THE LAKE MEAD FERTILIZATION PROJECT

PROGRESS REPORT: 1989 FERTILIZATION

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1. INTRODUCTION

1.1 Background

The Lake Mead Fertilization Project is a three-year experiment designed to investigate the potential for improving the game fisheries of this reservoir by using artificial fertilization to enhance the population of threadfin shad, the system's principal forage species. Paulson et al. (1988) present a detailed review of the history of and current problems associated with the Lake Mead fisheries. The decline in the game fisheries of this reservoir has two components. First, harvests of largemouth bass have decreased substantially since the late 1960's, following the construction of Glen Canyon dam in 1963, 456 km upstream of Lake Mead. Second, the condition of striped bass has declined to a point where, in the early and mid-1980's, emaciated fish were common in the population. Various studies have concluded that a major factor in the decline of these two gamefish species has been the decrease in the population of threadfin shad. This in turn is believed to be, in part, a result of decreased nutrient loading via the Colorado River following its impoundment upstream.

1.2 The 1989 Fertilizer Applications and Monitoring Programs

The 1989 fertilizer applications represent the third phase of the three-year experiment (Table 1). Barges were used to add a total of 20,000 gallons of liquid ammonium polyphosphate (10:34:0) to the Overton Arm of Lake Mead (Figure 1) in June, 1989. The

TABLE 1

OVERTON ARM FERTILIZATIONS: 1987-1989

		Area Fertilized		Gallons Added	P-Spike
1987:	May 30 *	Open water	~10,000 ha	20,000	20 ppb
1988:	May 21 *	Open water	~10,000 ha	15,000	15 ppb
	June 18 *¶	Open water	~10,000 ha	5,000	5 ppb
	Oct. 29 ¶	Coves	~500 ha	5,000	30 ppb
1989:	June 5 ¶	Open water	~10,000 ha	8,000	) 15 ppb
	June 8 ¶	Open water	~10,000 ha	7,000	)
	June 19 ¶	Open water	~10,000 ha	5,000	5 ppb

* Fertilizer applied by volunteers

¶ Fertilizer applied with barges

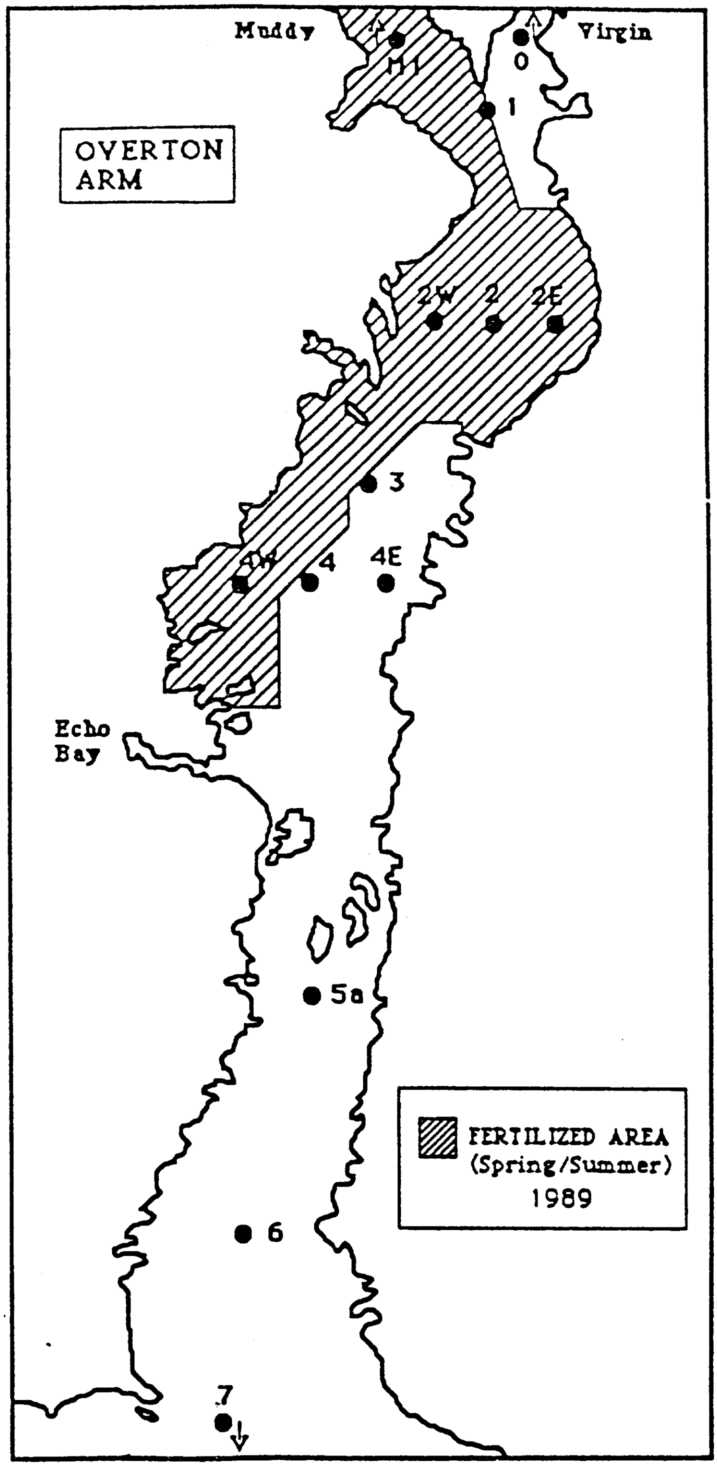


Figure 1: Map of the Overton Arm of Lake Mead, showing area fertilized in 1989 and major monitoring stations.

primary application (15,000 gallons, equivalent to an epilimnetic phosphorus spike of approximately 15 µg/l) was made over a two-day period (June 5 and 8); the secondary application was made two weeks later (June 19). Barge application of the fertilizer was a relatively straight-forward process, involving the pumping of fertilizer from storage tanks through distribution manifolds constructed of 3/4 inch PVC piping. Three barges and one boat were used for the fertilizer applications.

The monitoring program for evaluation of the 1989 experiment closely followed the schedule presented in Paulson and Vaux (1989), with only a few minor modifications resulting from bad weather and occasional equipment malfunctions.

The originally proposed fall fertilization of the Muddy Arm section of the Overton Arm (Paulson and Vaux 1989) was cancelled. Analyses of the 1988 fall fertilization pilot experiment indicated that this approach would be unlikely to produce a measurable impact on either shad or gamefish populations. Although the 1989 fall experiment was cancelled, sampling for both shad and gamefish is continuing through the spring of 1990 in order to monitor over-winter changes in population abundance and size structure.

1.3 Environmental Assessment

The 1989 fertilizations were carried out under the Environmental Assessment prepared in April 1988 (National Park Service 1988), for which a Finding of No Significant Impact (FONSI) was issued by the National Park Service. In April 1989, a briefing was given to all interested parties (state and federal agencies, and Nevada and California water users) on the results of the 1988 experiments and the proposed 1989 research program.

1.4 Objectives of This Report

The primary objective of this report is to present an overview of the currently available analyses emanating from the 1989 experiment.

Sample and data analyses are incomplete at the present time, so material presented in this report should be viewed as preliminary information. Some areas of investigation, such as shad feeding ecology and growth rates, are not addressed here at all, but will be included in the project final report.

Each of the three years of the Fertilization Project (1987-89) has resulted in an extensive data base on the Lake Mead food chain. In addition to completing analyses of the 1989 data set, a detailed synthesis of the entire three-year data base is currently underway. This synthesis is examining between-year trends in factors ranging from algal productivity and water quality issues to shad abundance, feeding ecology, growth rates and condition indices, to striped bass condition factors, population size structure and growth rates.

Analyses of temporal (between-year) variation in components of the Lake Mead food chain will complement analyses of within-year spatial variations between fertilized and control regions of the Overton Arm. As discussed in previous reports (Paulson et al., 1988; Paulson and Vaux 1989), controls set up for the Overton Arm experiment provided a reasonably good base of comparison for evaluating fertilization impacts. Nevertheless, the experimental design was imposed on a natural fertility gradient in the upper part of the Overton Arm (the result of Muddy and Virgin River inflows). Therefore a full evaluation of the impacts of artificial fertilization on the productivity of the Lake Mead food chain will require a temporal control, i.e. analysis of food chain dynamics throughout the Overton Arm in the absence of fertilization.

The final project report, to be issued in 1990, will contain a detailed presentation and synthesis of the three-year data base produced from the 1987-89 fertilization experiments.

2. RESULTS OF THE 1989 RESEARCH PROGRAM

2.1 Nutrients

Ammonium polyphosphate fertilizer (10:34:0) was applied to the northern part of the Overton Arm (Figure 1) at a loading rate calculated to provide an average epilimnetic spike of approximately 15 µg/l and 5 µg/l for the June 5 + 8 and June 19 applications, respectively. Figure 2(a) shows the concentrations of total-P and dissolved inorganic nitrogen (NH_4-N + NO_3-N) at fertilized and control stations in the Overton Arm. Figure 2(b) shows the depth profiles of these nutrients at fertilized station F-2. "Background" epilimnetic concentrations of total-P were

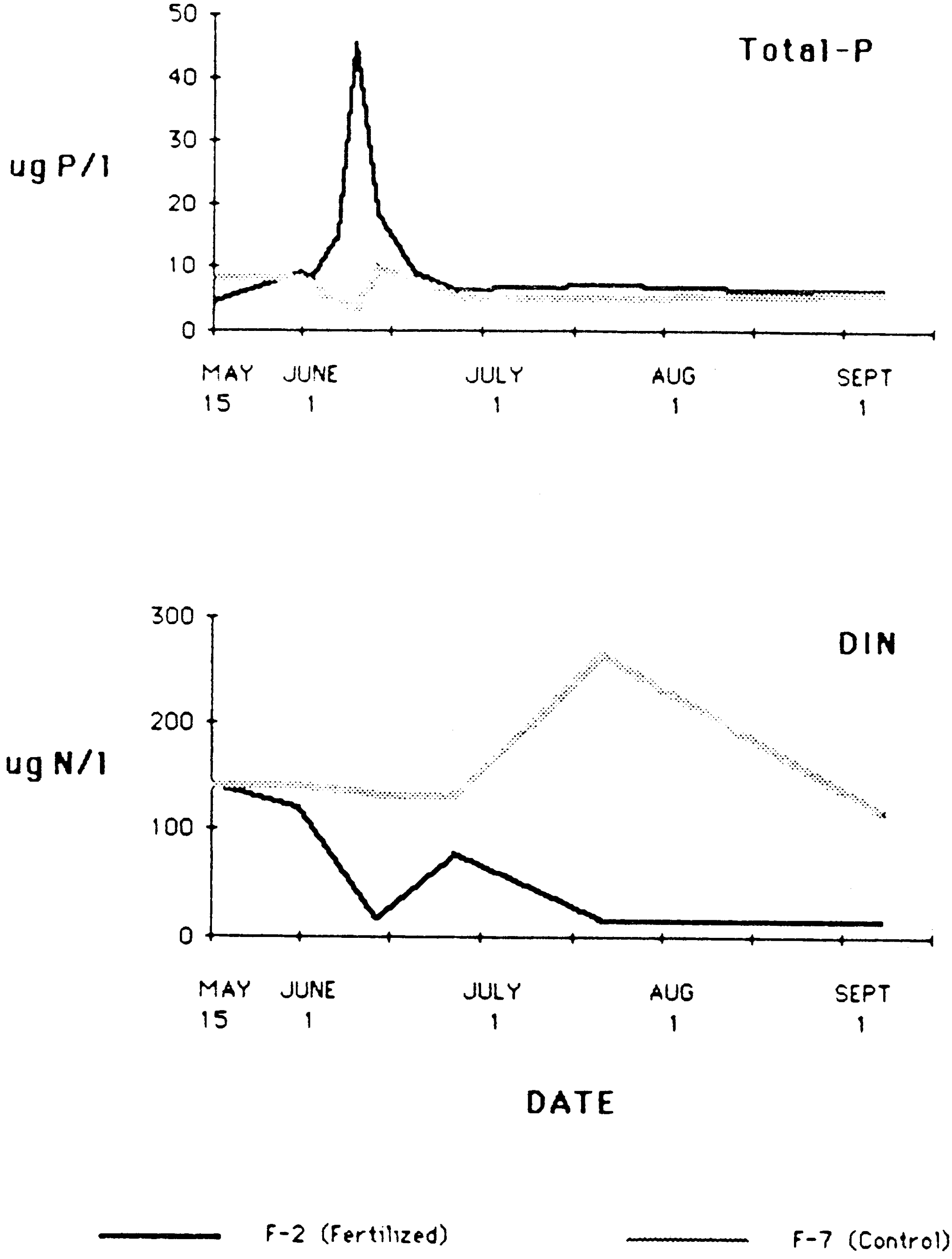


Figure 2(a): Variation in concentrations of total phosphorus and dissolved inorganic nitrogen (0-5 m integrated samples) at fertilized and control stations in the Overton Arm of Lake Mead, 1989.

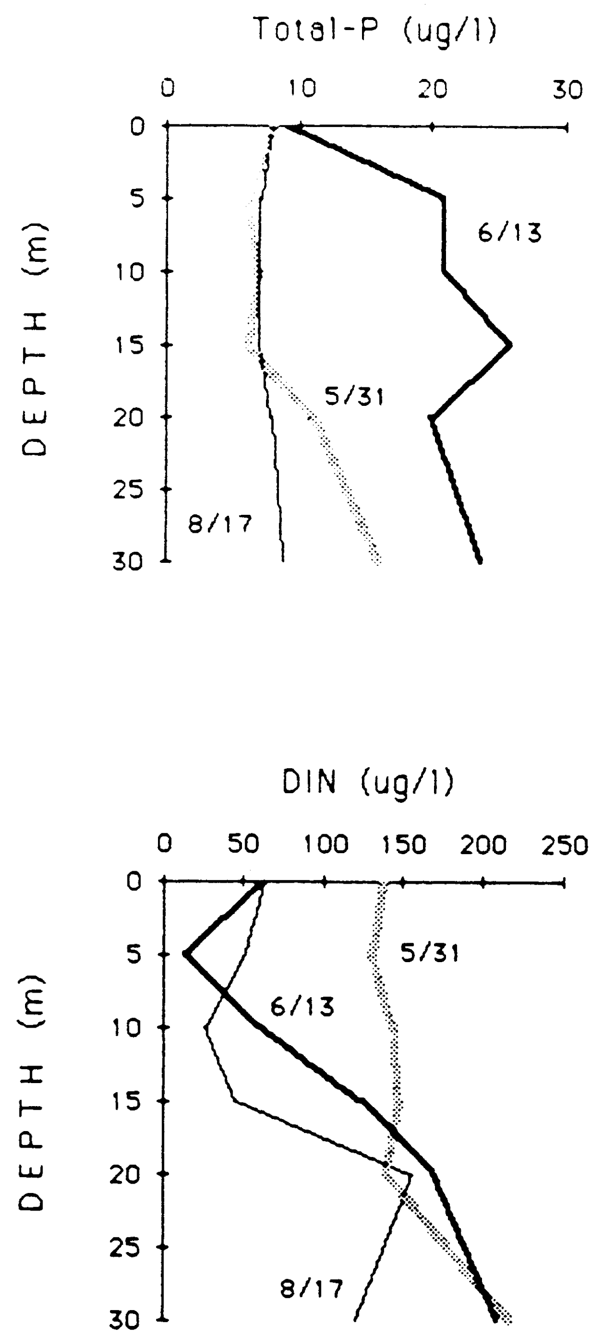


Figure 2(b): Depth profile of total phosphorus and dissolved inorganic nitrogen at station F-2 in the Overton Arm of Lake Mead, 1989.

about 8 µg/l prior to fertilizer application. Surface concentrations increased to over 40 µg/l at some stations immediately following fertilization and before the added nutrients were mixed throughout the epilimnion. By June 13, eight days after the initial application, total-P concentrations were around 20 µg/l in the treatment area. By the end of June, concentrations had returned to near background levels.

Dissolved inorganic nitrogen (DIN) underwent substantial depletion during the peak of algal production (about June 13 -- see below). Subsequently, there was some re-generation of DIN, presumably as a result of mineralization of algal cells (Figure 2a).

2.2 **Water Clarity**

Secchi depths in the fertilized region exhibited a temporary decrease of about 2 m, shortly after fertilization in early June (Figure 3). The bimodal Secchi decrease coincided with the peaks in fertilizer-induced algal production. By June 20, water clarity in the treatment region had returned to pre-fertilized conditions. Secchi depths did, however, decrease again in July, corresponding to a second period of elevated chlorophyll levels (see section 2.5).

It may be noted that natural variations in Secchi depth at control station F-6 (May 25-June 5, for example) were of a similar magnitude to the fertilization-induced variations in the upper part of the Overton Arm.

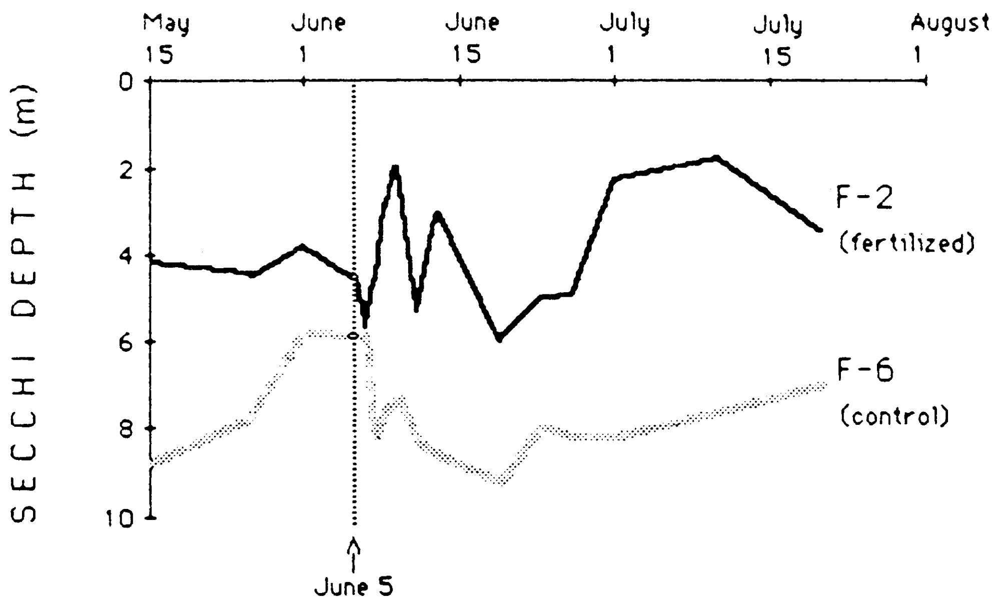


Figure 3: Temporal variation in water clarity (Secchi depth) at fertilized and control stations in the Overton Arm, 1989.

2.3 Taste and Odor

Threshold odor number (TON) refers to the dilution at which a water sample has no detectable odor when sensed under standard conditions (60°C) by a test panel (five persons were used for the panels in the present research). TON was monitored at fertilized and control stations over a series of five dates, from the week before the first application through the end of June. Mean TON values are presented in Table 2. Drinking water regulations stipulate that a TON value of 3 or below is acceptable for finished (i.e. treated) water. This parameter is generally not regulated for raw water supplies.

The two flavor-producing compounds, geosmin and 2-methylisoborneol, were not assayed in the 1989 research program. Data collected during the 1988 experiment indicated that fertilization did not result in any measurable increases in water column concentrations of these two compounds. Since the fertilizer load in 1989 was the same as in 1988, it was concluded that further monitoring of these substances in 1989 was not warranted.

2.4 Disinfection By-Product Formation Potentials

Chlorination of water results in the production of a series of chlorinated organic compounds, four of which (trihalomethanes) are currently regulated in finished water by both federal and state agencies. The impact of the Overton Arm fertilizations on the concentration of disinfection by-product (DBP) precursors was

Table 2: Threshold odor numbers: Overton Arm, 1989 *

DATE	STATION					
	2W	2E	4W	4E	6	7
5/31	2.7	3.0	2.9	2.2	3.4	2.5
6/8	1.9	4.8	3.2	1.7	1.3	1.5
6/11	5.3	2.9	2.6	1.5	1.7	---
6/15	3.2	3.8	4.4	2.7	3.3	1.6
6/26	1.7	2.3	3.5	1.9	2.2	1.8

* Data represent geometric means from five-member panels.

investigated by measuring the formation potentials of water samples collected from both treatment and control areas. Formation potential refers to the quantity of DBP's produced following incubation of water with a specified (and excess) amount of chlorine under standard conditions. The formation potential test procedure employed here does not intend to mimic treatment plant conditions. Rather, it provides a maximum estimate of the potential for DBP formation.

Formation potentials for two groups of DBP's were monitored during the 1989 experiment: (a) pentane-extractables (including trihalomethanes), and (b) haloacids. The former were extracted directly into pentane and subsequently quantified with a gas chromatograph (GC) equipped with an electron-capture detector (ECD). Haloacids were derivatized using diazomethane, extracted into t-butyl methyl ether and quantified on a GC/ECD. Pentane-extractable DBP analyses were done on unpreserved samples, chlorination beginning the day following sample collection. Haloacid analyses are currently being performed on samples that had been stored frozen (analyses will be completed by the end of December 1989). Sample storage was necessary because equipment limitations prevented both analyses from being undertaken at the same time. Holding times would have been violated if samples for haloacid analysis had been left unpreserved until the pentane-extractables had been completed. It is likely that freezing has some impact on the absolute values of the measured DBP formation potentials (this effect will be investigated in early 1990).

However, between-station and between-date <u>trends</u> in haloacid formation potentials are unlikely to be significantly affected by freezing. Thus, data from the current analyses will probably be a reliable indicator of the impact of fertilization on haloacid precursor concentrations.

Table 3 presents the results of the pentane-extractable DBP analyses. Within this group, only data for the four trihalomethanes (THM's) are given. Other pentane-extractable compounds, such as haloacetonitriles, were below the limits of analytical detection. Total THM's increased by about 30-40 µg/l at the fertilized stations between June 2 (before the first application) and June 11 (coincident with the fertilizer induced-peak in algal production). At the control station 4E, total THM's also increased, but by a much smaller amount than at the treatment stations. Concentrations at control station F-6 on June 11, however, were almost as high as those at the fertilized stations. Although there are no data from F-6 on June 2, it is likely that levels at this station were very similar to those at F-7. Thus the apparent increase in THM concentrations at F-6 between June 2 and June 11 suggests "natural" variation, to a large degree unrelated to fertilization. By June 15, total THM concentrations had decreased to levels characteristic of the pre-fertilization sampling (June 2).

Although the data from control station F-6 make it difficult to document a direct impact from fertilization on THM formation

Table 3: Trihalomethane formation potentials (ug/l): Overton Arm, 1989 *

THM	DATE	STATION					
		2W	2E	4W	4E	6	7
$CHCl_3$	6/2	72.4 (5.1)	72.4 (5.1)	67.4 (7.2)	72.6 (1.0)	---	60.8 (3.5)
	6/11	100.3 (1.1)	93.2 (1.6)	103.8 (2.4)	81.5 (0.1)	89.6 (0.4)	---
	6/15	69.6 (2.7)	70.1 (4.0)	69.7 (7.9)	64.3 (0.1)	63.0 (0.7)	65.8 (3.1)
$CHCl_2Br$	6/2	30.4 (4.0)	30.4 (4.0)	27.7 (3.5)	31.0 (1.2)	---	22.8 (1.1)
	6/11	30.4 (0.4)	31.6 (0.7)	31.9 (1.0)	29.2 (0.4)	32.3 (0.3)	---
	6/15	27.8 (1.1)	28.6 (2.0)	26.6 (2.4)	27.7 (0.4)	26.9 (0.2)	27.5 (1.5)
$CHClBr_2$	6/2	14.7 (2.3)	14.7 (2.3)	12.8 (1.6)	14.2 (1.2)	---	10.1 (0.6)
	6/11	13.6 (0.2)	15.1 (0.3)	14.2 (0.7)	13.8 (0.0)	14.9 (0.2)	---
	6/15	13.3 (0.7)	14.1 (1.2)	12.3 (1.0)	13.5 (0.2)	13.2 (0.2)	12.4 (0.3)
Total THM's	6/2	117.5	117.5	107.9	117.8	---	93.7
	6/11	144.8	140.5	149.9	124.5	137.7	---
	6/15	111.5	113.6	109.4	106.2	104.0	106.4

* Values represent means of replicate incubations (standard error).
Chlorination conditions: 5 ppm Cl; 7 days; pH=8.5; 25C; dark.
Bromoform ($CHBr_3$) below detection limits at all station/dates.

potentials, a significant relationship does exist within this data set between total THM formation potential and chlorophyll-a concentrations (Figure 4). Other studies carried out elsewhere in Lake Mead and in the downstream reservoir, Lake Mohave, also clearly demonstrate a positive relationship between DBP precursors and chlorophyll-a (Vaux and Paulson, unpublished data). Nevertheless, the Overton Arm study suggests that any impacts from the fertilization on THM precursor concentrations were short-lived -- within 10 days of the first fertilizer application, THM precursors had returned to their pre-fertilization concentrations.

2.5 Chlorophyll-a

Figure 5 shows the chlorophyll-a concentrations at three fertilized (2W, 2E, 4W) and three control (4E, 6, 7) stations. The algal increase that resulted from the primary fertilizer application is clearly seen at stations 2W, 2E and 4W. The increase is bimodal because the first batch of fertilizer (15,000 gallons) was applied over a two-day period (June 5 and 8). The smaller chlorophyll peak at "control" station 4E shows that some of the fertilized water was advected in an easterly direction. The 1987 and 1988 experiments also demonstrated this type of large-scale water movement.

The June 19 fertilizer application (5 µg/l) apparently did not produce a short-term chlorophyll peak. It appears, however, that it may have contributed to a lower level, longer-term increase in chlorophyll levels, extending from the end of June

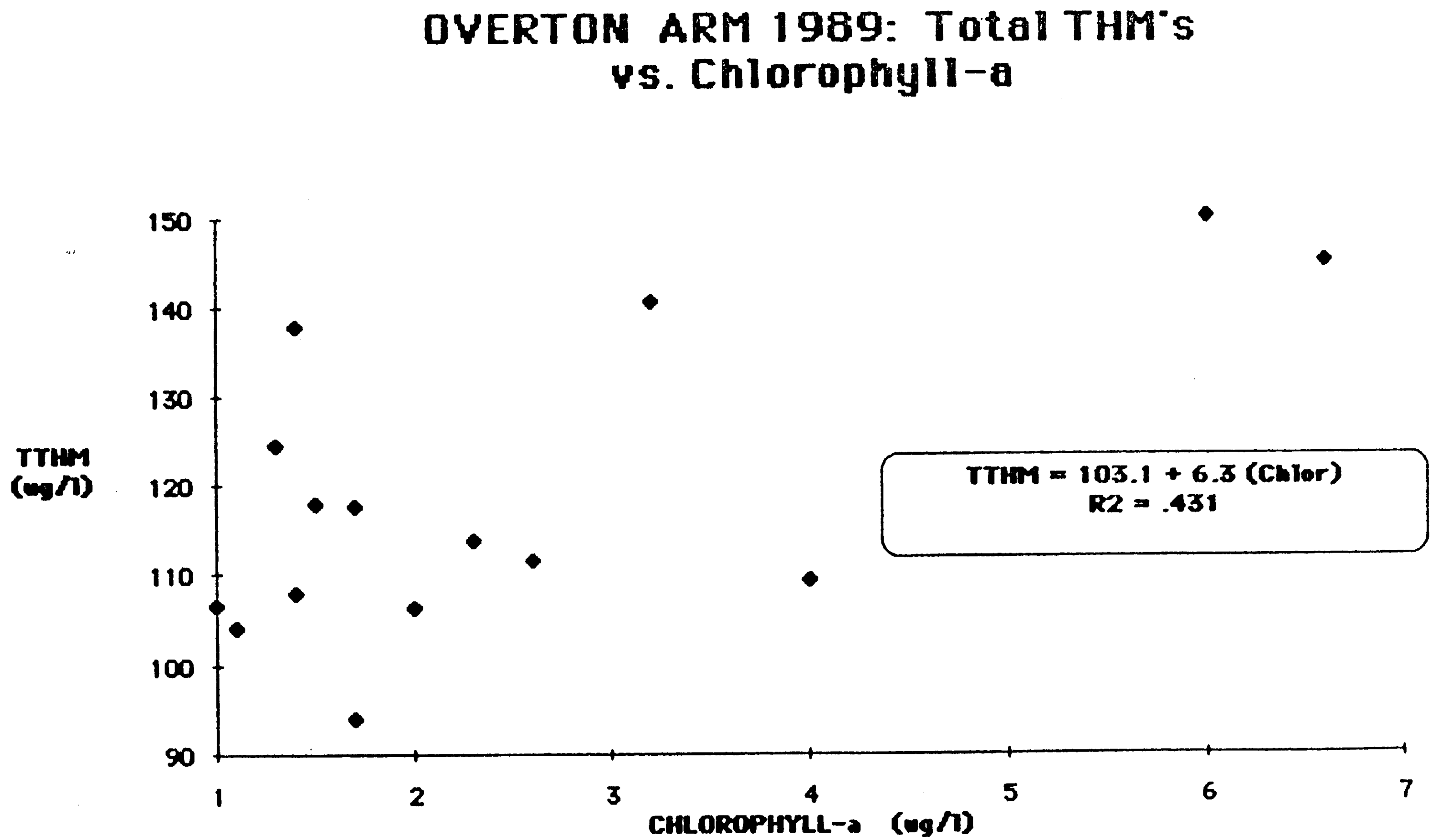


Figure 4: Relationship between total trihalomethane formation potential and chlorophyll-a concentrations, Overton Arm of Lake Mead, June 1989.

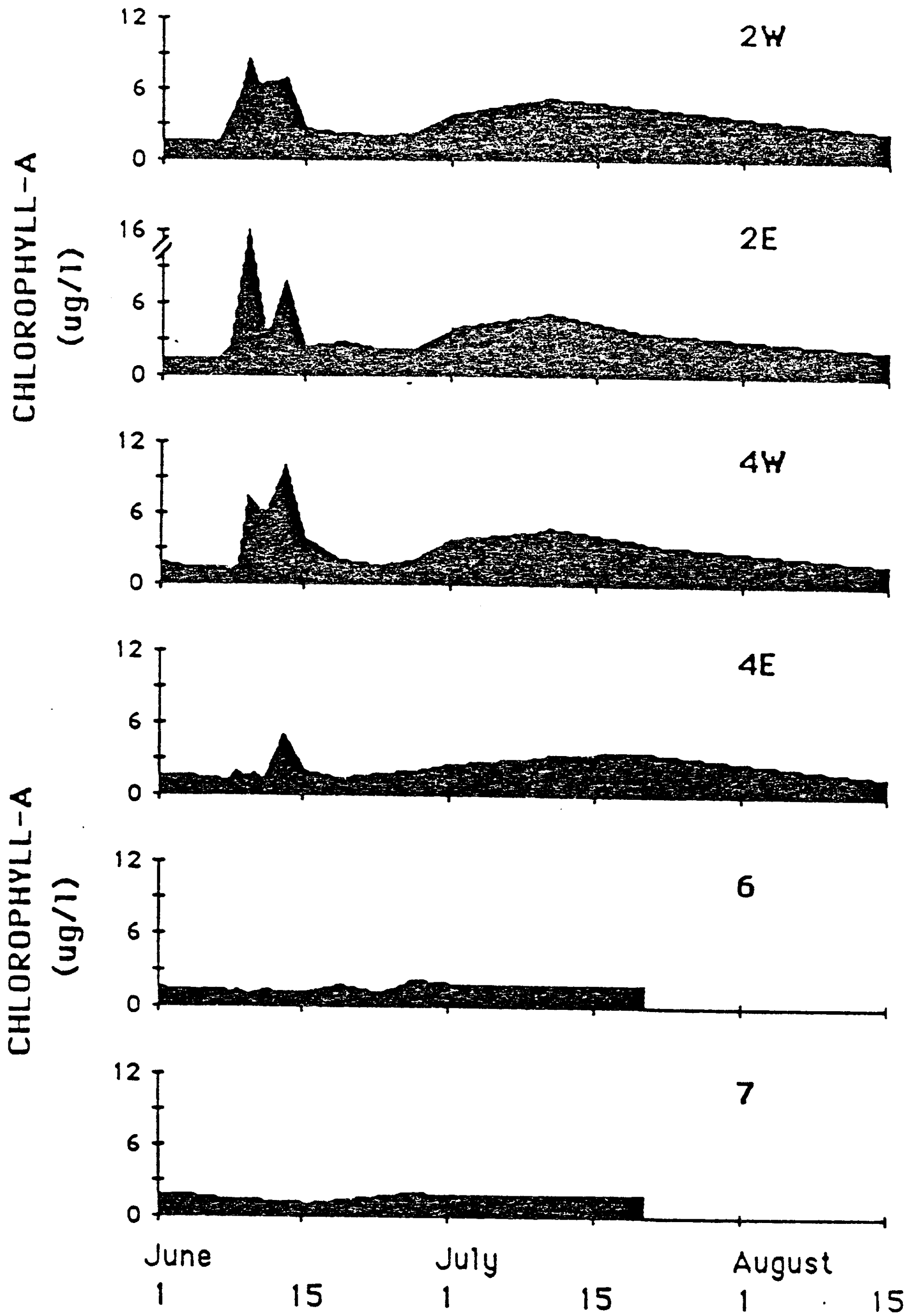


Figure 5: Chlorophyll-a concentrations at three fertilized (2W, 2E, 4W) and three unfertilized (4E, 6, 7) stations in the Overton Arm of Lake Mead.

through mid July (Figure 5, stations 2W-4E). Re-cycling of phosphorus from the primary application presumably also contributed to the observed increases at this time. Data analyses are continuing in order to further evaluate the various processes involved here.

In order to obtain a better impression of spatial variation in algal biomass, chlorophyll was also measured on 8 dates at a series of 46 synoptic stations spanning the Overton Arm. Figures 6-9 illustrate data from four dates. Prior to fertilizer application, chlorophyll concentrations were less than 2 µg/l throughout the Overton Arm, with the exception of a small area around the F-0 station that receives discharge from the Virgin River. The synoptic of June 9 (Figure 6) clearly demonstrates the effect of fertilization (compare with the treatment area in Figure 1). Four days later, the fertilized water mass had spread in an easterly direction (Figure 7). Chlorophyll concentrations had returned to below 3 µg/l by June 23 (Figure 8) but, as discussed above, increased to around 4 µg/l towards the end of that month (Figure 9).

Thirty-day (June 1-30) mean chlorophyll-*a* concentrations were highest at station F-0 (Table 4). This pattern is similar to the one observed during the 1988 experiment and, in part, is a result of nutrient loading from the Virgin River. With the exception of F-0, mean chlorophyll concentrations at all stations were below the 5 µg/l standard for Lake Mead.

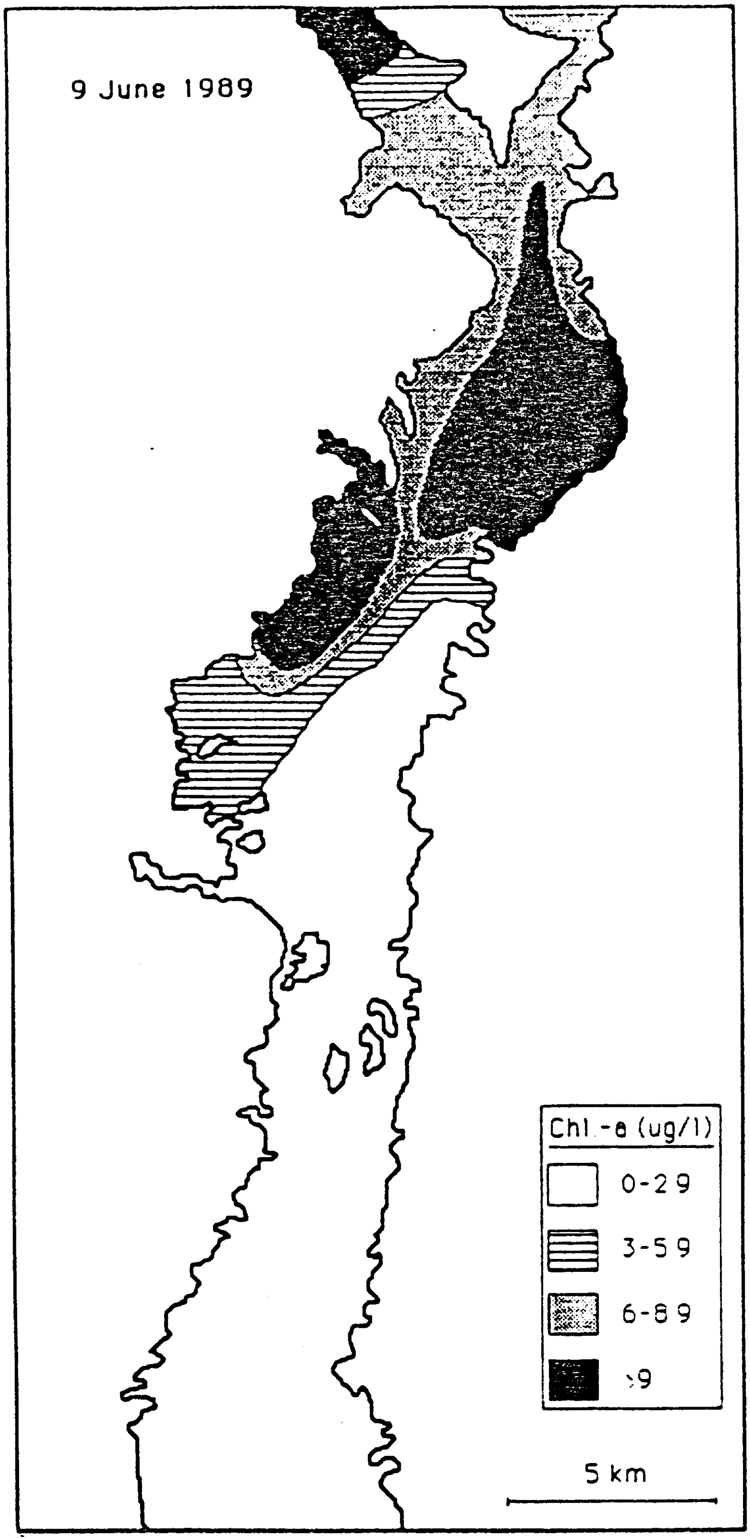


Figure 6: Chlorophyll-a concentrations in the Overton Arm of Lake Mead, June 9, 1989.

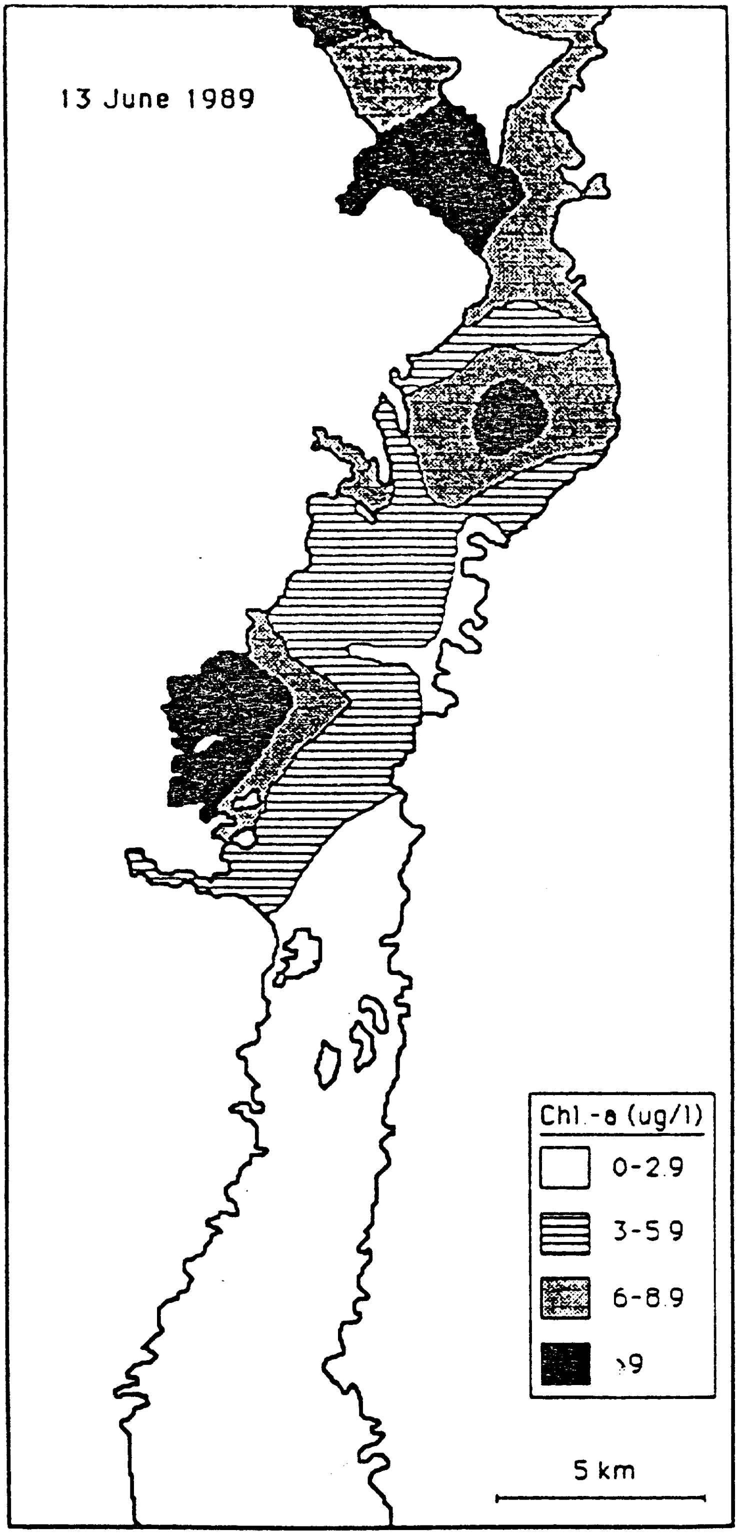


Figure 7: Chlorophyll-a concentrations in the Overton Arm of Lake Mead, June 13, 1989.

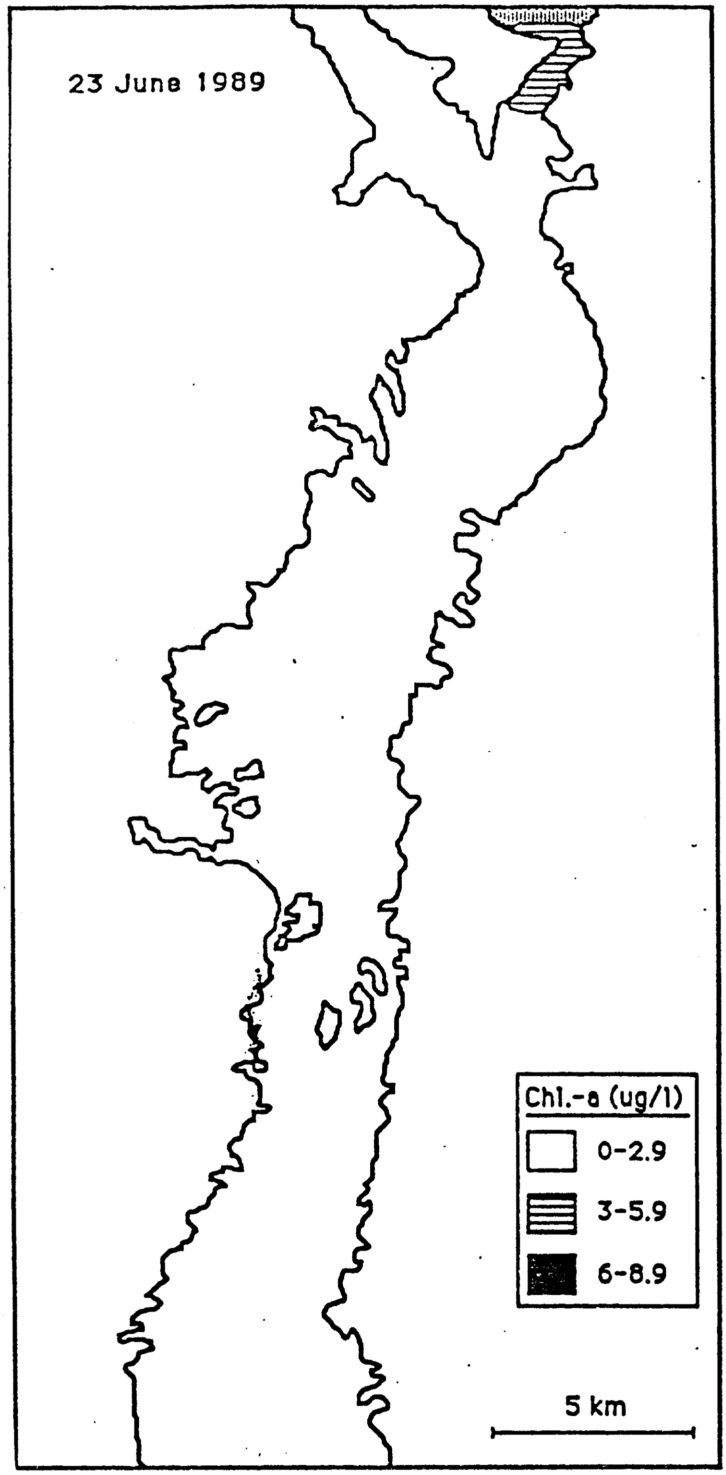


Figure 8: Chlorophyll-a concentrations in the Overton Arm of Lake Mead, June 23, 1989.

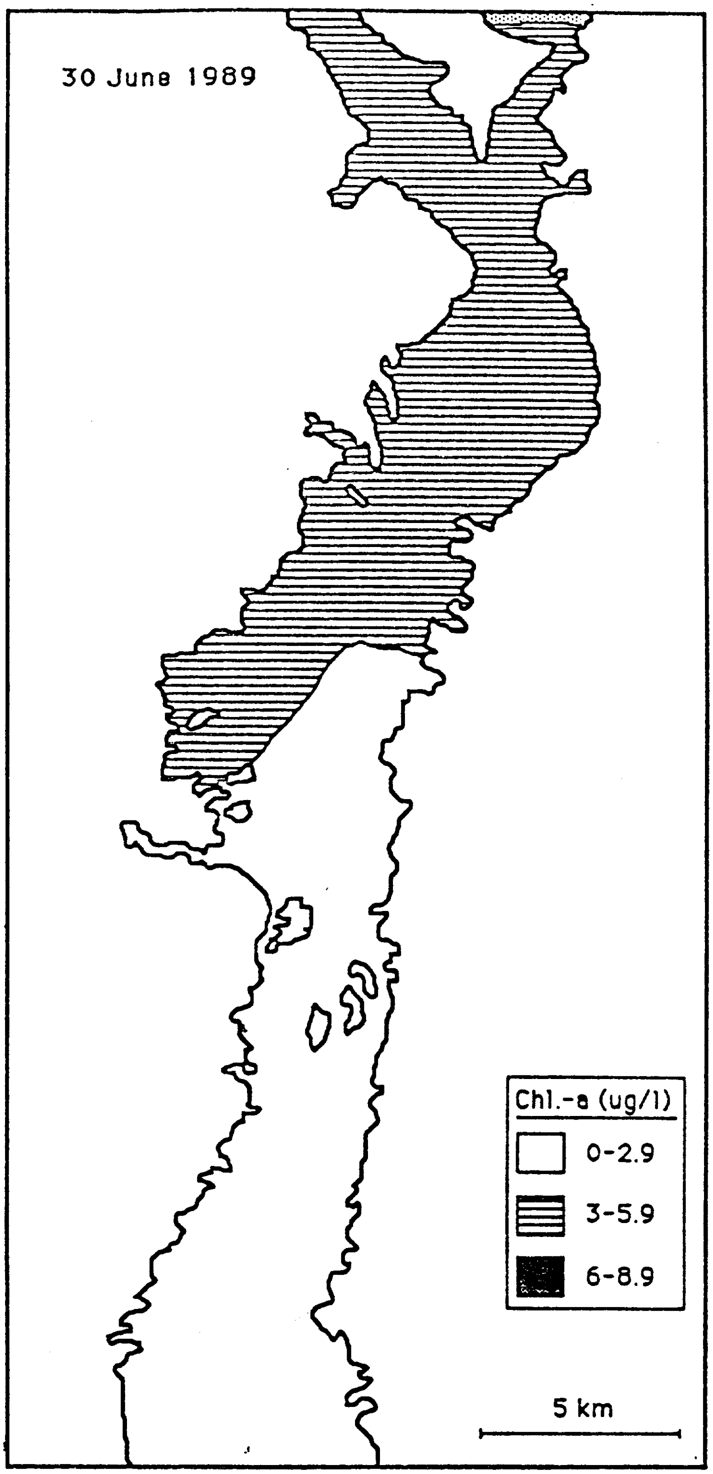


Figure 9: Chlorophyll-a concentrations in the Overton Arm of Lake Mead, June 30, 1989.

Table 4. Thirty-day (June 1-30) mean chlorophyll-*a* concentrations at various stations in the Overton Arm of Lak Mead.

Station	Chlorophyll
M-1	4.3
F-0	6.0
F-1	3.5
2W	3.3
2E	3.5
4W	3.1
4E	1.9
F-6	1.5
F-7	1.5

2.6 Phytoplankton Biomass and Species Composition

A detailed evaluation of the impacts of fertilization on the base of the Lake Mead food chain is being undertaken through identification and enumeration of phytoplankton samples. These analyses are currently in progress and no data are available for inclusion in this report. Sample enumerations are scheduled for completion in February 1990.

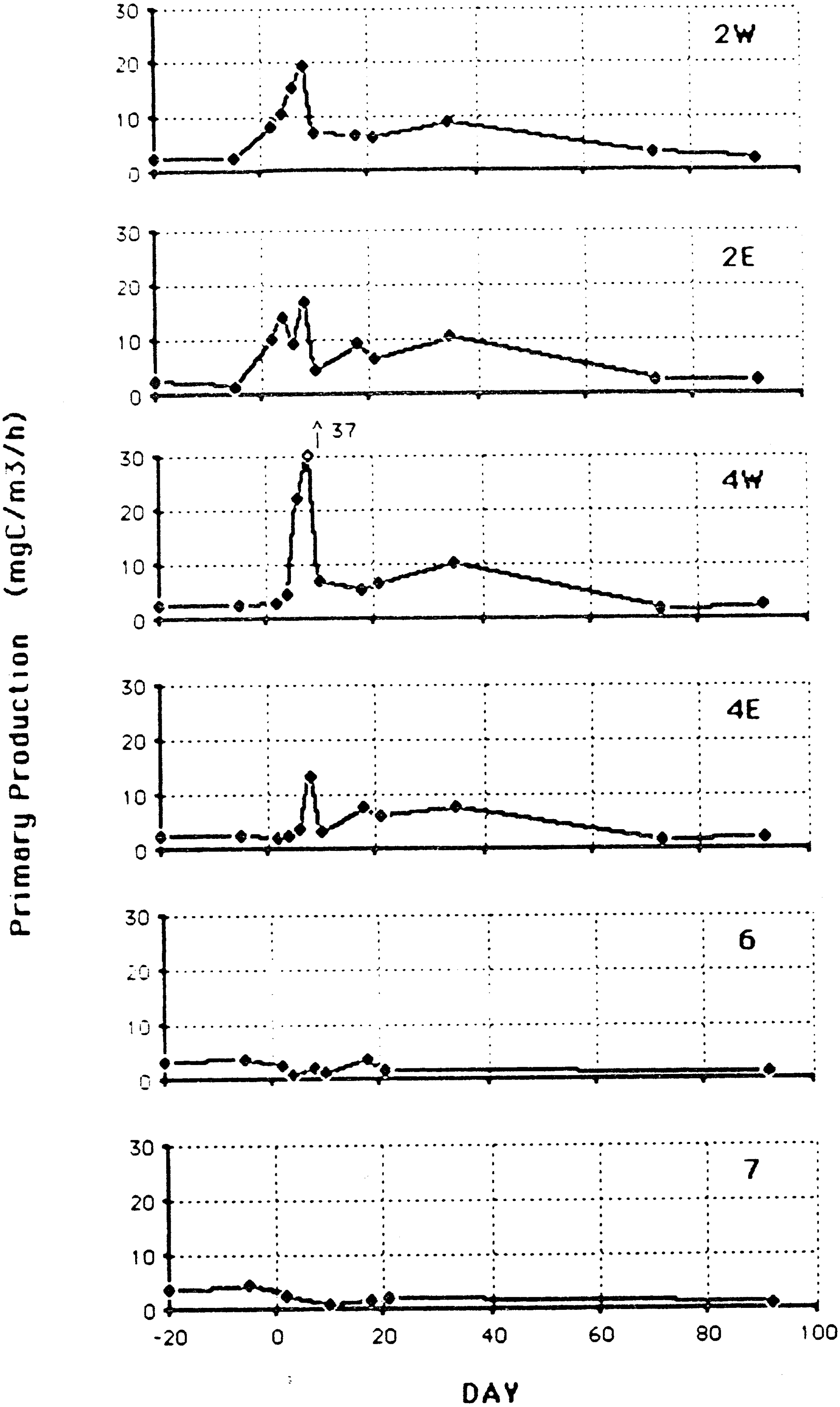
2.7 Primary Production

Phytoplankton primary productivity (PPR) was monitored in 1989, as in 1987-88, by laboratory incubation of samples with ^{14}C bicarbonate. These production measurements provide a relative index of spatial and temporal patterns in PPR in the fertilized and control regions of the Overton Arm. On their own, the data do not, however, represent absolute, or *in situ* (in-lake), rates of primary production. Data collected elsewhere in Lake Mead are currently being analyzed for a relationship between laboratory and *in situ* ^{14}C uptake rates. This should allow *in situ* estimates to be made of PPR in the Overton Arm.

Figure 10 illustrates the temporal patterns of algal PPR at six stations in the Overton Arm. The impacts of the primary fertilizer application (June 5 & 8) are clearly visible, with highest production rates being measured at station 4W.

Figure 10 also shows that PPR exhibited a secondary increase in late June/early July. This parallels the increase in chlorophyll-*a* concentrations observed at that time (see Figure 5

Figure 10: Temporal variation in algal primary productivity at three fertilized (2W, 2E, 4W) and three control (4E, 6, 7) stations in the Overton Arm, 1989.



(Day 0 = June 5, 1989)

and section 2.5) and may have been caused by phosphorus re-cycling from the primary fertilization and, to a lesser extent, from the secondary application (June 19). It is unlikely that this later increase in PPR was a "direct" result of the June 19 application (c.f. section 2.5).

The routine PPR monitoring was complemented by a series of size-fractionated measurements of algal productivity. Samples incubated with ^{14}C were drawn through a stacked series of nylon filters with the following pore sizes: 50 µm, 20 µm, 10 µm, 5 µm and 0.45 µm. Figure 11 shows the carbon uptake at each pore size for one fertilized (2W) and one control (6) station. From these data it is clear that (a) a large proportion (50-70%) of the algal community primary production, under non-fertilized conditions, occured within the 20-50 µm fraction and (b) this pattern remained relatively stable following fertilizer addition (e.g. station 2W, June 7-13).

2.8 Zooplankton Population Dynamics

Zooplankton sample analyses are incomplete at the present time, but the available data show that the cladoceran *Daphnia pulex* exhibited the clearest response to fertilization, in terms of both egg production and (related to this) abundance (Figure 12). Densities increased to over 2000 individuals/m^3 at station 2W following the primary fertilizer application (June 5 & 8), while at control station F-6 they remained low (<300 individuals/m^3). The currently available data record does not allow evaluation of

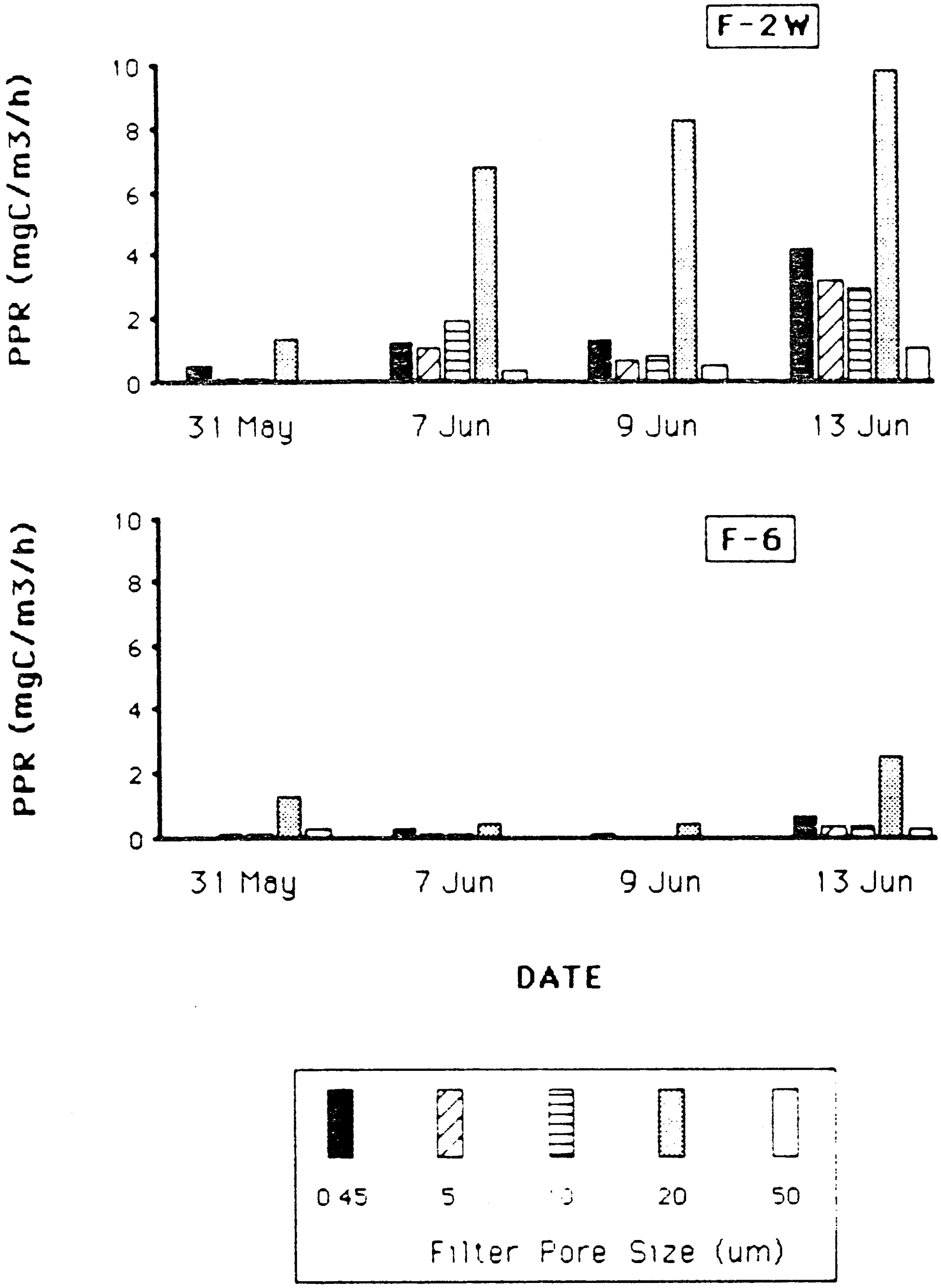


Figure 11: Size-fractionated algal primary productivity at one fertilized (2W) and one control (6) station in the Overton Arm, 1989.

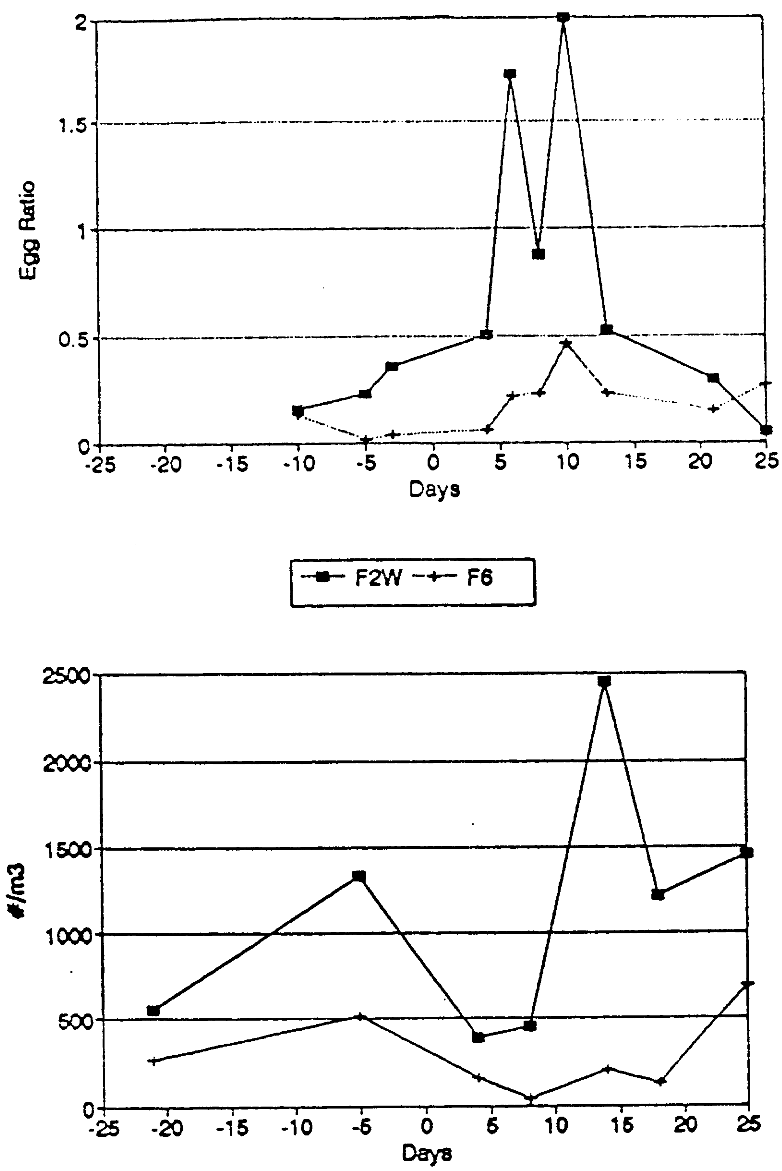


Figure 12: Variation in adult egg ratios (upper panel) and densities (lower panel) of Daphnia pulex at a fertilized (2W) and control (6) station in the Overton Arm, 1989. (Day 0 = June 5, 1989.)

the impacts of the secondary application (June 19) on *Daphnia pulex* densities at this time.

Once the 1989 zooplankton data base is complete, it will be analyzed in considerably greater detail for fertilization effects on other components of the community. Analyses of the 1987 and 1988 data records have demonstrated a wide variety of impacts on zooplankton community structure following the fertilizer-induced increase in algal production.

2.9 Shad

Three sampling strategies were used for studying the ecology and population dynamics of threadfin shad in Lake Mead. Larval and juvenile fish were sampled intensively with sub-surface tows of a one-meter diameter conical ichthyoplankton net. Figure 13 shows the set of Overton Arm stations routinely sampled with this gear. In addition, some sampling was carried out in the Lower Basin, from the Las Vegas Bay through mid Boulder Basin, and (by Arizona Game and Fish Department) at a series of four stations in the Colorado Arm. All samples were collected with the same type of ichthyoplankton net. The depth distribution of young shad was studied at three stations in the Overton Arm using a $1m^2$ Tucker trawl (samples collected by the Nevada Department of Wildlife). The sampled depths were 0, 5 and 15 m (June 12-13) or 0, 5 and 10m (all subsequent dates).

The third sampling approach used gill nets to monitor the abundance of all shad age classes in the Overton Arm. Gill-

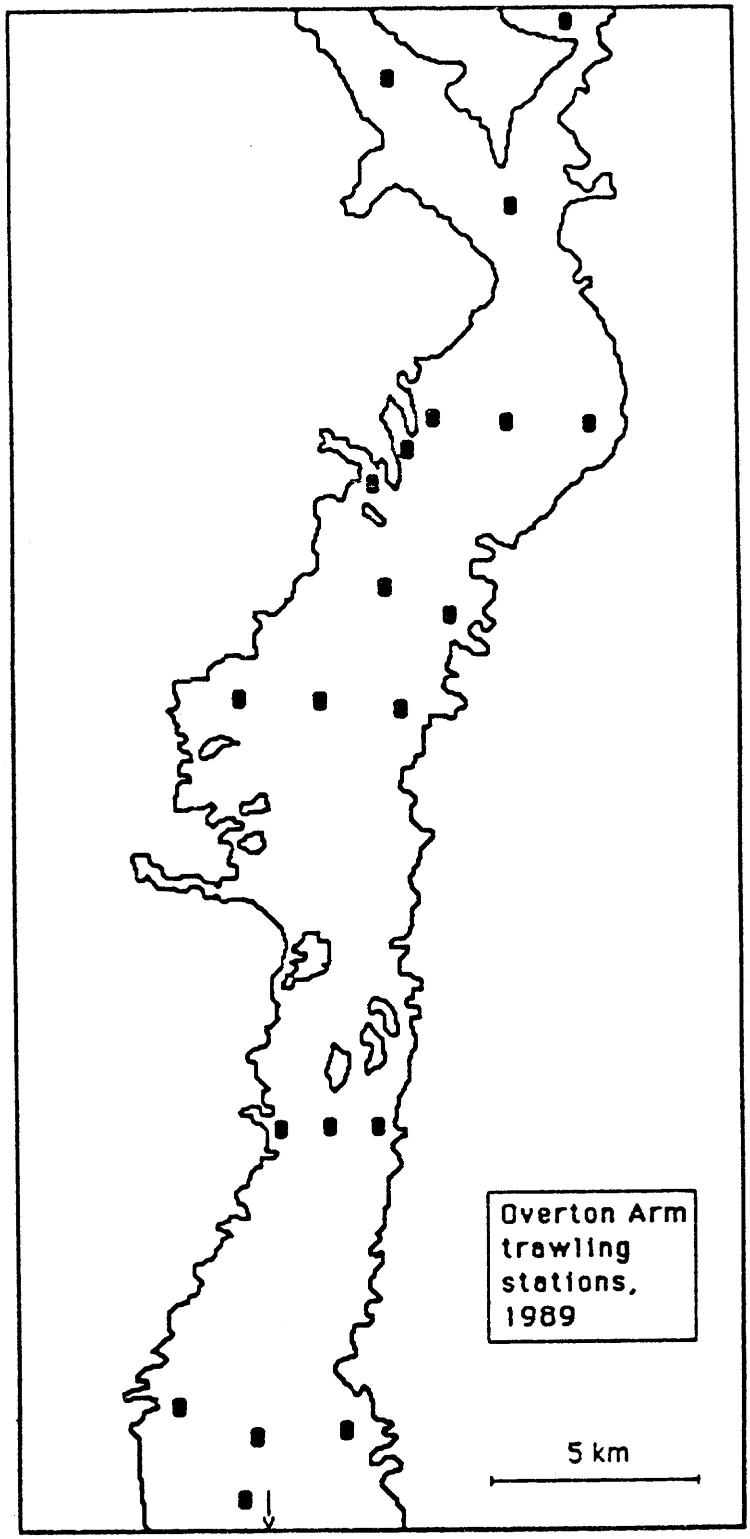


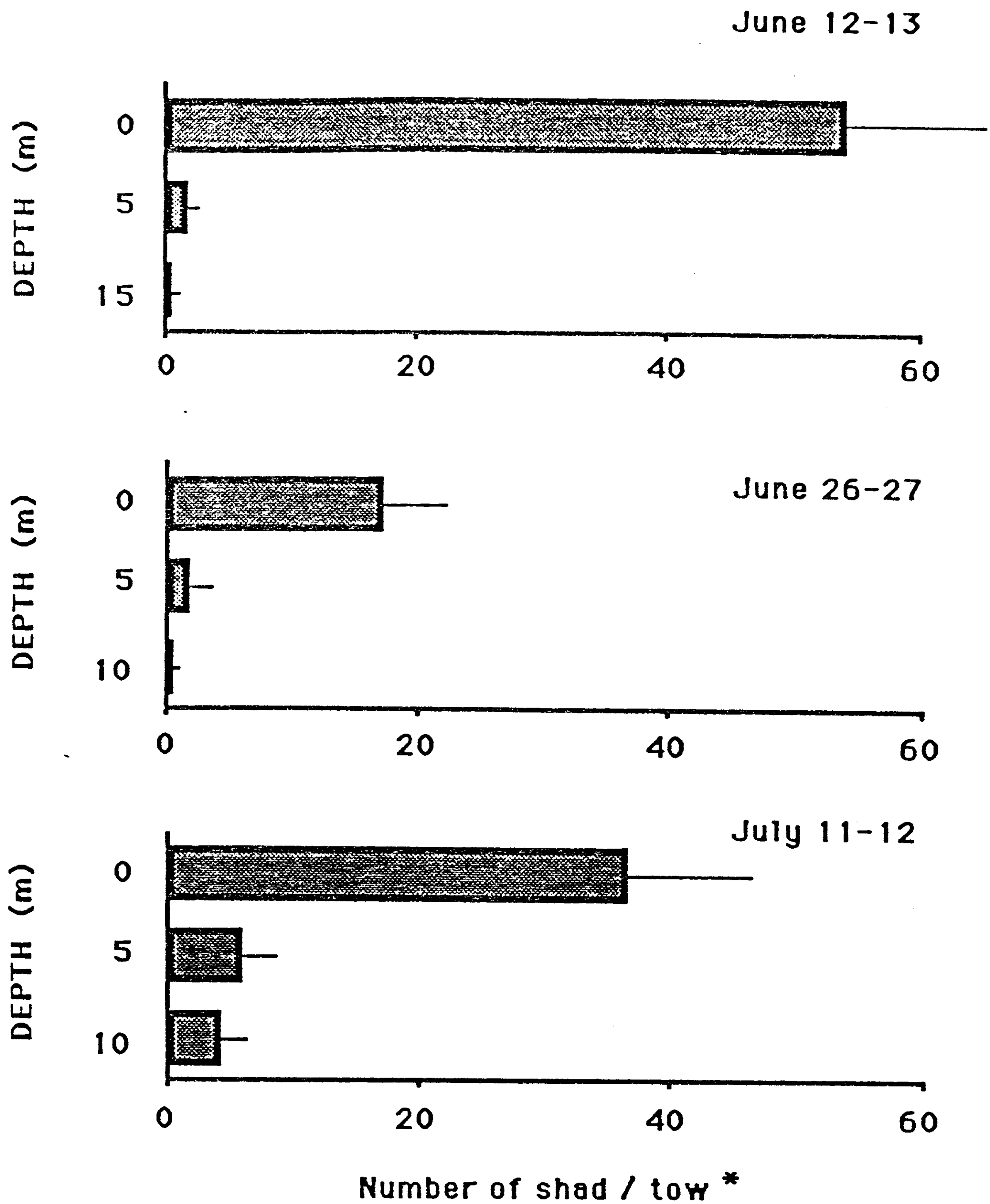
Figure 13: Map of the Overton Arm showing primary shad trawling stations for the 1989 research.

netting will continue through the spring of 1990 in order to follow over-winter survival of the shad population. Gill-netted samples will not be further discussed in this report since sample and data analyses are continuing. Full analyses will be included, however, in the 1990 final report on the Fertilization Project.

Depth-specific sampling clearly showed that most (usually >75%) of the "trawlable" shad were in the upper part of the water column at night. Figure 14 illustrates the depth distributions at station F-2 on three dates. The available data also suggest that the size frequency distribution of the shad was generally independent of depth (Figure 15). These findings indicate that the routine shad trawling, done with sub-surface (approx. 1 m depth) tows of the conical meter net, was sampling the most important stratum of the water column (in terms of the night-time shad distribution).

Figures 16-18 show the patterns of larval/juvenile shad abundance at a series of mid-channel stations throughout Lake Mead. Metering of the ichthyoplankton net allowed filtering efficiencies to be calculated and shad densities to be expressed on a volumetric basis. The following discussion focuses on the 1989 data; a full comparison of the 1987-89 data base is deferred to the final project report.

Highest shad densities were observed in the upper part of the Overton Arm (Figure 16; stations F-0 through F-4; also in west-side coves, not shown in this figure). Densities in the southern



*(Mean and standard deviation of 3 replicate tows per depth)

Figure 14: Depth distribution of shad in trawl samples at station F2 in the Overton Arm of Lake Mead, 1989.

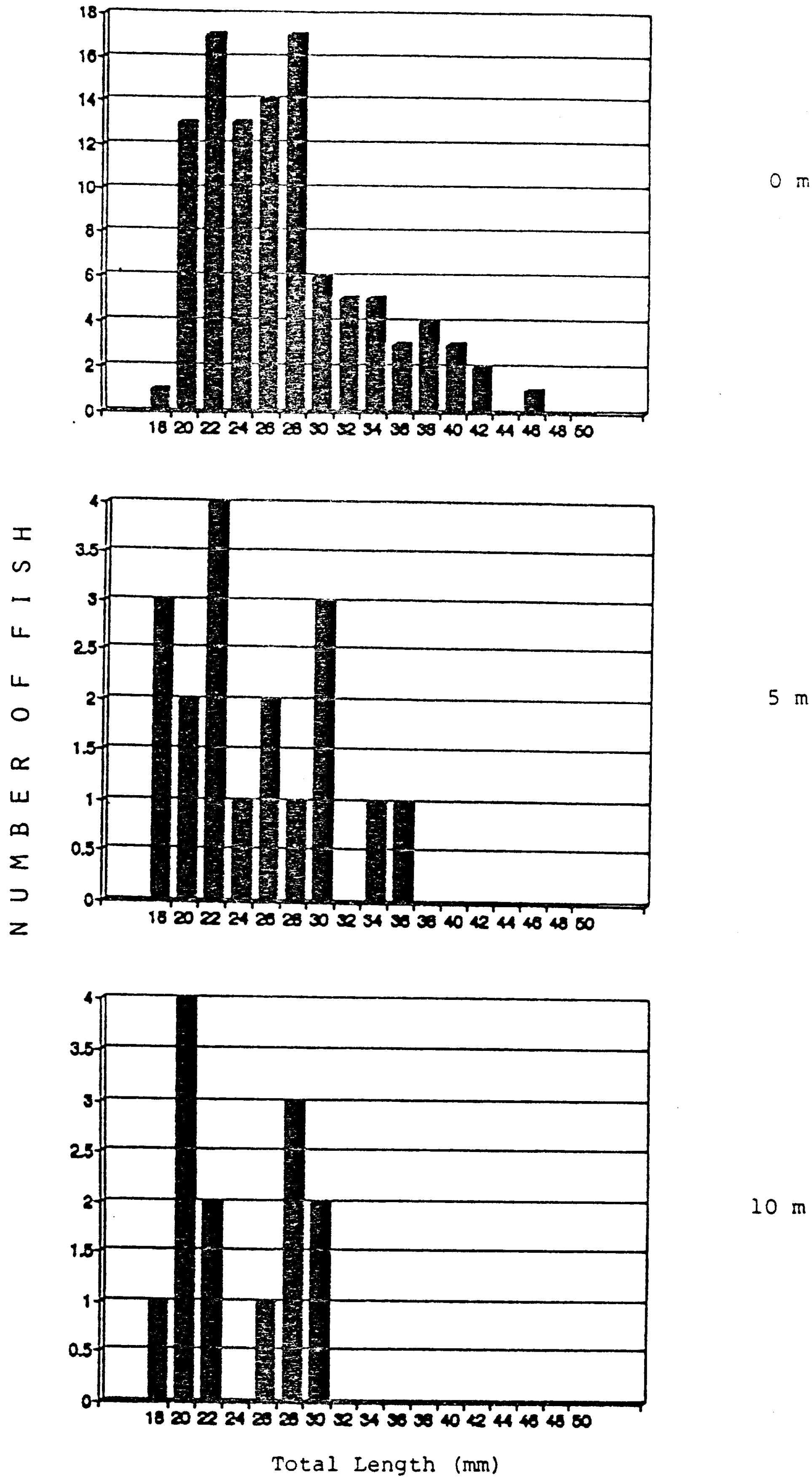


Figure 15: Size frequency of shad trawled from three depths in the Overton Arm of Lake Mead (station F2), 1989.

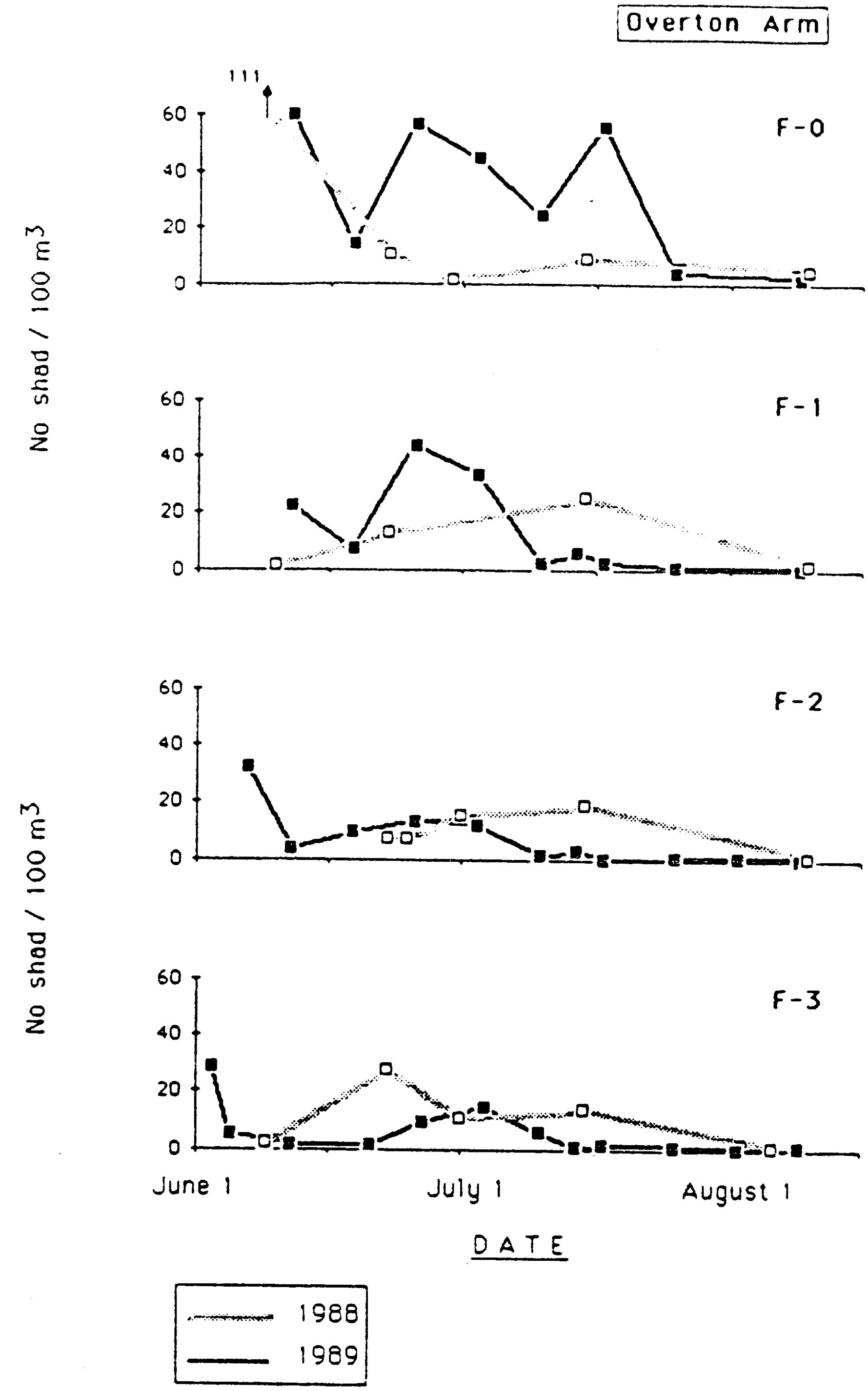


Figure 16: Densities of threadfin shad in the Overton Arm of Lake Mead (1988-1989), as estimated by sub-surface (approximately 1 m) trawling with a 1 m diameter ichthyoplankton net.

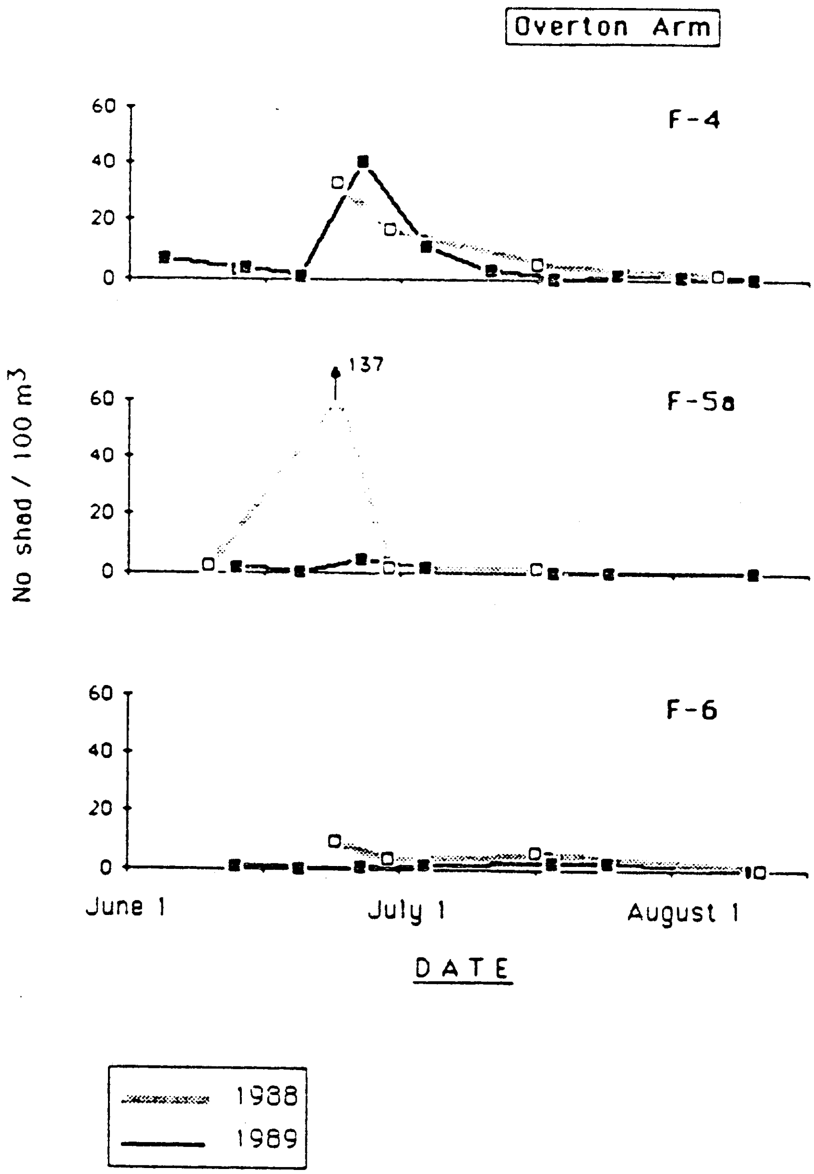


Figure 16: (continued).

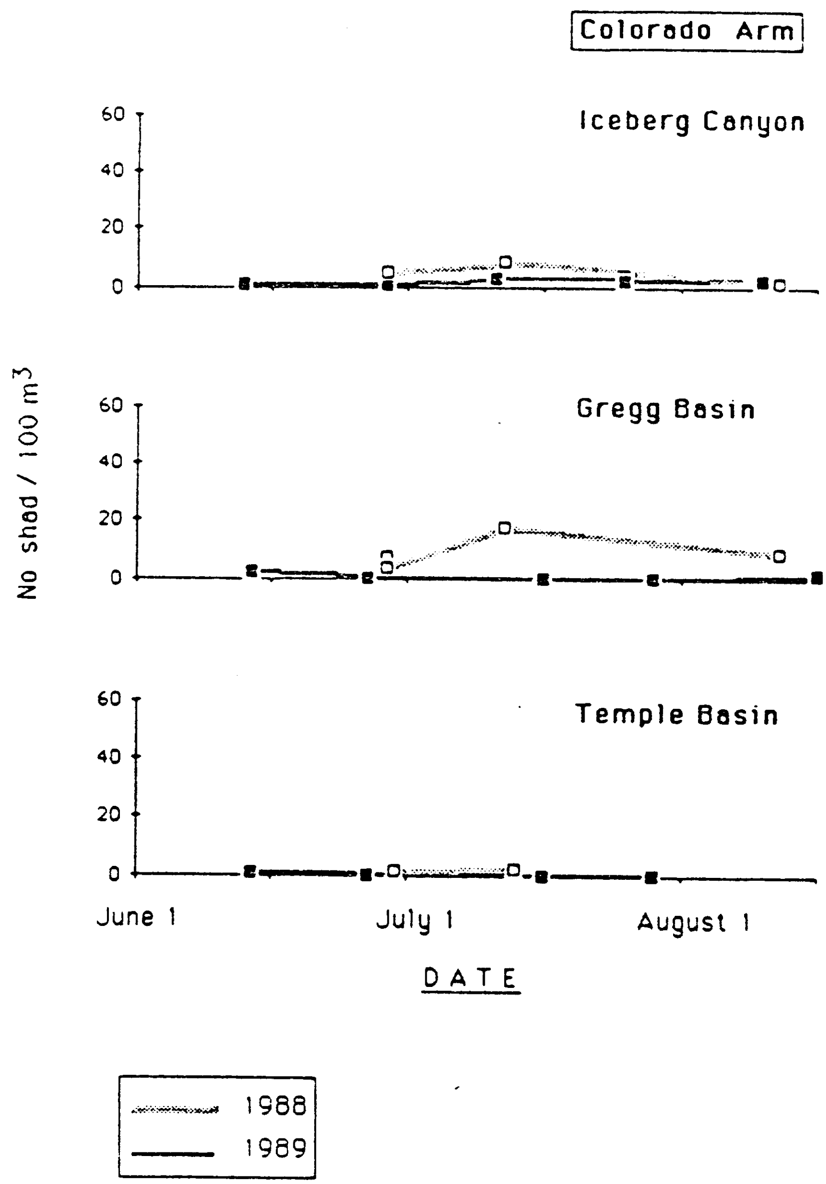


Figure 17: Densities of threadfin shad in the Colorado Arm of Lake Mead (1988-1989), as estimated by sub-surface (approximately 1 m) trawling with a 1 m diameter ichthyoplankton net.

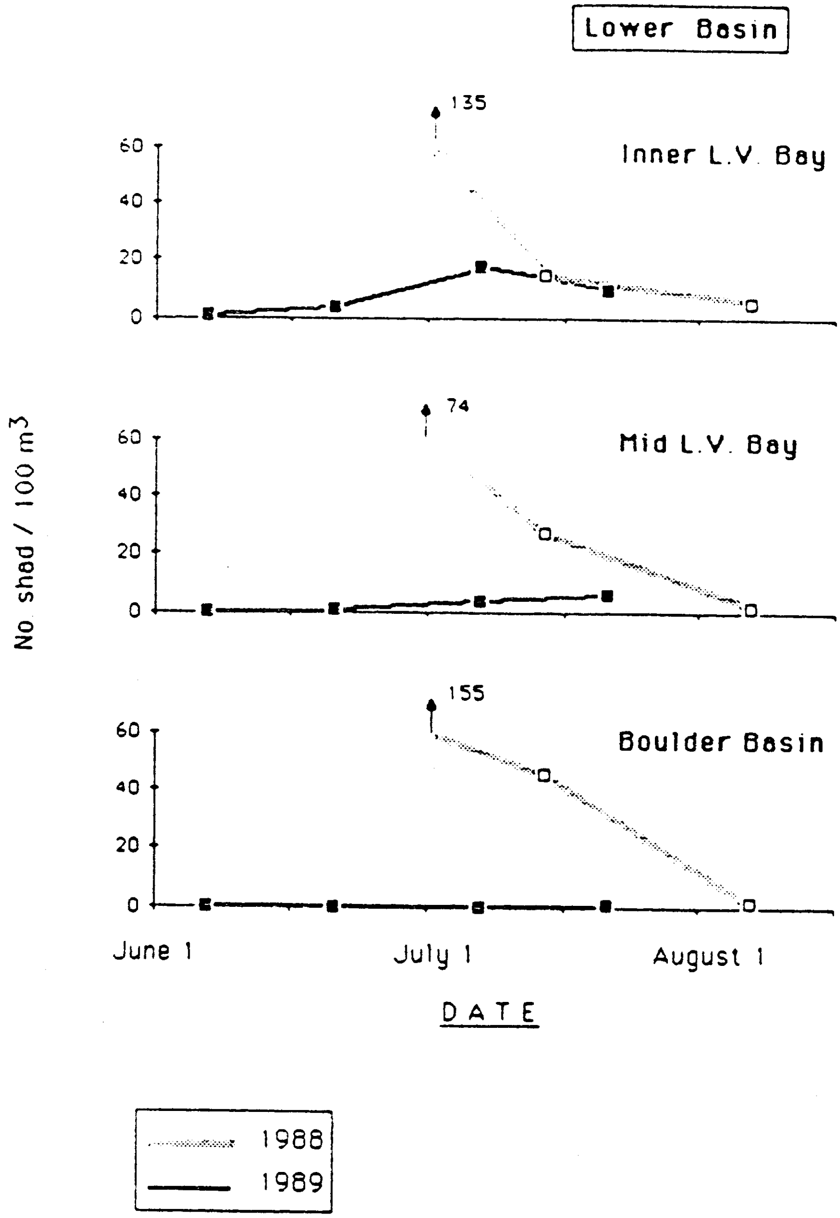


Figure 18: Densities of threadfin shad in the Lower Basin of Lake Mead (1988-1989), as estimated by sub-surface (approximately 1 m) trawling with a 1 m diameter ichthyoplankton net.

part of the Overton Arm (stations F-5A and F-6) were considerably lower. Low shad densities also characterized the main body of the Colorado Arm (Figure 17). Only at Grand Wash (not shown in Figure 17), close to the Colorado River inflow, were moderate densities encountered (an average of 11 individuals/100m^3 between June 12 and July 27).

Densities of larval and juvenile shad in the Lower Basin were also low in 1989 (Figure 18), providing a strong contrast to the pattern in 1988 (and 1987). The reasons for this dramatic decline in Lower Basin shad densities are unclear at the present time; biotic and/or abiotic factors may be involved. Further discussion of this subject is deferred until analysis of the entire data base is complete.

When shad abundance in the Overton Arm is expressed as biomass, similar trends through time are observed (Figure 19). Highest biomasses were recorded in the upper part of the Overton Arm. In addition, Figure 19 shows that more shad were present at stations 3W and 4W (fertilized) than at the corresponding control stations on the east side of the lake (3E, 4E). Interestingly, in the F-2 region of the Overton Arm, shad abundance was similar on both east (2E) and west (2W) sides. Both sides were fertilized.

Mean shad abundance, expressed as either density or biomass, was significantly correlated to mean chlorophyll-a concentrations. Figures 20 and 21 illustrate these relationships. Shad abundance is expressed as time-weighted means for the period June 10-July 10

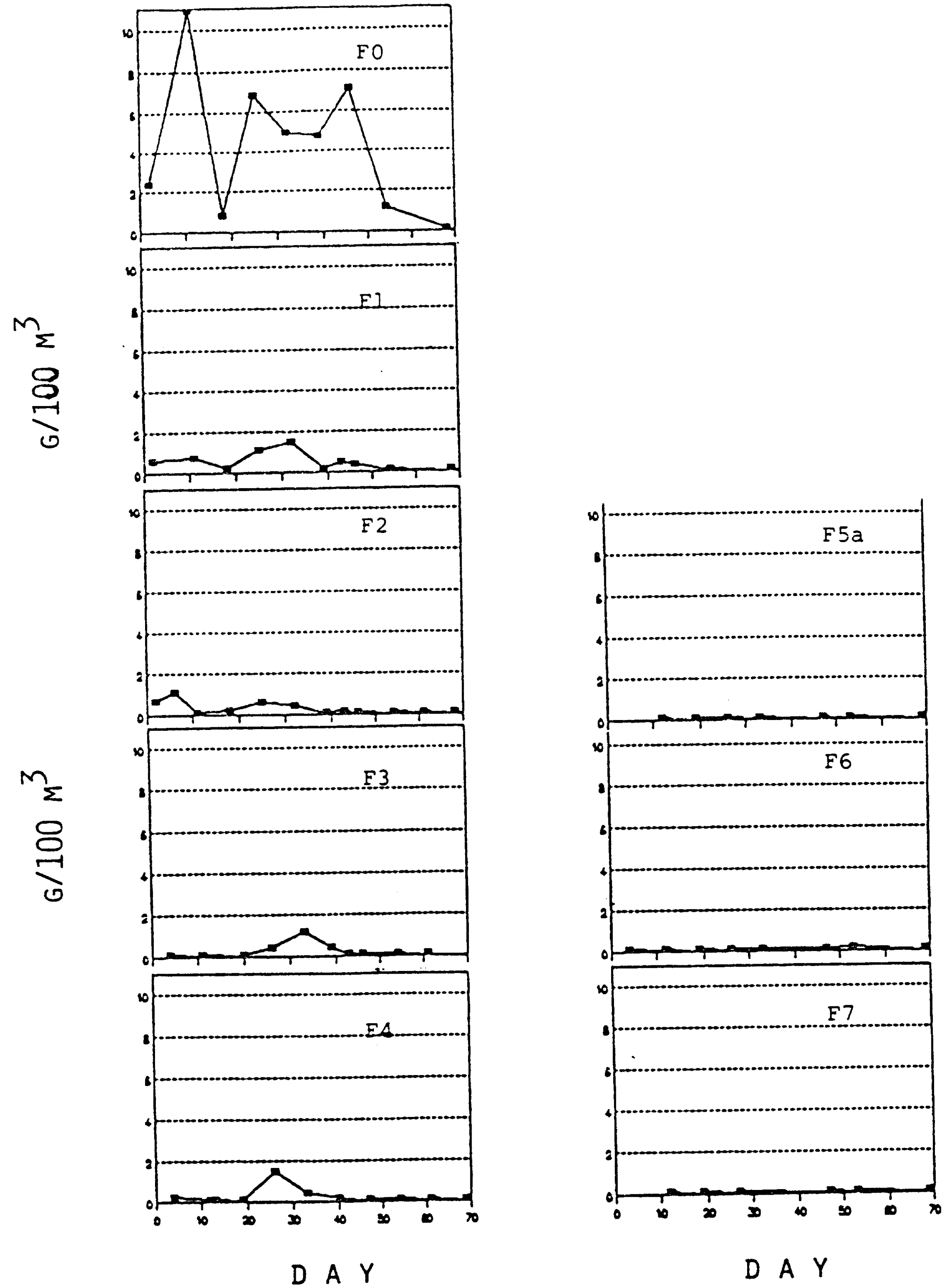


Figure 19: Temporal variation in biomass of shad sampled with a 1 m-diameter ichthyoplankton net in Lake Mead, 1989. (Day 1 = June 1, 1989.)

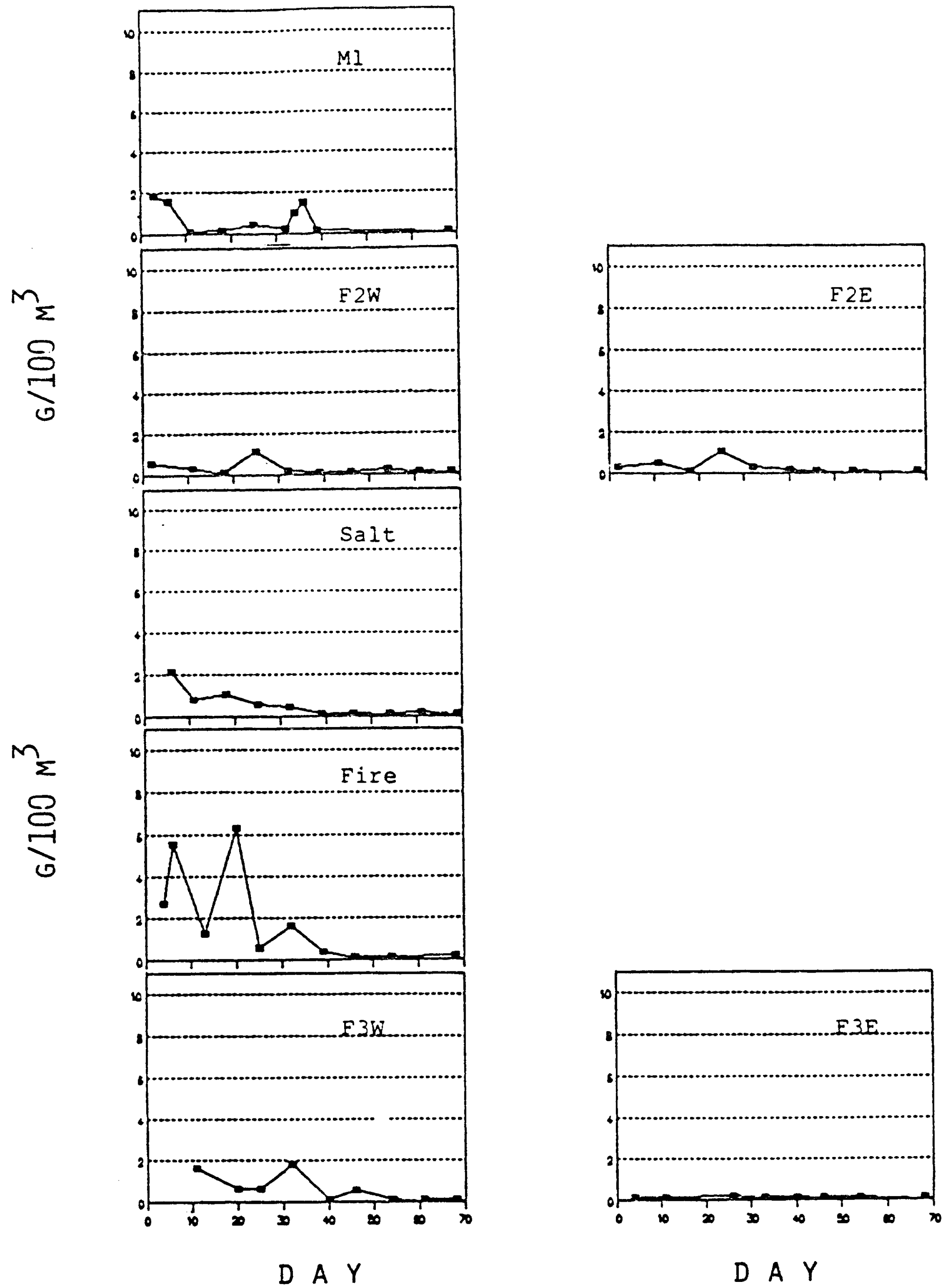


Figure 19: (continued).

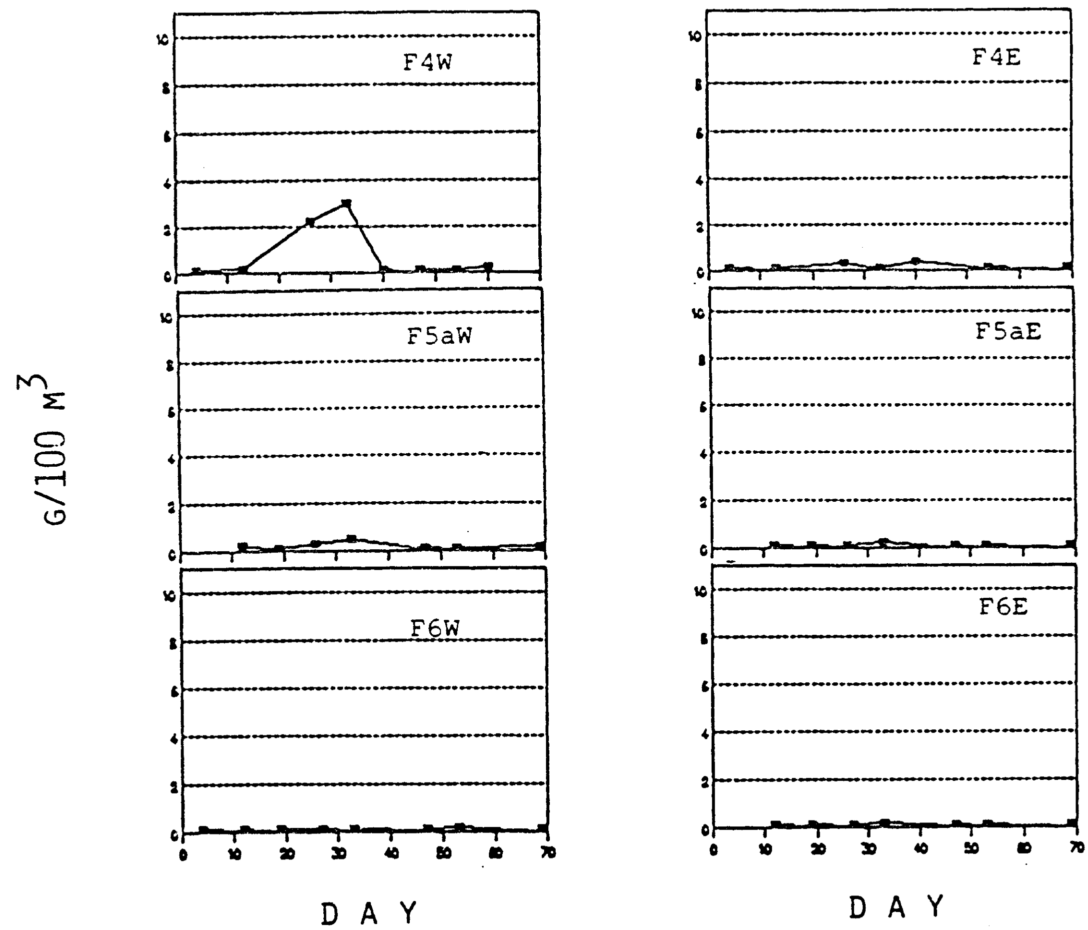


Figure 19: (continued).

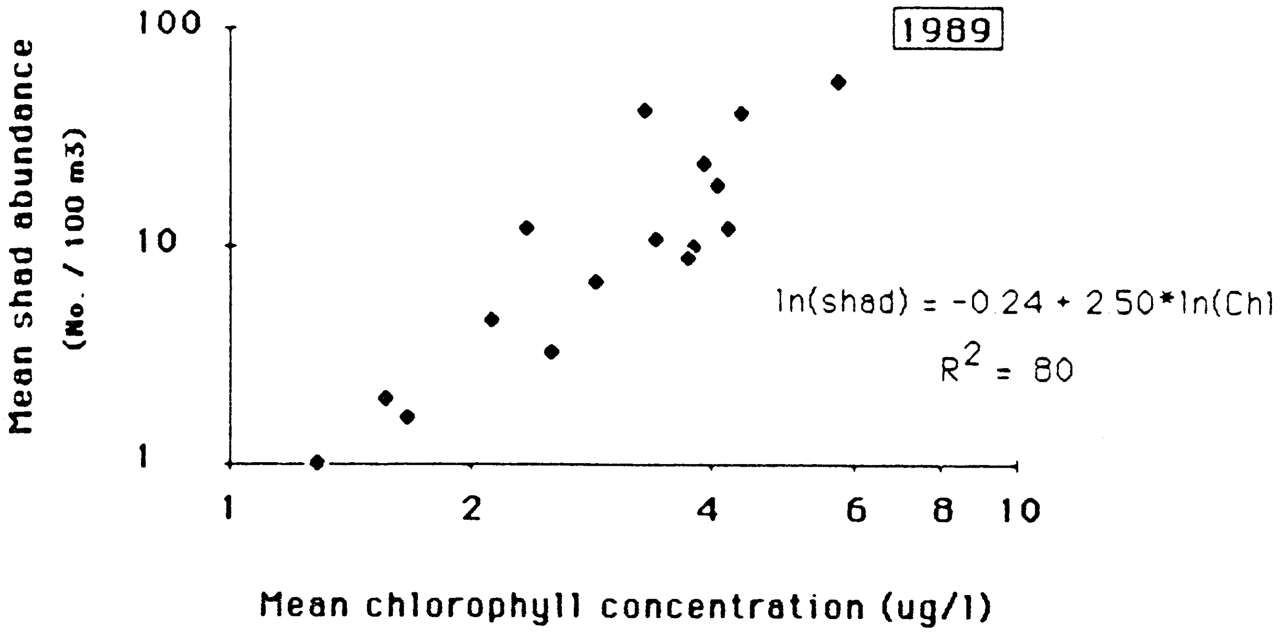


Figure 20: Relationship between mean shad densities (as estimated by trawling) and mean chlorophyll-a concentrations in the Overton Arm, 1989. (See text for details of calculations.)

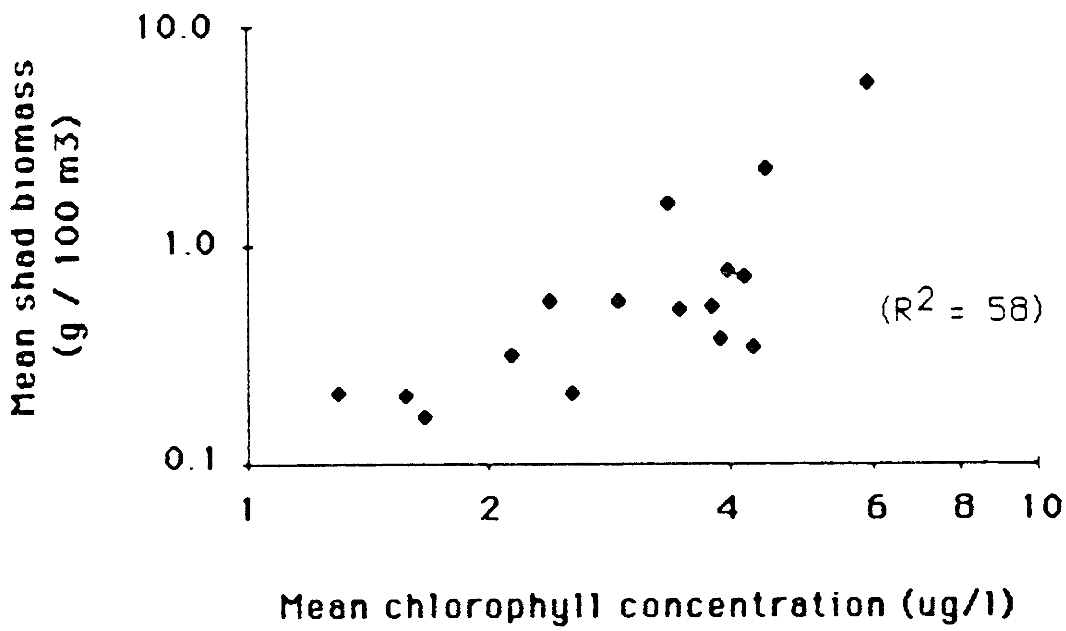


Figure 21: Relationship between mean shad biomass (as estimated by trawling) and mean chlorophyll-a concentrations in the Overton Arm, 1989. (See text for details of calculations.)

(days 10-40 in Figures 17-19). Time-weighted mean chlorophyll-a concentrations were calculated for the period June 1-July 10. The rationale behind selection of these time intervals was that any impacts from food levels on the abundance of young shad might be expected to include a "feeding history" component, in this case the 10-day chlorophyll record preceding the beginning of the shad record. The time windows selected for calculation of abundance and chlorophyll means were closed at July 10, since after this time a significant proportion of the shad population was beginning to outgrow the size range at which it was susceptible to trawling with a meter net.

2.10 Gamefish

As was the case for the first two years of this experiment, the number of largemouth bass samples taken in 1989 was too low to enable the impact of fertilization on this species to be evaluated. The following discussion is therefore restricted to striped bass. The NDOW creel and UNLV angler-caught fish form the sample base for this species.

Striped bass condition factors in 1989 showed a dramatic decrease from the previous two years. The condition factor data base will be analyzed in depth in the final report, but Figure 22 illustrates a section of it. These data are from August, over the 3-year period 1987-89. By plotting condition factor against fish length, Figure 15 differentiates time-related changes in condition from size-related changes. (Note that the number of data points

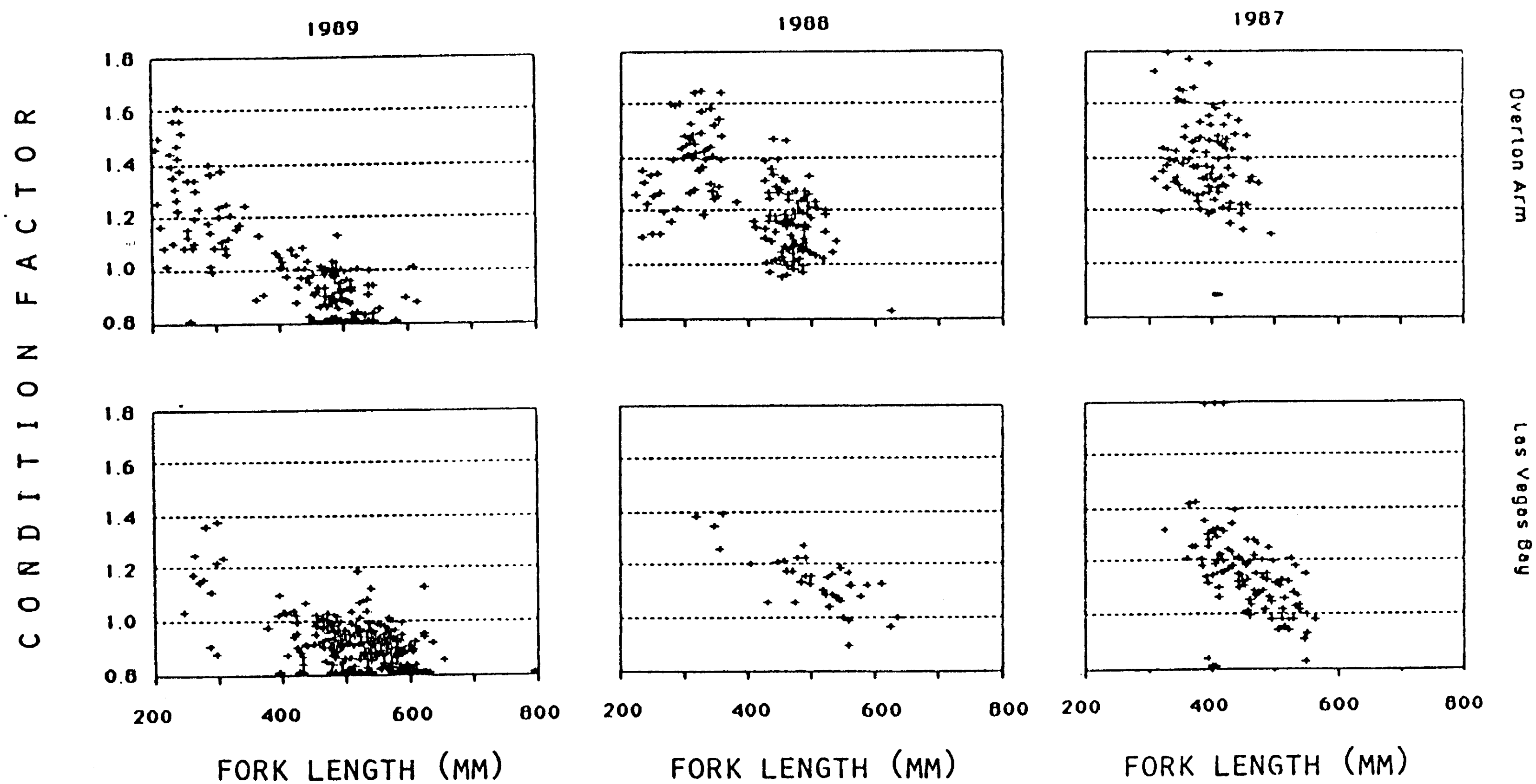


Figure 22: Scatterplots of striped bass condition factors vs. fork length in the Overton Arm and Lower Basin of Lake Mead, August, 1987-1989. (Data from NDOW and UNLV)

in Figure 15 is not an indicator of striper population size. It simply reflects the number of fish sampled. The size-frequency distributions indicated by these plots, however, probably are representative of the population's size structure).

The 1989 graphs clearly show the poor condition of large sub-adult and adult of stripers (>400 mm FL) in both the Overton Arm and the Lower Basin; most fish had a condition factor of below 1.0. Only the sub-adult size classes exhibited better condition (mostly >1.1). There are two reasons for the latter observation. First, smaller fish tend to have higher condition factors simply as a result of body morphology. Second, the younger stripers have a wider thermal tolerance and are therefore better able to exploit epilimnetic shad populations.

The contrast in the condition factors of the larger stripers between 1987 and 1989 suggests that temperature tolerance is not the only factor involved in their poor condition in 1989. The larger fish in the Overton Arm in 1989 simply were not feeding on shad (in the summer), even when they were occupying similar depth strata. Stripers taken from depths at which large numbers of shad were present (as observed on echo traces) had empty stomachs. The size structure of the striper population in 1989 may perhaps have had some influence on these observations. In the Overton Arm, the 1989 striper population contained a fairly high proportion of sub-adults (<300 mm). These fish may have in some way out-competed the larger size classes for the available shad.

In the Lower Basin, condition factors of the larger stripers were also low in August. From their apparent proportional abundance in the population, any impact of the younger age classes on the larger fish (via competition, as above) was probably of less importance in the Lower Basin than in the Overton Arm. The larger stripers in the Lower Basin were in poor condition in August primarily because there was a dramatic decline in the year class strength of shad in this part of the lake (see Figure 18). Thus, large stripers in the Lower Basin contained few shad (in August) because shad densities were low, whereas, in the Overton Arm, these fish contained few shad because they were unable to harvest the prey population that was present.

Table 5 summarizes the currently processed data on the proportion of striper stomachs containing shad. In July over half the samples from the Overton Arm contained shad (young of the year fish). These samples represented mainly sub-adult fish. In the Lower Basin, the majority of striped bass stomachs at this time were empty. It was only later on in the year that shad became more common in the diets. Shad being taken by stripers in the Lower Basin during September and October were, on average, larger than those being taken in the Overton Arm (Figure 23). Preliminary data analyses suggest that this observation is not fully explained by differences in the striper population size structure, but rather reflects primarily the size distribution of the prey population.

Table 5: Percent of Lake Mead striped bass stomachs containing shad, 1989.* (Numbers in parentheses refer to number of stomachs analyzed.)

MONTH	OVERTON ARM		LOWER BASIN	
	%	N	%	N
January	19	(32)		
February				
March	0	(24)		
April			6	(36)
May	5	(99)	1	(70)
June	3	(107)	1	(104)
July	67	(386)	10	(78)
August	18	(265)	16	(125)
September	30	(210)	44	(102)
October	36	(36)	53	(89)
November			53	(85)
December				

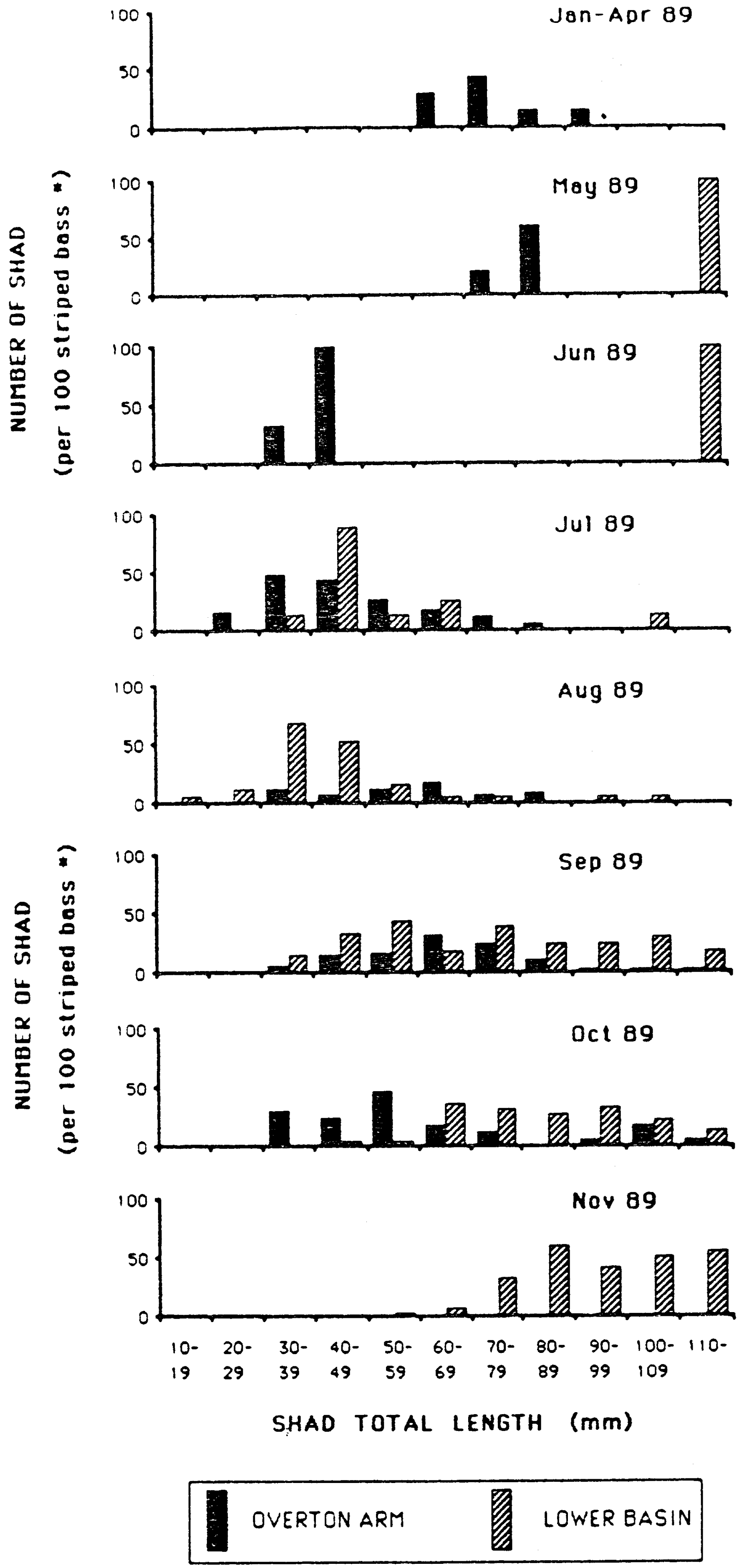
*(Data available as of November 30, 1989.)

Figure 23: Size-frequency distribution of shad found in striped bass stomachs from the Overton Arm and Lower Basin of Lake Mead, 1989. (*Number of shad is normalized to 100 striped bass containing shad.) ++

Numbers of stomachs containing shad are as follows:

		O.A.	L.B.
January-April	:	7	0
May	:	5	1
June	:	3	1
July	:	262	8
August	:	46	19
September	:	62	44
October	:	17	45
November	:	0	45

++(Data available as of November 30, 1989.)



NUMBER OF SHAD
(per 100 striped bass *)
Jan-Apr 89
May 89
Jun 89
Jul 89
Aug 89
Sep 89
Oct 89
Nov 89
100
50
0
10-19
20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-99
100-109
110-
SHAD TOTAL LENGTH (mm)
OVERTON ARM
LOWER BASIN

3. CONCLUSIONS

Barge application of fertilizer worked very well and produced the desired short-term increases in algal production. In addition, it appears that fertilization as undertaken in the Overton Arm may also have stimulated a longer-term, lower-level increase in algal productivity, lasting from June through at least the end of July. This effect is still being studied.

Preliminary analyses indicate that the cladoceran zooplankton community responded in a similar fashion in 1989 as it did in 1987 and 1988. However, additional in-depth analyses are also suggesting that artificial fertilization probably also has a much wider range of impacts on zooplankton productivity than was originally suspected.

Abundance of larval and juvenile shad in 1989 was strongly correlated to chlorophyll-a concentrations in the Overton Arm. Analysis of shad population dynamics (together with productivity at lower levels of the food chain) in a control year will be the only way of fully evaluating whether this correlation is actually causative, i.e. whether one resulted from the other, or whether the observed spatial variations in shad abundance were superimposed on but otherwise unrelated to spatial variations in food levels.

Shad abundance in the upper Overton Arm in 1989 was higher than anywhere else in the lake during this year. The dramatic decline in shad densities in the Lower Basin (relative to 1987 and

1988) indicates that abiotic factors may also be having a significant impact on shad year class strength in Lake Mead. Nevertheless, it might be expected that most between-year abiotic variation in the environment would affect both lower and upper basins of the lake.

Although age 0 shad were relatively abundant in the fertilized region of the Overton Arm (with 1989 densities being broadly similar to those of 1988), these shad were not utilized by the larger striped bass during the period from June through August. As a result, these stripers exhibited poorer condition factors in 1989 than in the previous two years. The reason for this is not just the restricted thermal tolerance of adult stripers. Other factors, such as between-age class competition, must to some extent be contributing to this variation.

Analyses of the 1989 data set are only partially complete at the present time; sample analyses are scheduled for completion by March, 1990. A detailed synthesis of the entire 1987-89 data record has begun and is including an assessment of between-year variations in the responses of the food chain to artificial fertilization. However, because of the well-recognized limitations for establishing controls in a large in-lake experiment such as the Overton Arm Fertilization Project, a <u>full</u> evaluation of the potential for using artificial fertilization to increase forage fish abundance in Lake Mead will require at least one control year of biological monitoring in the absence of fertilization.

The final project report, to be issued in 1990, will contain a detailed presentation and synthesis of the results of the 1987-89 fertilization experiments.

4. REFERENCES

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