Fish aid: The Lake Mead fertilization project

Richard Axler  
*University of Minnesota - Duluth*

Larry Paulson  
*University of Nevada, Las Vegas*

Peter Vaux  
*University of Nevada, Las Vegas*

Patrick Sollberger  
*University of Nevada, Las Vegas*

Donald H. Baepler  
*University of Nevada, Las Vegas*

Follow this and additional works at: [http://digitalscholarship.unlv.edu/water_pubs](http://digitalscholarship.unlv.edu/water_pubs)

Part of the [Aquaculture and Fisheries Commons](http://digitalscholarship.unlv.edu/water_pubs), [Biology Commons](http://digitalscholarship.unlv.edu/water_pubs), [Fresh Water Studies Commons](http://digitalscholarship.unlv.edu/water_pubs), [Natural Resources and Conservation Commons](http://digitalscholarship.unlv.edu/water_pubs), [Natural Resources Management and Policy Commons](http://digitalscholarship.unlv.edu/water_pubs), [Terrestrial and Aquatic Ecology Commons](http://digitalscholarship.unlv.edu/water_pubs), and the [Water Resource Management Commons](http://digitalscholarship.unlv.edu/water_pubs)

Repository Citation

Available at: [http://digitalscholarship.unlv.edu/water_pubs/89](http://digitalscholarship.unlv.edu/water_pubs/89)

This Article is brought to you for free and open access by the Water Resources at Digital Scholarship@UNLV. It has been accepted for inclusion in Publications (WR) by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact [digitalscholarship@unlv.edu](mailto:digitalscholarship@unlv.edu).
Fish Aid — The Lake Mead Fertilization Project

Richard Axler
Larry Paulson
Peter Vaux
Patrick Sollberger
Lake Mead Limnological Research Center, Environmental Research Center, University of Nevada-Las Vegas, Las Vegas, Nevada 89154

Donald H. Baepler
Museum of Natural History, University of Nevada-Las Vegas, Las Vegas, Nevada 89154

ABSTRACT

Sport fishing at Lake Mead in Nevada and Arizona is a resource valued at nearly $100 million per year to southern Nevada. During the past two decades, salmonids, mostly trout, have disappeared entirely, the largemouth bass catch has drastically declined despite greater fishing pressure, and the condition factors for striped bass have steadily deteriorated. It appears that a major reduction in phosphorus loading caused by the upstream impoundment of the Colorado River to form Lake Powell in 1963 and advanced wastewater treatment removal of phosphorus from domestic wastewater inflows in 1981 are the principal factors responsible for decreased production at all levels of the food chain. The Lake Mead Fertilization Project is an attempt to reverse these declining fisheries. The first large-scale test of fertilization occurred on May 30, 1987. More than 300 boats and 1,000 volunteers helped spread 20,000 gallons (75.7 m$^3$) of liquid ammonium polyphosphate over 19,000 acres (7700 ha) of lake surface. Highlights of the history of the project and initial results, which indicate that the test was extremely successful, are discussed.

Introduction

The sport fisheries in Lake Mead, located in Nevada and Arizona, are comprised mainly of largemouth bass (*Micropterus salmoides*), striped bass (*Morone saxatilis*), and rainbow trout (*Salmo gairdnerii*). Largemouth bass were introduced soon after impoundment, in 1935, and threadfin shad (*Dorosoma petenense*) were introduced in 1954 to expand their forage base (Allan and Roden, 1978). The reservoir supported a nationally recognized largemouth fishery for many years, but it began to decline in 1963 after the Glen Canyon Dam was constructed 456 km upstream (Fig. 1). Striped bass and rainbow trout were introduced in 1969 to augment the failing largemouth bass fishery. Striped bass successfully reproduced in 1973, and this fishery rapidly expanded during the mid 1970s (Allan and Roden, 1978). Trout, which were sustained by stocking, also did quite well in the early and mid-1970s (Ariz. Game Fish Dep. 1987).

The trout fishery collapsed in 1977 and has not recovered despite heavy stocking in some years. Striped bass catch rates decreased drastically in 1980 and 1981 (Nev. Dep. Wildl. 1986) and, although catch rates increased again from 1982 to the present, the population consisted of smaller, often emaciated fish (Table 1; Baker and Paulson, 1983; Hutchings, 1987). The increased yield of stripers in recent years appears to be due largely to increased fishing effort, since fishing for largemouth bass and trout is so poor.

*Dr. Richard Axler is presently at the Natural Resources Research Institute, University of Minnesota, Duluth, MN 55811*
Zooplankton graze primarily on phytoplankton and threadfin shad feed on these zooplankton and phytoplankton (Allan and Roden, 1978; Baker and Schmitz, 1971). Since gamefish feed primarily on either zooplankton or shad at different stages of their lifecycle, it is clear how a nutrient limitation of phytoplankton growth can spiral up the food chain (Fig. 2).

The only way to restore the previous fertility of Lake Mead was to add nutrients. Large-scale fertilization programs to enhance salmon fisheries in unproductive lakes have been extremely successful in British Columbia, Canada, and Alaska (Stockner, 1981; Koenings, 1986). This concept was formally agreed upon by the Nevada Department of Wildlife (NDOW) and Arizona Game and Fish Department (AGFD) in January, 1985. A technical advisory panel, comprised of representatives from the Limnological Research Center at the University of Nevada-Las Vegas (UNLV), NDOW, AGFD, the Nevada Division of Environmental Protection (NDEP), the U.S. Bureau of Reclamation (USBR), the National Park Service at Lake Mead National Recreation Area, and the

Recent limnological studies have indicated that the fisheries problems in Lake Mead are related to a decline in fertility and productivity that began to develop after the Glen Canyon Dam created Lake Powell upstream in 1963. Phosphorus-laden silt particles in the Colorado River were retained in Lake Powell instead of flowing into the upper basins of Lake Mead. This sharp decrease in phosphorus loading resulted in decreased biomass and growth at all levels of the food chain. The problem was exacerbated in the lower basin in 1981, when advanced wastewater treatment plants began removing phosphorus from domestic wastewater discharged to the lower basin (Ariz. Game Fish Dep. and Nev. Dep. Wildl. 1982; Evans and Paulson, 1983; Paulson and Baker, 1983, 1984; Prentki and Paulson, 1983).

Table 1.—Striped bass condition factors for Lake Mead. Values were calculated from creel census records as \( k = \frac{\text{weight} \times 100,000}{\text{forklength}^3} \), where weight is in grams and forklength is in mm.*

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MEAN CONDITION FACTOR (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>1.76</td>
</tr>
<tr>
<td>1978</td>
<td>1.62</td>
</tr>
<tr>
<td>1979</td>
<td>1.53</td>
</tr>
<tr>
<td>1980</td>
<td>1.11</td>
</tr>
<tr>
<td>1981</td>
<td>1.35</td>
</tr>
<tr>
<td>1982</td>
<td>1.19</td>
</tr>
<tr>
<td>1983</td>
<td>1.10</td>
</tr>
<tr>
<td>1984</td>
<td>1.08</td>
</tr>
<tr>
<td>1985</td>
<td>1.09</td>
</tr>
<tr>
<td>1986</td>
<td>1.04</td>
</tr>
</tbody>
</table>

Figure 2.—The Lake Mead Food Chain.
U.S. Fish and Wildlife Service, was created to develop a plan for large-scale nutrient enrichment of Lake Mead. The USBR subsequently funded UNLV to conduct a Prefertilization Study consisting of laboratory and pilot-scale field experiments in order to design a large-scale fertilization method (Axler et al. 1987b).

An environmental assessment (Lake Mead Nutrient Enrichment Tech. Comm. 1987) was then prepared for National Park Service in March 1987, to comply with the provisions of the National Environmental Policy Act. A Finding of No Significant Impact was authorized in May 1987. A National Pollutant Discharge Elimination System (NPDES) Jischarge permit was issued by NDEP that same month. On May 30, 1987, UNLV, with the help of 1,000 volunteers and 300 boats, applied 20,000 gallons (75.7 m$^3$) to approximately 19,000 acres (7700 ha) of the Overton Arm of Lake Mead.

### Objectives

The purpose of the experiment was to evaluate the potential for controlled nutrient addition (fertilization) to be used as a management tool for enhancing the forage base and the quality of the Lake Mead sport fishery. Our specific objectives for this first year test were to:

- Boost levels of phytoplankton biomass and primary productivity to moderate (mesotrophic) levels;
- Intensively monitor algal, zooplankton, and shad responses to increased fertility;
- Assess effects of fertilization on other beneficial uses of the lake;
- Establish community involvement and volunteer help for fertilizing the lake and monitoring gamefish populations.

| Table 2. — Morphometric characteristics of Lake Mead, at full capacity, and the epilimnion of the Overton Arm assuming a water surface at 366m elevation, 1200 feet MSL, and a thermocline depth of 13m. |
| AREA | VOLUME | FERTILIZER VOLUME WEIGHT |
| LAKE MEAD: | | |
| 66096 ha | 36.9 x 10$^9$ m$^3$ | — |
| 163,320 acres | 29.9 x 10$^8$ a-f | — |
| OVERTON ARM: (fertilization region) | | |
| 7669 ha | 0.854 x 10$^8$ m$^3$ | 75.7 m$^3$ | 106 tons |
| 18,950 acres | 0.692 x 10$^7$ a-f | 20,000 gal | 117 tons |

Note: The fertilizer quantities are for liquid ammonium polyphosphate (formulation 10-34-0), which is 10% nitrogen, 15% phosphorus, and has a density of $\sim$1.4 g/cc. The totals assume a final enrichment of $+20 \mu$gP/L.

### Site Description and Methods

Lake Mead is located in the Mohave Desert in southeastern Nevada and northwestern Arizona about 15 km southeast of Las Vegas. The reservoir was formed in 1935 and extends 183 km from the mouth of the Grand Canyon to Black Canyon, the ssite of Hoover Dam. It is the largest reservoir in the United States by volume and second only to Lake Powell in surface area. Approximately 98 percent of its inflow is from the Colorado River and its retention time is typically three to four years. The mean depth of the lake is 55 m and it discharges to Lake Mohave from a depth of 83 m in the hypolimnion (Paulson and Baker, 1984).

The Overton Arm covers the former channel of the Virgin and Muddy rivers, and extends approximately 35 km from the Colorado River channel (Fig. 3). The upper half of the arm from Echo Bay to about Overton Beach was used for fertilization. More than 90 percent of the area of the arm stratifies thermally with a typical thermocline depth of 13 m in late spring or early summer (Paulson and Baker, 1984). Morphometric characteristics in relation to the entire lake are presented in Table 2. The fertilized water represents about 12 percent of the total lake area and about 2.3 percent of total lake volume.

Sampling sites are designated in Figure 3. Stations F2, F3, and F4 represented approximately equal areas of the fertilization region. Station F1, to the north, and F5 and F6, to the south, were chosen to be control stations, although it was later found that only F6 remained entirely uninfluenced throughout the experiment. Routine sampling and analytical methods are described in detail in Kellar et al. (1981).

Carbon-14 ($^{14}$C) uptake rates were estimated by incubating 100 ml subsamples of 0 to 5 m integrated composites with $H^{14}$CO$_3$ for two hours in an incubator with temperature ($\sim$22°C) and light ($\sim$80 μeinstein/m$^2$/sec) approximating mid-epilimnion values at the time of fertilization. Primary productivity rates were then calculated using dissolved inorganic carbon concentrations obtained from standard alkalinity titrations.

Chlorophyll $a$ was estimated from fluorescence values for the three intensive synoptic studies discussed in this report. A regression equation of trichromatically-determined chlorophyll $a$ versus fluorescence was used based on 56 data pairs from nine dates in the period May 22 to June 12, 1987, span-
Results and Discussion

Fertilizer Application

Twenty thousand gallons (75.7 m$^3$) of liquid ammonium polyphosphate (formulation 10-34-0 "white") were successfully applied to 18,950 acres (7669 ha) of the Overton Arm of Lake Mead on May 30, 1987. It was particularly important to perform this initial experiment relatively early in the growing season, but after stable stratification had occurred. The thermocline would restrict the soluble fertilizer to the upper mixed layer where most of the algal production occurred. Further, during spring and early summer there was still sufficient inorganic nitrogen present, mostly as nitrate, to provide a balanced nitrogen to phosphorus ratio (~10:1). Late summer fertilization would require an additional supplement of nitrogen, an estimated five-fold increase in weight, since inorganic nitrogen is depleted to near detection limit by then. Late May also coincides with the major period of recruitment for shad and largemouth bass.

More than 1,000 volunteers and 300 boats were used to uniformly disperse the solution. Although aerial spraying and barge dispersal were originally considered, a volunteer effort was organized to save money and to involve recreational users in the project. Even though the fisheries represent an economic resource to the region valued at up to $100 million a year (Ariz. Game Fish Dep. and Nev. Dep. Wildl. 1982), the project was, and remains, controversial.
Public participation and political support were very important in obtaining the necessary permits from state and federal agencies to conduct the experiment. The enthusiasm of the regional fishing community also generated much more creel census data for the Overton Arm than had been obtained historically. A striped bass fishing tournament was held in this region in September 1987, and a series of them were planned for 1988. They will provide a large sample size for evaluating the physiological responses of game fish.

Fertilizer was dispensed in 4400 five-gallon (20 L) jugs, which were distributed to boat owners based on the capacity of their boats. The flotilla was formed into three rows across the lake near Echo Bay (Fig. 3). Boats were spaced approximately 30 m apart and leaders were assigned to each group of 36 boats to set the pace of about 5 knots and maintain order. Each row had a predetermined area to fertilize to ensure a uniform dispersal over the designated area.

Support services were provided by the National Park Service, NDOW, U.S. Coast Guard Auxiliary, Echo Bay Resort and Marina, local fire departments, Boy Scout troops, and many other volunteer ground crews for emergency medical services, safety enforcement, boat repair and towing, parking, launching organization, etcetera.

The actual fertilization was accomplished in several hours. There were no serious injuries or accidents, and at the end of the day, everyone was treated to a barbecue with live entertainment and a raffle with many varied prizes donated by local merchants, sponsors, and volunteers.

**Phytoplankton Responses**

Figure 4 summarizes chlorophyll a and $^{14}$C-primary productivity (PPr) values obtained during three synoptic sampling efforts, from just before fertilization (Day -3), near the peak algal response (Day +4), and during the decline of the "bloom" (Day +9). Both algal biomass and productivity were quite uniformly distributed throughout the Overton Arm just prior to fertilization.

Chlorophyll concentrations increased rapidly in the fertilization region from a baseline of about 1 $\mu$g/L on Day +2, reached a peak of 11 $\mu$g/L at F4, on Day +5, and declined to values of ~3 $\mu$g/L by
Day +9. After day +18, values for all stations were almost always <2 µg/L for the remainder of the summer (Axler et al. 1987a). The pattern of primary productivity was generally similar to that of chlorophyll. Rates in the fertilized region on Day +4 were approximately triple those measured at control stations F1 and F6, and at all stations on Day -3, prior to fertilization.

Most of the algal bloom caused by nutrient enrichment was contained within the fertilization area. However, the data suggest that some fertilizer was rapidly transported about 4 km south to station F5. Chlorophyll increases at F5 lagged behind the main region by several days and were probably associated with wind-generated seiches noted a few days previously. The standard deviations about the center channel concentrations in Figure 4 indicate the degree of east-west variability.

The observed algal response to nutrient enrichment did not present a threat to other beneficial uses of the lake. Peak levels of biomass and primary productivity remained moderate and the response could be clearly observed for only two to three weeks. The 30-day chlorophyll a mean for the fertilized region was only 3.4 ± 1.8 µg/L (x ± s.d.), relative to values of 2.2 ± 0.7 for north control site F1, and 1.7 ± 0.4 for south control site F6. The actual algal responses to fertilization were very similar to those predicted in the environmental assessment based on microcosm and cove fertilization experiments (Axler et al. 1987b; Lake Mead Nutr. Enrich. Tech. Comm. 1987).

**Zooplankton Responses**

Fertilization appears to have resulted in an improvement within days in the condition and reproductive rate of cladoceran zooplankton. Figure 5 shows lipid droplet indices and the number of eggs per female for *Daphnia pulex* and *Daphnia galeata* collected from the middle of the fertilization zone, site F3, and at south control, site F6. Lipid droplets were assayed according to Tessler and Goulden (1982) as modified by Bjorkman and Shapiro (1986).

The assay was initially tested on zooplankton collected along the fertility gradient from eutrophic Inner Las Vegas Bay to oligotrophic Boulder Basin in the main lake. This study indicated that increased food availability would result in higher lipid reserves and egg production in Lake Mead cladocerans (Vaux, unpubl). Previous feeding experiments performed with *D.pulex* had also shown that individuals reared in the more productive waters of the bay had significantly greater rates of growth and reproduction than those from oligotrophic Boulder Basin (Paulson and Baker, 1984).

Mean lipid index values and egg production in the fertilized area increased dramatically between two and five days after fertilization, peaked at about the same time as chlorophyll, and remained elevated until Day +17. Values in the control region remained low and exhibited only minor variations throughout the entire data record.

**Shad Responses**

Historically, significant numbers of shad in pelagic areas of the Overton Arm have been limited mostly to its extreme northern end, in the more productive waters near the Muddy and Virgin River inflows (Paulson and Baker, 1983; Hutchings, 1987).

Echosounding conducted in the fertilized and control areas in May 1987, prior to fertilization iden-
R. Axler, L. Paulson, P. Vaux, P. Sollberger, & D. H. Baepler

Identified low densities of shad throughout the Overton Arm (Fig. 6). It appears that shad spawned around the time of fertilization, since on June 4 (Day +5), numerous targets were noted in the upper part of the Overton Arm, site F1, and in the fertilized region, site F4. Comparable densities were not found at the control region, site F6, or anywhere in the Overton Arm in 1986 (Fig. 6). By July 1 a few targets were recorded in the lower arm but by this time target densities were dramatically higher in the fertilized region, sites F2, F3, and F4, than even at the northernmost station, site F1. This general pattern persisted for much of the summer and sonar targets in the fertilization zone were clearly more abundant than in the other main basins of the lake (Paulson et al. 1988).

It was not possible to include an intensive program of trawl sampling in the 1987 study, but a pilot series confirmed the presence of shad in areas with high densities of sonar targets (Table 3). Similar results were found in previous trawling (Allan and Roden, 1978; Hutchings, 1987) and trapping (Paulson and Espinosa, 1975) efforts.

One hypothesis to explain the apparent increase in shad densities in the fertilization zone is that the enhanced phytoplankton and zooplankton production due to fertilization helped larval shad survive a "food bottle-neck" during the first few critical days after hatching (May, 1974). Starvation of larval and adult shad has been attributed to low densities of zooplankton in some systems (Kilambi and Barger, 1975; Matthews, 1984; Kashuba and Matthews, 1984).

Game Fish Responses

When the 1987 fertilization experiment was designed it was thought that it would be extremely difficult to gauge the effect of a first-year program on the sport fisheries. Results would likely be confounded by the enormous size of the reservoir, the poor fishing success in the Overton Arm, and the difficulty of ascertaining exactly where a free-ranging predator such as a striped bass actually spends most of its time. It was assumed it would require a number of years before improvements in the condition or numbers of game fish could be demonstrated.

However, the apparent population boom of threadfin shad in the fertilization region seemed to attract tremendous numbers of striped bass. Large schools of surface-feeding striped bass were first observed in mid-July 1987, and "top-water" fishing remained excellent through December 1987. Furthermore, the condition factors for striped bass caught in the Overton Arm in 1987 were 22 percent higher than for fish caught in the rest of the lake in 1987, 19 percent higher than in the Overton Arm prior to fertilization, 1984 to 1986, and 28 percent higher than in the entire lake combined in the period 1984 to 1986 (Table 4).

Water Quality Impact

No adverse impacts on the beneficial uses of the lake resulted from the fertilization, as predicted in the environmental assessment (Table 5). The major issues raised during the public comment period re-

Table 3.—Comparison of numbers of larval threadfin shad (<20 mm) caught in the fertilized and unfertilized areas of the Overton Arm of Lake Mead on the night of June 16-17, 1987, 17 days post-fertilization.

<table>
<thead>
<tr>
<th>Site</th>
<th>NORTH CONTROL</th>
<th>FERTILIZED</th>
<th>SOUTH CONTROLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>166</td>
<td>487</td>
<td>36</td>
</tr>
<tr>
<td>F2</td>
<td>82</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>F3</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F4</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F5</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F6</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The shad were captured by trawling for three minutes with a 500 micron x 1 m² net at a depth of 1 to 2 m in open waters. See Figure 3 for site locations.

Table 4.—Summary of average condition factors (K, based on forklength) for Lake Mead striped bass.

<table>
<thead>
<tr>
<th>Year</th>
<th>LAS VEGAS BAY</th>
<th>BOULDER BASIN</th>
<th>VIRGIN BASIN</th>
<th>UPPER BASIN</th>
<th>OVERTON ARM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NDOW</td>
<td>AGFD</td>
<td>NDOW</td>
<td>AGFD</td>
<td>AGFD</td>
</tr>
<tr>
<td>1987</td>
<td>1.11</td>
<td>1.11</td>
<td>1.08</td>
<td>0.991</td>
<td>1.28</td>
</tr>
<tr>
<td></td>
<td>(1111)</td>
<td>(550)</td>
<td>(16)</td>
<td>(260)</td>
<td>(491)</td>
</tr>
<tr>
<td>1986</td>
<td>1.06</td>
<td>1.07</td>
<td>0.90</td>
<td>0.85</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>(140)</td>
<td>(60)</td>
<td>(2)</td>
<td>(809)</td>
<td>(282)</td>
</tr>
<tr>
<td>1985</td>
<td>1.05</td>
<td>1.07</td>
<td>—</td>
<td>1.03</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>(66)</td>
<td>(28)</td>
<td></td>
<td>(182)</td>
<td>(341)</td>
</tr>
<tr>
<td>1984</td>
<td>1.10</td>
<td>1.06</td>
<td>1.05</td>
<td>0.89</td>
<td>1.09</td>
</tr>
<tr>
<td></td>
<td>(178)</td>
<td>(56)</td>
<td>(20)</td>
<td>(512)</td>
<td>(160)</td>
</tr>
</tbody>
</table>

* Based on NDOW creel (k = 0.99, n = 16), AGFD creel (k = 0.93, n = 171), and AGFD survey (k = 1.15, n = 73)

Source: Data for Upper Basin from Arizona Game and Fish Department (AGFD) creel census except for 1987, as noted. University of Nevada - Las Vegas (UNLV) data for the Overton Arm are for the period July to November, 1987. All other values are from Nevada Department of Wildlife (NDOW) creel records (Hutchings, 1987). NDOW data for 1987 are provisional. ( ) = n, the # of fish in the sample.
Figure 6.—Echograms recorded along approximately 1 km north-south transects in the center channel near each station.
Table 5.—Changes in certain limnological parameters in the fertilized region, mean values from 0 to 5 m composites from stations F-2/3/4, following the 1987 Overton Arm Fertilization. \( \gamma \) = as predicted in the Lake Mead Fertilization Project Environmental Assessment (Lake Mead Nutr. Enrich. Tech. Comm. 1987). Error bars denote standard deviation.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>(5/14-5/27) PRE (n = 9)</th>
<th>(5/31-6/16) FERTILIZATION (n = 21)</th>
<th>(6/24-7/8) POST (n = 8)</th>
<th>NOTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total-P (ppb)</td>
<td>9 ± 1</td>
<td>23 ± 17 (46 max, day 1)</td>
<td>5 ± 2</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>NH(_4)-N (ppb)</td>
<td>5 ± 1</td>
<td>7 ± 8 (22 max, day 1)</td>
<td>6 ± 6</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>NO(_3)-N (ppb)</td>
<td>164 ± 7</td>
<td>76 ± 21</td>
<td>14 ± 8</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>TN (ppbN)</td>
<td>409 ± 51</td>
<td>315 ± 102</td>
<td>246 ± 31</td>
<td>(increased depletion)</td>
</tr>
<tr>
<td>pH</td>
<td>8.4 ± 0.1</td>
<td>8.6 ± 0.2</td>
<td>8.4 ± 0.2</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>EC (( \mu )moL/cm)</td>
<td>833 ± 5 (day -1)</td>
<td>834 ± 4 (day + 1)</td>
<td></td>
<td>( \gamma )</td>
</tr>
<tr>
<td>DO (ppm)</td>
<td>saturated</td>
<td>supersaturated (120 -150% @ midday)</td>
<td>saturated</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>Chlor-a (ppb)</td>
<td>&lt;2</td>
<td>3 - 11 (&gt;5 ppb for 4 days)</td>
<td></td>
<td>( \gamma )</td>
</tr>
<tr>
<td>Clarity (extinction of PAR, 0 - 10 m, as k, m(^{-1}))</td>
<td>0.31 ± 0.05 (n = 3)</td>
<td>0.42 ± 0.06 (n = 6)</td>
<td>0.34 ± 0.07 (n = 2)</td>
<td>( \gamma )</td>
</tr>
<tr>
<td>Secchi (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fert (F2/3/4)</td>
<td>7.0 ± 1.9 (n = 15)</td>
<td>3.2 ± 0.8 (n = 30)</td>
<td>5.0 ± 1.6 (n = 10)</td>
<td>( \gamma ), some clarity loss due to Colorado River</td>
</tr>
<tr>
<td>- Control (F6)</td>
<td>8.1 ± 1.9 (n = 5)</td>
<td>5.2 ± 1.1 (n = 9)</td>
<td>6.7 ± 2.3 (n = 4)</td>
<td>silt as seen at F6</td>
</tr>
</tbody>
</table>

related to domestic and agricultural uses of lake water and involved questions of eutrophication and salinity (Natl. Park Serv. 1987). The increase in chlorophyll was moderate, with a maximum of 11 \( \mu \)g/L, and levels only exceeded 5 \( \mu \)g/L for less than a week. Water clarity declined by about 30 percent during the first week, but this effect was reduced to \(<20\) percent after two weeks. The salinity of the water did not increase and the nutrient increases associated with the fertilization returned to baseline conditions in about a week (Axler et al. 1987a).

Even the southernmost portion of the fertilization region was still located about 60 km distant from the hypolimnetic drinking water input for the Las Vegas Metropolitan Area and from Hoover Dam, which discharges hypolimnetic water to downstream users. Consequently, even if fertilizer were not biologically assimilated in the Overton Arm, which of course it was, considerations of dilution in the main basins of the lake in addition to isolation by thermal stratification clearly indicated that down-lake water quality degradation was not possible at the application rates used.

**Conclusions**

"Fish Aid" was extremely successful. Moderate increases in algal production were achieved without adversely affecting other beneficial uses of the lake. Cladoceran zooplankton benefited from increases in edible phytoplankton and threadfin shad densities in the region appeared to improve dramatically compared to previous years. Although it is not yet possible to directly attribute these high shad densities to fertilization, it is clear that the shad attracted striped bass to surface waters in the fertilization area. This caused a resurgence of fishing activity in the region and improved the condition of the striped bass.

The experimental fertilization program calls for additional applications in 1988 and 1989. Decisions
References


ACKNOWLEDGEMENTS: We especially thank the following UNLV personnel: J. Stephens-Haley for advice and organizational support; S. Paulson for help in the lab and graphics; B. Dickes, L. Cody, and L. Heki for analytical help; L. Shepard for field assistance; P. Baldwin for 'smooth' program administration; and A. Sims, S. Stonehocker and M. Salas for assisting in numerous ways. John Hutchings (NDOW) graciously provided Lake Mead fishery data and discussion and loaded lots of jugs. We also thank D. Sollberger, J. Kimak and J. Goff of the Lake Mead Enhancement Society, all the volunteers who came to help, and staff members from NDOW, National Park Service, NDEP, AGFD and USBR who helped make the project a success. Funding sources included the National Oceanic and Atmospheric Administration, the Nevada Department of Wildlife, the U.S. Bureau of Reclamation, and donations from volunteers.