alternative would have a significant adverse impact on cyst production; under meromictic conditions, implementation would have a less-than-significant impact on cyst production. However, the point-of-reference ranges for no impacts on cyst production are quite narrow and the monomictic predictions lie close to the range boundaries (Figure 3E-22), so the significant adverse impact predicted under monomictic conditions probably would be relatively minor.

Near-Term Changes

Because the difference in lake level between this alternative and the point of reference is only 4 feet, near-term changes are unlikely to have any significant impacts on the alkali fly and brine shrimp populations.

Drought Effects

Under the 6,372-Ft Alternative, drought would have minor effects on the alkali fly and brine shrimp populations.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (6,372-Ft Alternative)

Significantly decreases lakewide and areal mean brine shrimp cyst production by 21% and 14%, respectively, during monomictic conditions that are estimated to occur about 60% of the time.

Mitigation Measures. None are available.

IMPACTS AND MITIGATION MEASURES FOR THE 6,377-FT ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

The lake level dynamic equilibrium for the 6,377-Ft Alternative is about 6,380 feet, 4 feet above the lake level point of reference. Lake surface area would increase slightly from 40,724 acres to 43,670 acres, and effective alkali fly habitat area would increase from 981 acres to 1,173 acres. This alternative has the greatest estimate of effective alkali fly habitat area. Salinity would fall from 90.8 g/l to 84.6 g/l. LAAMP simulations of lake level fluctuations under the 6,377-Ft Alternative indicate that the lake level would vary between 6,377 feet and 6,383 feet.

Very weak meromictic conditions are simulated for a few years, but the salinity differences between the surface and bottom layers are so small (1-2 g/l) that meromictic conditions do not persist for more than a single year. A total of 7 years (out of 50) are simulated as meromictic under the 6,377-Ft Alternative (Figure 3E-19). Only 1 year of the final decade was meromictic, so predictions were examined for monomictic conditions only.

Alkali Fly Effects. The 6,377-Ft Alternative was simulated with the alkali fly model by assuming a lake level of 6,380 feet, the dynamic equilibrium lake level predicted for this alternative by LAAMP.

Third instar productivity would increase 32%, from 919 MT at the point of reference to 1,210 MT (Table 3E-6). These increases are beneficial effects.

Seasonal lakewide drift production would increase 29%, from 409 MT at the point of reference to 526 MT. Drift densities would increase 15%, from 16.5 to 19 ind/m^2. These increases are beneficial effects.

Brine Shrimp Effects. Predicted brine shrimp biomass, areal mean production, and lakewide total production are about 10% higher than point-of-reference values (Table 3E-9) and within point-of-reference ranges for no impacts (Figures 3E-20 and 3E-21). Slight benefits to brine shrimp would occur.

Predicted areal mean and lakewide total brine shrimp cyst production are 10% and 14% higher, respectively, than point-of-reference values (Table 3E-9). Mean cyst production is within the point-of-reference range for no impacts (Figure 3E-21a), but total cyst production is slightly above the range (Figure 3E-21b). Implementation of this alternative would benefit lakewide total cyst production.

Near-Term Changes

Because the difference in lake level between this alternative and the point-of-reference is only 2-3 feet, near-term changes are unlikely to have any measurable benefits or significant impacts on the alkali fly and brine shrimp populations.

Drought Effects

Under the 6,377-Ft Alternative, drought might reduce the lake level to 6,373 feet (Chapter 2). The effects of drought on alkali fly and brine shrimp would therefore probably be slightly adverse under the 6,377-Ft Alternative.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (6,377-Ft Alternative)

- Causes beneficial increases in lakewide alkali fly production, lakewide drift production, and areal mean drift density of 32%, 29%, and 15%, respectively.

- Causes beneficial increases in lakewide brine shrimp cyst production of 14%.

IMPACTS AND MITIGATION MEASURES FOR THE 6,383.5-FT ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

The lake level dynamic equilibrium for the 6,383.5-Ft Alternative is about 6,385 feet, 9 feet above the lake level point of reference. Lake surface area would increase slightly from 40,724 acres to 46,310 acres, and effective alkali fly habitat area would increase from 981 acres to 1,163 acres. Salinity would decrease from 90.8 g/l to 77.5 g/l. LAAMP simulations of lake level fluctuations under the 6,383.5-Ft Alternative indicate that the lake level would rise from the initial elevation of 6,376 to 6,383 feet during the first 6 years, then vary between 6,383 and 6,389 feet.

Weak meromictic conditions are predicted by DYRESM for a few years with higher than average runoff, but the salinity differences between the surface and bottom layers are so small (2-4 g/l) that meromictic conditions would not persist for more than a single year, except during the initial rise from 6,376 to 6,383 feet. A total of 9 years (out of 50) are predicted to be meromictic under the 6,383.5-Ft Alternative (Figure 3E-19). Because only 1 year of the final decade was meromictic, predictions were examined only for monomictic conditions.

Alkali Fly Effects. The 6,383.5-Ft Alternative was simulated with the alkali fly model by assuming a lake level of 6,385 feet, the dynamic equilibrium lake level predicted for this alternative by LAAMP.

Third instar productivity would increase 47%, from 919 MT to 1,353 MT (Table 3E-8). This alternative would have a very high lakewide alkali fly productivity due to a large effective alkali fly habitat area combined with a low salinity.

Seasonal lakewide drift production would increase 47%, from 409 MT to 601 MT. Drift densities would increase 19%, from 16.5 to 19.6 ind/m^2. This alternative has the highest drift densities because drift production is high relative to the lake surface area.

Brine Shrimp Effects. Predicted brine shrimp biomass, areal mean production, and lakewide total production lie 26%, 12%, and 25%, respectively, above point-of-reference values (Table 3E-7). Mean production is within the point-of-reference ranges for no impacts (Figure 3E-21a), but biomass and total production exceed these ranges for no impacts (Figures 3E-20 and 3E-21b). Lakewide total production is only slightly above the range. The 6,383.5-Ft Alternative would have substantial benefits to total brine shrimp production and brine shrimp biomass and would have minor benefits to mean brine shrimp production. The benefits to total brine shrimp production are greater than those for mean production because total production is affected by both reduced salinity and increased surface area, whereas mean production is affected by reduced salinity only.

Predicted areal mean and lakewide total brine shrimp cyst production are 40% and 58% higher, respectively, than point-of-reference values (Table 3E-9), and both values exceed point-of-reference ranges for no impacts (Figure 3E-22). The 6,383.5-Ft Alternative would have significant benefits on cyst production.

Near-Term Changs

Flooding of grasses and other shoreline vegetation during lake filling would temporarily increase suitable substrate for alkali fly larvae and pupae and therefore would probably be a substantial near-term benefit.

DYRESM simulations for this alternative predict an early period of meromixis caused by the high volume of fresh water entering the lake. Meromixis may be an important near-term impact of this alternative, but its effects are difficult to assess because the effects of meromixis on productivity are uncertain. Any impacts of meromixis during the early filling phase for this alternative could be monitored, and mitigated if necessary, by filling the lake more slowly than presently assumed by LAAMP for this alternative.

Drought Effects

Under the 6,383.5-Ft Alternative, drought might reduce the lake level to about 6,378 feet (Chapter 2). The effects on alkali fly and brine shrimp would therefore probably be similar to the impacts predicted for the 6,377-Ft Alternative. Substantial benefits to alkali fly and drift production and to brine shrimp cyst production were predicted for the 6,377-Ft Alternative, but the effects were less than predicted for the 6,383.5-Ft Alternative. Therefore, alkali fly and brine shrimp would still benefit under drought conditions with the 6,383.5-Ft Alternative, compared to the point-of-reference, but would not benefit as substantially under drought conditions as under normal conditions for the 6,383.5-Ft Alternative.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (6,383.5-Ft Alternative)

Causes beneficial increases in lakewide alkali fly production, lakewide drift production, and areal mean drift density of 47%, 47%, and 19%, respectively.

Causes beneficial increases in brine shrimp biomass, lakewide production, and mean and lakewide cyst production of 26%, 25%, 40%, and 58%, respectively.

IMPACTS AND MITIGATION MEASURES FOR THE 6,390-FT ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

Under the 6,390-Ft Alternative, lake levels stabilize at approximately 6,390 feet, 14 feet above the point of reference. Lake surface area would increase from 40,724 acres to 48,245 acres, and effective habitat area would increase very slightly from 981 acres to 993 acres. Salinity would decrease from 90.8 g/l to 71.3 g/l. LAAMP simulations of lake level fluctuations under the 6,390-Ft Alternative indicate that 30 years will be required for the lake level to rise from the initial elevation of 6,376 to 6,390 feet. The lake level will then fluctuate between 6,389 and 6,385 feet.

Weak meromictic conditions are simulated by DYRESM only for the first few years during the initial rise from 6,376 feet. The salinity drops from an initial value of about 90 g/l to about 70 g/l, and the differences between the surface and bottom layers are relatively small (2-5 g/l). Only the first 6 years (out of 50) are simulated as meromictic under the 6,390-Ft Alternative (Figure 3E-19). Because all years in the final decade were monomictic, predictions were examined for monomictic conditions only.

Alkali Fly Effects. Third instar lakewide production would increase 46%, from 919 MT to 1,341 MT (Table 3E-8).

Seasonal lakewide production of drift would increase 55%, from 409 MT to 635 MT. The 6,390-Ft Alternative has a greater total drift production than other alternatives because of a high third instar production in combination with high dislodgement rates. Drift densities would increase 15%, from 16.5 to 19 ind/m^2.

Brine Shrimp Effects. Predicted brine shrimp biomass, areal mean production, and lakewide total production lie 45%, 34%, and 49%, respectively, above point-of-reference values (Table 3E-9). Mean production is within the point-of-reference range for no impacts (Figure 3E-21a), but biomass and total production well exceed their ranges (Figures 3E-20 and 3E-21b). Mean production is only slightly below the upper boundary of the range for no impacts (Figure 3E-21a). Predicted areal mean and lakewide total brine shrimp cyst production are about twice the point-of-reference values (Table 3E-8) and greatly exceed point-of-reference ranges for no impacts (Figure 3E-22). Substantial benefits to brine shrimp for this alternative are similar to those previously described for the 6,383.5-Ft Alternative.

Near-Term Changes

Predicted near-term impacts and mitigation for this alternative are the same as those previously described for the 6,383.5-Ft Alternative. Flooding of shoreline vegetation would benefit alkali fly production. Meromixis during lake filling might affect brine shrimp production.

Drought Effects

Under the 6,390-Ft Alternative, drought might reduce the lake level to about 6,383 feet (Chapter 2). Substantial benefits to alkali fly and drift production and to brine shrimp cyst production were predicted for the 6,385.5-Ft Alternative. Therefore, alkali fly and brine shrimp would still benefit substantially under drought conditions with the 6,390-Ft Alternative compared to the point of reference.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (6,390-Ft Alternative)

Causes beneficial increases in lakewide alkali fly production, lakewide drift production, and areal mean drift density of 46%, 55%, and 15%, respectively.

Causes beneficial increases in brine shrimp biomass, lakewide production, and mean and lakewide cyst production of 45%, 49%, 82%, and 118%, respectively.

IMPACTS AND MITIGATION MEASURES FOR THE 6,410-FT ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

Lake levels under the 6,410-Ft Alternative would eventually stabilize at about 6,410 feet, 34 feet above the lake level point of reference. Lake surface area would increase from 40,724 acres to 53,534 acres. Effective alkali fly habitat area would be reduced by more than half, from 981 acres to 427 acres, and salinity would decrease from 90.8 g/l to 52.9 g/l. LAAMP simulations of lake level fluctuations under the 6,410-Ft Alternative indicate that 80 years will be required for the lake level to rise from the initial elevation of 6,376 to 6,410 feet.

Meromictic conditions are simulated by DYRESM for the first 10 years during the initial rise from 6,376 feet. The salinity drops from an initial value of about 90 g/l to about 80 g/l, and the differences between the surface and bottom layers are moderate (5-10 g/l), similar to that actually observed during the 1982-1988 period. Based on the DYRESM simulations of the 6,390-Ft Alternative, additional meromictic events would be expected for annual inflows of greater than 150 thousand acre-feet (TAF), which occurred in 5 years during the second 25 years of the historical 1940-1989 sequence (not simulated with DYRESM). A total of perhaps 15 years might be meromictic for the 6,410-Ft Alternative because of the large and prolonged inflows required to raise the surface elevation of the lake (Figure 3E-19). Meromixis would be unlikely after final equilibrium conditions were attained.

Alkali Fly Effects. Third instar production would decrease 7%, from 919 MT/lake to 855 MT/lake, because of a reduced effective alkali fly habitat area (Table 3E-8). The decrease is considered to be less than significant.

Lakewide total production of drift would increase 15%, from 409 MT to 470 MT. Drift densities would decrease by a third, from 16.5 to 11 ind/m^2. The increase in total drift production is considered a substantial benefit, but the decrease in drift density, which is greater than 10%, would be considered a significant adverse impact, except that model estimates for the highest lake levels may underestimate productivity.

Brine Shrimp Effects. No biological model simulations were made for this alternative, but benefits are assumed to be somewhat greater than those previously described for the 6,390-Ft Alternative. Because predicted areal mean brine shrimp production for the 6,390-Ft Alternative falls very near the boundary of the no-impact range (Figure 3E-21a) and would likely be greater at 6,410 feet than at 6,390 feet, it is concluded that the 6,410-Ft Alternative would have a substantial benefit to areal mean brine shrimp production.

Near-Term Changes

The predicted near-term impacts (flooding shoreline vegetation and meromixis) and mitigation for this alternative are the same as those previously described for the 6,383.5-Ft Alternative.

Drought Effects

Under the 6,410-Ft Alternative, drought might reduce the lake level to about 6,400 feet (Chapter 2). Effects of drought under the 6,410-Ft Alternative would generally be beneficial in comparison to the point of reference, but probably would be reduced in comparison to normal conditions for the 6,410-Ft Alternative.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (6,410-Ft Alternative)

Causes unknown changes in alkali fly drift production and drift density.

Causes beneficial increases in brine shrimp biomass, lakewide production, and mean and lakewide cyst production.

IMPACTS AND MITIGATION MEASURES FOR THE NO-DIVERSION ALTERNATIVE

Changes in Resource Condition

Long-Term Changes

Lake levels under the No-Diversion Alternative would eventually reach a dynamic equilibrium at about 6,420 feet, 44 feet above point-of-reference elevations. Lake surface area is the most extensive under this alternative, increasing 36% from 40,724 acres to 55,534 acres. Effective alkali fly habitat area, however, is smallest, decreasing from 981 acres to 307 acres under this alternative, because of the presence of steep rims with unsuitable habitat. Salinity would decrease from 90.8 g/l to 46.5 g/l, the lowest salinity estimated for any alternative. DYRESM simulations were not made for the No-Diversion Alternative. Meromictic conditions would be expected during the initial lake rise, which would require 50 years with no diversions to reach elevation 6,410 feet. Meromixis would be unlikely after final equilibrium conditions were attained.

Alkali Fly Effects. The No-Diversion Alternative was simulated with the alkali fly model by assuming a lake level of 6,420 feet, the dynamic equilibrium lake level predicted for this alternative by LAAMP.

Lakewide total third instar productivity would decrease 33%, from 919 MT to 708 MT, due to a reduced effective habitat area (Table 3E-8). This decrease is considered a significant adverse impact.

Lakewide total production of drift would increase only 2%, from 409 MT to 419 MT. Drift density would decrease 46%, from 16.5 to 8.9 ind/m^2, and would be a significant adverse impact except that model estimates for the highest lake levels may underestimate productivity.

Brine Shrimp Effects. No biological model simulations were made for the No-Diversion Alternative, but benefits are assumed to be greater than those predicted for the 6,390-Ft Alternative.

Near-Term Changes

The predicted near-term impacts (flooded vegetation and meromixis) and mitigation for this alternative are the same as those previously described for the 6,385.5-Ft Alternative.

Drought Effects

Under the No-Diversion Alternative, drought would reduce the lake level to about 6,416 feet (Chapter 2). Effects of drought under the No-Diversion Alternative would be beneficial for brine shrimp but uncertain for alkali fly in comparison to the point of reference.

Summary of Benefits and Significant Impacts and Identification of Mitigation Measures (No-Diversion Alternative)

- Causes unknown changes in alkali fly drift production and drift density.
- Causes beneficial increases in brine shrimp biomass, lakewide production, and mean and lakewide cyst production.

CUMULATIVE IMPACTS OF THE ALTERNATIVES

Related Impacts of Earlier Stream Diversions by LADWP

Alkali Fly

Effective Habitat Area and Salinity. Effective habitat surface area and salinity of Mono Lake strongly affect alkali fly production. At the prediversion lake level, effective alkali fly habitat area was only about 307 acres because inshore areas are steeply sloping and include little hard substrate habitat. However, as noted previously, effective habitat area estimates of the alkali fly productivity model do not include submerged vegetation, assume constant relative densities of alkali fly on hard and soft substrates, and may therefore underestimate suitable habitat area for alkali fly at higher lake elevations. Prediversion salinity was about 46.5 g/l.

Third Instar Productivity. Monthly and seasonal third instar lakewide production estimates for the 6,350-6,420 feet range of lake elevations are shown in Figure 3E-23, which allows direct comparison between the EIR alternatives and the No-Diversion Alternative. As discussed, the prediversion condition is unknown.

Drift. Monthly and seasonal lakewide drift production estimates for the 6,350-6,420 feet range of lake elevations are shown in Figure 3E-24, which allows direct comparison between the EIR alternatives and the No-Diversion Alternative. As discussed, the prediversion condition is unknown.

Brine Shrimp

Lake Surface Area, Salinity, and Probability of Meromixis. Surface area and salinity of Mono Lake strongly affect brine shrimp production. Based on estimates for the No-Diversion Alternative, the prediversion lake level was about 6,420 feet, the lake surface area was about 55,534 acres, and salinity was about 46.5 g/l. Surface area decreased about 27% and salinity increased about twofold as the lake level dropped to the point-of-reference elevation (Table 3E-8). Under the No-Restriction Alternative, the lake surface area would be just over half of the prediversion surface area and salinity would be more than three times as high.

Brine Shrimp Biomass and Production. Simulated cumulative impacts on the brine shrimp population were generally large because the population was affected by both the increased salinity and the decreased lake surface area accompanying the decrease in lake level from the prediversion level. However, as noted in the section, "Criteria for Determining Impact Significance", little is known about how changes in brine shrimp biomass or production affect bird populations that feed on shrimp. The cumulative impacts were not generally affected by whether the lake was monomictic or meromictic (Table 3E-9).

As noted in the section, "Determination of Point-of-Reference and Prediversion Conditions", brine shrimp model simulations were not run for lake levels above 6,390 feet, so results for the 6,390-Ft Alternative simulation were used as a proxy for prediversion conditions. Results of simulations for lake levels below 6,390 feet (Table 3E-9) were considered to indicate significant impacts if the values fell below the lower bound of the no-impact range for prediversion conditions (i.e., 6,390 feet) (Table 3E-4). Thus, for example, brine shrimp biomass for all alternatives except the 6,383.5-Ft Alternative were considered to represent significant impacts because the simulated values (Table 3E-9) were below the lower bound of the prediversion no-impact range for brine shrimp biomass (i.e., 58 mg N/m^3) (Table 3E-4). Estimated areal and lakewide cyst production of the brine shrimp under all the alternatives were below prediversion no-impact ranges and therefore all the alternatives were considered to have a significant impact on cyst production.

Results for total lakewide production and areal mean production, probably the two brine shrimp impact variables most directly related to bird production, lead to somewhat inconsistent conclusions regarding impacts. Total lakewide production for all alternatives except the 6,383.5-Ft Alternative were below the prediversion no-impact range, while areal mean production was below the prediversion range under the No-Restriction Alternative only (compare Tables 3E-4 and 3E-9). This inconsistency complicates efforts to determine how changes in brine shrimp production affect the bird populations. Given that the impact assessment variables other than areal mean brine shrimp production were below prediversion no-impact ranges at most alternatives, and given that cumulative impacts were probably underestimated because estimates for the 6,390-Ft Alternative were used to represent prediversion conditions, all lake level alternatives below the 6,390-Ft Alternative had a significant cumulative impact on brine shrimp productivity.

Cumulative Adverse Impacts

No-Restriction Alternative

Predicted values of the alkali fly impact assessment variables for the No-Restriction Alternative (lakewide total third instar annual production, areal mean drift density, and lakewide total annual drift production) ranged from 37% to 80% below estimated values for the No-Diversion Alternative (Table 3E-8). The relationship to prediverison conditions, however, is unknown.

Predicted values of the brine shrimp impact assessment variables for the No-Restriction Alternative (brine shrimp biomass, areal mean and lakewide total brine shrimp production and cysts production) ranged from 46% to 82% below estimated prediversion values. All these predicted values were below the prediversion ranges for no impacts (compare Tables 3E-9 and 3E-4). This alternative is considered to have a significant cumulative adverse impact on the brine shrimp population.

6,372-Ft Alternative

Predicted values of the alkali fly impact assessment variables for the 6,372-Ft Alternative ranged from 11% below to 74% above estimated values for the No-Diversion Alternative (Table 3E-8), but the relationship to prediversion conditions is unknown.

Predicted values of the brine shrimp impact assessment variables for the 6,372-Ft Alternative ranged from 22% to 64% below estimated prediversion values, assuming monomictic conditions for the alternative, and from 30% to 57% below the prediversion values, assuming meromictic conditions. Predicted brine shrimp biomass, brine shrimp lakewide production, cyst areal production, and cyst lakewide production were below the prediversion ranges for no impacts. Predicted brine shrimp areal production was below the no-impact range for simulations assuming meromictic conditions, but was within the no-impact range for simulations assuming monomictic conditions (compare Tables 3E-9 and 3E-4).

The 6,372-Ft Alternative is considered to have a significant cumulative adverse impact on the brine shrimp population.

6,377-Ft Alternative

Predicted values of the alkali fly impact assessment variables for the 6,377-Ft Alternative ranged from 26% above to more than twice estimated values for the No-Diversion Alternative (Table 3E-8), but the relationship to the prediversion condition is unknown.

Predicted values of the brine shrimp impact assessment variables for the 6,377-Ft Alternative ranged from 15% to 48% below estimated prediversion values. Predicted brine shrimp biomass, brine shrimp lakewide production, cyst areal production, and cyst lakewide production were below the prediversion ranges for no impacts, but predicted brine shrimp areal production was within the no-impact range (compare Tables 3E-9 and 3E-4). The 6,377-Ft Alternative is considered to have a significant cumulative adverse impact on the brine shrimp population.

6,383.5-Ft Alternative

Predicted values of the alkali fly impact assessment variables for the 6,383.5-Ft Alternative ranged from 43% above to more than twice estimated values for the No-Diversion Alternative (Table 3E-8), but the relationship to the prediversion condition is unknown.

Predicted values of the brine shrimp impact assessment variables for the 6,383.5-Ft Alternative ranged from 10% to 28% below estimated prediversion values. Predicted brine shrimp lakewide production, cyst areal production, and cyst lakewide production were below the prediversion ranges for no impacts, but predicted brine shrimp biomass and areal production were within the no-impact range (compare Tables 3E-9 and 3E-4). The 6,383.5-Ft Alternative is considered to have a significant cumulative adverse impact on the brine shrimp population.

6,390-Ft Alternative

Predicted values of the alkali fly impact assessment variables for the 6,390-Ft Alternative ranged from 52% above to more than twice estimated values for the No-Diversion Alternative (Table 3E-8), but the relationship to the prediversion condition is unknown.

Cumulative impacts of the 6,390-Ft Alternative were not simulated with the biological model for brine shrimp. It is assumed that cumulative impacts of the 6,390-Ft Alternative would be less than significant.

6,410-Ft Alternative

Predicted values of the alkali fly impact assessment variables for the 6,410-Ft Alternative ranged from 12% to 24% above estimated values for the No-Diversion Alternative (Table 3E-8), but the relationship to the prediversion condition is unknown.

Cumulative impacts of the 6,410-Ft Alternative were not simulated with the biological model for brine shrimp. It is assumed that cumulative impacts of the 6,410-Ft Alternative would be less than significant.

No-Diversion Alternative

Conditions under the No-Diversion Alternative would probably be similar to prediversion conditions. The cumulative impact of the No-Diversion Alternative on alkali fly and brine shrimp populations would therefore be practically nonexistent.

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