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## Temporal and spatial patterns of abundance of age 0 threadfin shad (*Dorosoma petenense*) in Overton Arm, Lake Mead

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shad (*Dorosoma petenense*) in Overton Arm, Lake Mead**

Pelle, William Lee, M.S.

University of Nevada, Las Vegas, 1990

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TEMPORAL AND SPATIAL PATTERNS OF ABUNDANCE  
OF AGE 0 THREADFIN SHAD (*Dorosoma*  
*petenense*) IN OVERTON ARM,  
LAKE MEAD

by  
William Lee Pelle

A thesis submitted in partial fulfillment  
of the requirements for the degree of

Master of Science

in

the Biological Sciences

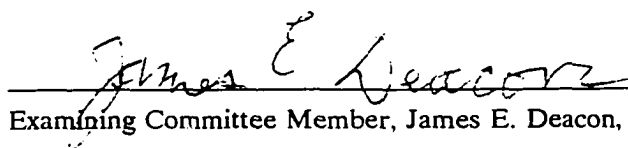
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University of Nevada, Las Vegas  
June, 1989



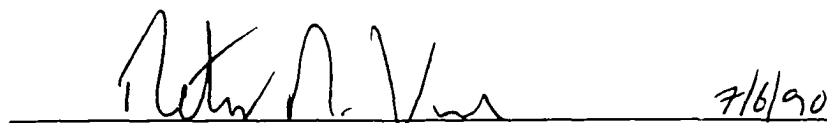
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Chairperson, Larry J. Paulson, Ph.D.



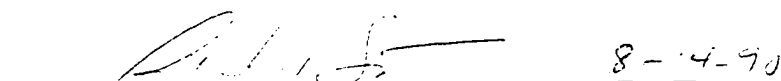
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July, 1990

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## Abstract

Temporal and spatial patterns of age 0 threadfin shad (*Dorosoma petenense*) abundance and growth, in the Overton Arm of Lake Mead, were examined to evaluate the effects of resource availability on the young fish. This was part of a larger, game fishery enhancement study (Lake Mead Fertilization Project), designed to assess feasibility of increasing survivorship of larval/juvenile shad by boosting phosphate levels, thereby increasing algal and zooplankton biomass, during the shad spawning period. Shad are the primary forage base for the striped bass (*Morone saxatilis*) and black bass (*Macropterus salmoides*) fisheries. Weekly samples were taken by night surface trawl with a 1 meter diameter ring net, from early June to mid-August, at 12 stations in 1988 and 21 stations in 1989. To examine vertical distribution, depth series samples were taken with a Tucker Trawl at some stations and dates. Chlorophyll *a* concentrations and *Daphnia pulex* egg/adult female ratios, used as indicators of resource availability, were also determined for some stations and dates. Patterns of abundance were analyzed with log-log regressions of shad abundance on resource availability and more complex models including large-scale geographic factors with chlorophyll *a*. In 1988 shad abundance was not significantly correlated ( $p < 0.05$ ) with chlorophyll *a* concentration, or *Daphnia* egg ratios, but was significantly higher in west-side coves. Conversely, in 1989 abundance correlated significantly with chlorophyll *a* and *Daphnia* egg ratios, and the west-side effect was insignificant. Abundance was not correlated with distance from inflow, independent of chlorophyll *a*, in either year. To conclude, there was an apparent link between resource availability and young shad abundance, with evaluation of this relationship being confounded in 1988 by lowered predation in the west-side coves. There was little temporal or spatial variation in mean length from 20 millimeters total length, possibly due to a combination of net bias and selective predation upon larger fish. Growth rates could not be determined. With regard to vertical distribution, greater than 75 % of the fish were in the top 1 meter of water at night. Size did not vary significantly with depth.

## Acknowledgements

I gratefully acknowledge the support and patience of my committee members during the course of this study, with special thanks to Jim Deacon for assistance late in the game. I would also like to thank Joe McAuliffe for insights into theoretical ecology and to Gene Wilde for statistical advice. Perhaps most importantly, thanks are also due to the entire staff of the Lake Mead Limnological Research Center, especially Greg Brown, for many hours in the lab, and Larry Shepherd and Allen Simms for all their help in the field.

## INTRODUCTION

Lake Mead is a monomictic impoundment of the lower Colorado River system, formed in 1935 by the closing of Hoover Dam (Paulson and Baker, 1984). The Lake Mead game fishery, composed largely of striped bass (*Morone saxatilis*) and black bass (*Micropterus salmoides*), is believed to be in general decline, limited by the lack of an adequate forage base (Axler *et al.*, 1988). The forage base is comprised primarily of threadfin shad (*Dorosoma petenense*) (Allen and Roden, 1978).

The threadfin shad is a member of the herring family (Clupeidae). Shad are generally planktivorous omnivores, schooling as adults and limnetic/pelagic in nature (Moyle and Cech, 1982). Threadfin shad are native to the southeastern U.S. They were introduced into Lakes Mead, Mojave and Havasu in 1954 and 1955, and by 1956 had become distributed throughout the entire lower Colorado River system (LaRivers, 1962; as cited by Allan and Roden, 1978).

The rapid dispersal of shad can be attributed, in part, to high fecundity of this species. The number of eggs in mature females varies from 800 (Minckley, 1973) to 12,000 (Burns, 1966; as cited by Allen and Roden, 1978). Shad spawn in other southwestern reservoirs when surface temperatures reach 21.1° C (Gerdes and McConnel, 1963; Lambou, 1965; Kimsey, 1958). In Lake Mead this temperature is generally reached sometime in May. Deacon *et al.* (1972) found spawning to be segregated temporally by age class, with the age II and older fish spawning in May and June, and the age I spawning peak occurring in July.

In general, eggs hatch in four to five days, producing larvae approximately 3 mm

total length (TL) Larval shad start feeding three or four days after hatching and transform to the juvenile stage about two weeks after swim-up (Minckley, 1973). Burns (1966; as cited by Allen and Roden, 1978) found shad to undergo this transformation at about 13 mm TL.

Instantaneous growth rates for individuals have not been determined for age 0 shad in Lake Mead. However, Deacon *et al.* (1972), using cohort analysis, found first year's growth to be 35 - 50 mm TL, with no growth occurring between October and April. Johnson (1970), Deacon *et al.* (1972) and Minckley (1973) have suggested that when shad in an established population reach the juvenile stage and begin forming schools, niche overlap with adults occurs. Growth of the individuals is then limited by intraspecific competition.

Minckley (1973) reported selective predation by larval shad upon zooplankton in central Arizona reservoirs. Applegate and Mullan (1969) found that in Beaver Reservoir, Arkansas, 4 - 14 mm TL threadfin shad fed mainly on subadult copepods. They also found *Daphnia* were present in the diet of 14 - 16.5 mm TL fish, and predominated in shad 15 - 37 mm TL. In a study of gizzard shad (*D. cepedianum*) larvae/juveniles, Miller (1960; as cited by Kilambi and Barger, 1975) reported that after development of the gizzard, 26 mm TL larvae switched from a zooplankton diet to one of phytoplankton.

In general, it appears that the composition of the juvenile/adult shad diet is dependent on the availability of forage types (Minckley, 1973). Although zooplankton and phytoplankton are considered to be the primary forage, large percentages of detritus and sand have been found in some fish in Lake Mead (Deacon *et al.*, 1972), as well as in other impoundments (Haskell, 1959; Gerdes and McConnel, 1963; Mundahl and Wissing, 1987). Detritus is certainly of inferior food value, and its dominance in the diet of gizzard shad has been correlated with poor growth and condition (Mundahl and Wissing, 1987). In Lake Mead, however, detritus appeared to have been selected for, and at a time of maximum growth and reproductive development (Deacon *et al.*, 1972). It appeared fish were forced



to select for plant debris due to low availability of better quality forage.

Fish larvae in general have been found especially vulnerable to starvation during the period of transition from yolk sac to exogenous feeding (May, 1974; Yin and Blaxter, 1987). Hjort (1914, 1926; as referenced by Kashuba and Matthews, 1984) referred to this developmental stage as the "critical period" in which year class strength is determined mostly by the availability food.

Kilambi and Barger (1975) and Matthews (1984) reported rapid drops in larval shad abundance (gizzard and threadfin) during or following decreases in zooplankton abundance in Beaver Reservoir, Arkansas and Lake Texoma, Texas-Oklahoma, respectively. They believed, as did Hempel (1965), that this type of situation indicated starvation rather than predation. Matthews (1987) observed mass starvation of larvae when total zooplankton concentrations dropped to < 100 animals/liter. Threadfin shad larvae in the Overton Arm of Lake Mead may be similarly prone to starvation since total zooplankton concentrations, during the spring/summer, are generally not greater than 10 animals/liter (Paulson and Vaux, unpubl.).

Predation by shad in Lake Mead may influence the seasonal shift of zooplankton community composition from predominantly *Daphnia galeata mendota* and *D. pulex* to *Bosmina longirostris*, as this shift coincides with the early shad spawn (Wilde, 1984). In parts of the lake where there are high shad densities, the zooplankton population virtually disappears by late summer, the apparent result of continued predation by the young-of-the-year shad (Wilde, 1984). Eventually, however, the shad themselves may be affected, as little food remains for larvae spawned in July (Deacon *et al.*, 1972). Deacon *et al.* (1972) suggested that shad year class strength was established by the early spawn of the age II fish, with success of the age 0 class being limited by the availability of food. Evidence supporting this hypothesis was two-fold: 1) the large percentage of organic detrital matter found in the

diet of juvenile/adult shad, suggesting a general shortage of plankton; and 2) the low success of the age I spawn in July, which could have been the result of starvation.

It appears that in Lake Mead there are two crucial stages in shad development influenced by resource availability: the larval stage, when survivorship may be dependent on zooplankton concentrations, and the late juvenile stage when age 0 fish begin to compete for food with adults. As primary and secondary productivity are limited by nutrient levels in most parts of Lake Mead, shad productivity can be thought of as being partially controlled from the "bottom up" (Axler, *et al.*, 1988). Predation pressure from striped bass presumably also has an effect on shad abundance. Nevertheless, shad carrying capacity must be influenced by nutrient levels.

Since the shad was introduced into Lake Mead, nutrient levels have been reduced in two ways: first by the closing of Glen Canyon Dam in 1963, which decreased sediment loading to the lower Colorado River; and secondly, by the operation of the Clark County Advanced Waste Water Treatment Plant, which, in 1981, began to remove phosphorous from treated effluent discharged into the Las Vegas Bay of Lake Mead. It seems likely that these reductions in nutrient loading have had a negative impact on shad abundance in Lake Mead. Nevertheless, it has been difficult to distinguish the effects of nutrient limitation from those of predation. The mechanisms and interactions controlling shad abundance in Lake Mead have yet to be determined.

The Lake Mead Fertilization Project, which began in 1987, was a three-year study designed to assess the feasibility of enhancing the threadfin shad population in the the Overton Arm of the Lake by applications of liquid ammonium polyphosphate to the epilimnion (Axler, *et al.*, 1988). The Overton Arm is a geographically distinct area, comprising the former lower drainage and mouth of the Virgin River. With the exception of small areas in close proximity to the inflow of the Virgin and Muddy Rivers, it is an

oligotrophic region. Fertilizer applications were made in spring and early summer, when shad spawn. The ultimate objective was to provide more forage for game fishes. The rationale was that nutrient loading would cause a temporary increase in phytoplankton and zooplankton biomass, thus providing more food for, and increasing the survivorship of, larval/juvenile shad (Axler *et al.*, 1988). A more thorough discussion of the fertilization project can be found in (Axler *et al.*, 1988).

Studies of the phytoplankton and zooplankton communities clearly documented the effects of fertilization on productivity at the primary and secondary trophic levels (Paulson and Vaux, unpubl.). Here I examine the effects of resource availability on abundance and growth of young-of-the-year threadfin shad in Overton Arm of Lake Mead.

## METHODS

### Study Area

The study site for this project was the Overton Arm of Lake Mead, Nevada-Arizona, with one additional station (F7) being located in Virgin Basin, approximately 2 km southwest of the mouth of Overton Arm (Figures 1-3). This station was considered uninfluenced by fertilization. Twelve main sampling stations were used in 1988, with the number being expanded to twenty-one in 1989 by the addition of east and west laterals to mid-channel stations F2 - F6 (Figure 3). This design allowed the assessment of large-scale geographical patterns in shad abundance. Also included as sampling stations in both years were two additional west-side coves (Fire and Salt Bays) (Figures 2 and 3).

### Sampling Program

Weekly samples were collected by surface trawl (0 - 2 m depth) from the first week of June to the second week of August in 1988 and 1989. Three replicate, six minute tows were taken at each station every week. The trawling rig used was a 1 m diameter ring net, towed 8 m behind a 240 horsepower jet boat at a mean speed of 4.3 km/hr. A flowmeter, attached with a bridle to the net ring, was used to estimate volume of water sampled. Tows of known length were made with and without the net attached to estimate net efficiency and filtering rate. All trawling was done at night, when young shad congregate near the surface. This appears to be the only time these fish can be sampled effectively with a meter net. Samples were preserved in 10% formalin in 1988 and 80% ethanol in 1989.

A 505  $\mu\text{m}$  mesh net (length, 3 m) was used for the first three weeks in 1988, with a 1600  $\mu\text{m}$  net (length, 6 m) being used for all subsequent tows. The latter net was

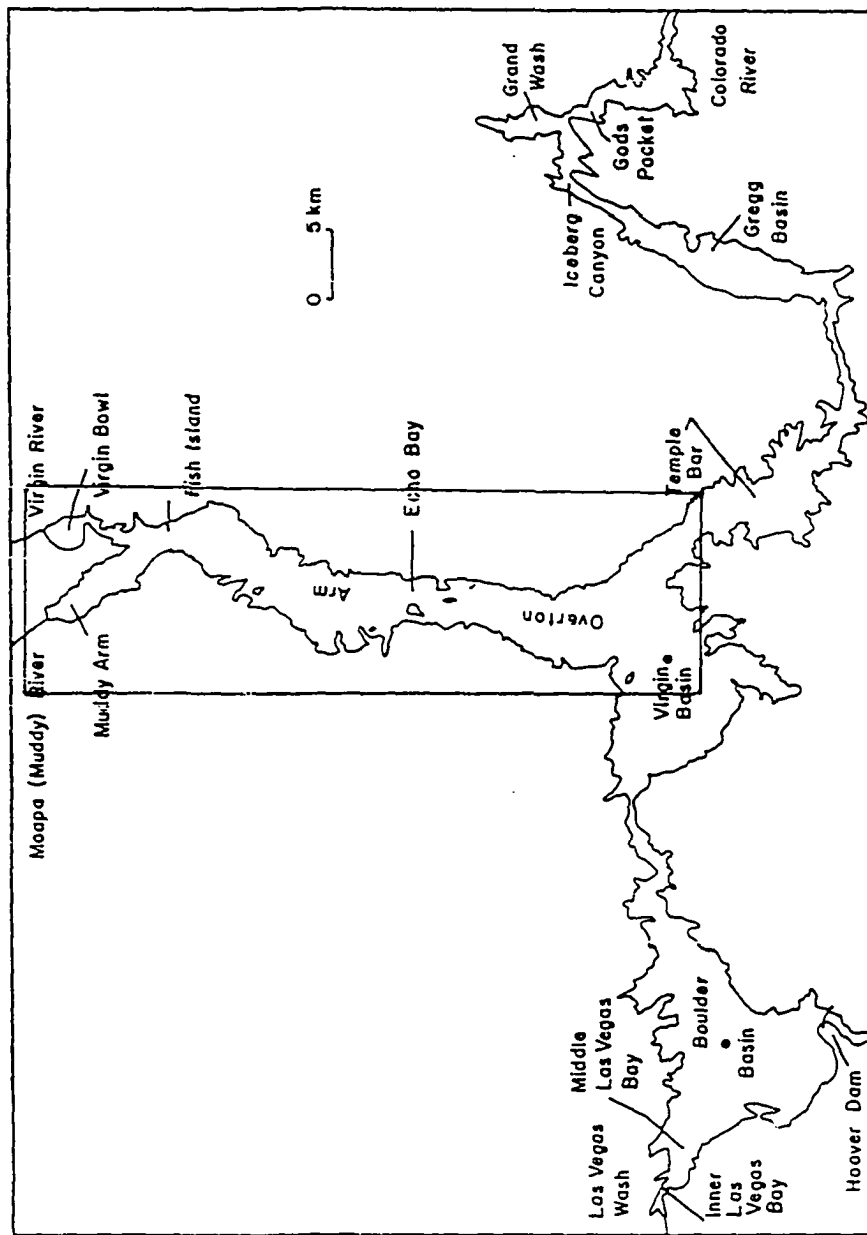


Figure 1. Map of Lake Mead, showing location of study area (Overton Arm).

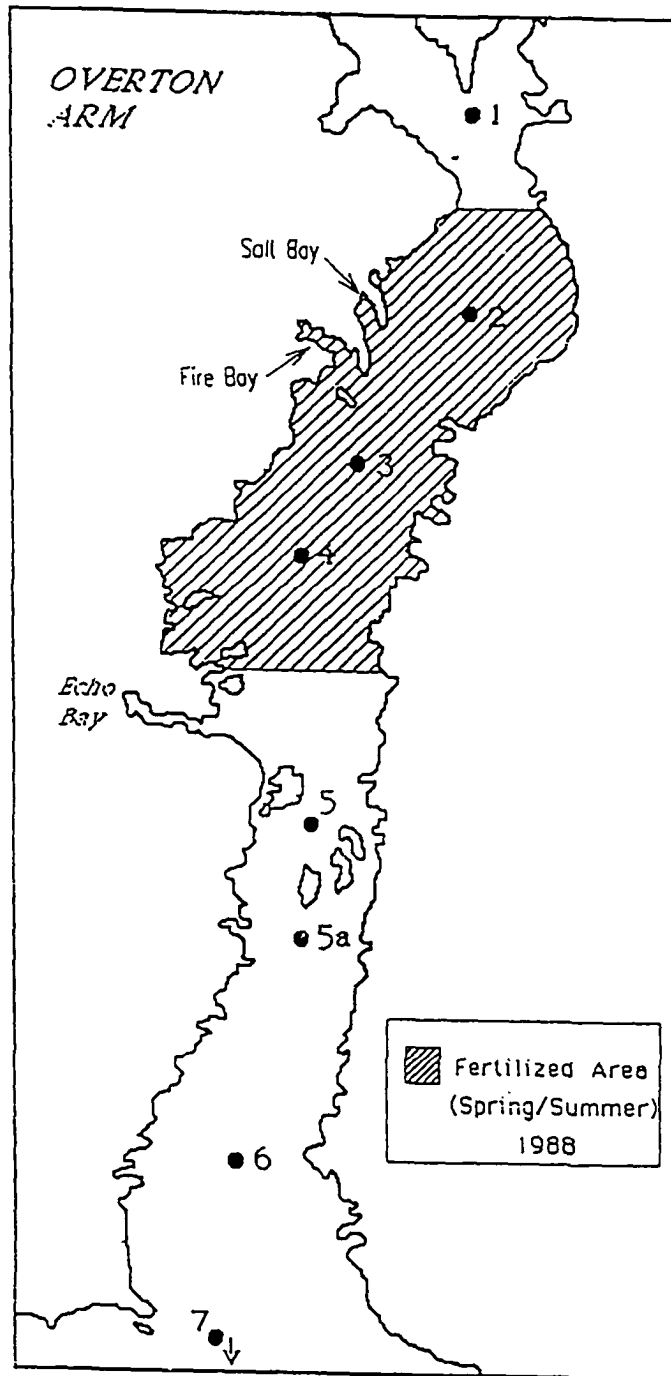


Figure 2. Sampling stations and fertilized area - 1988.

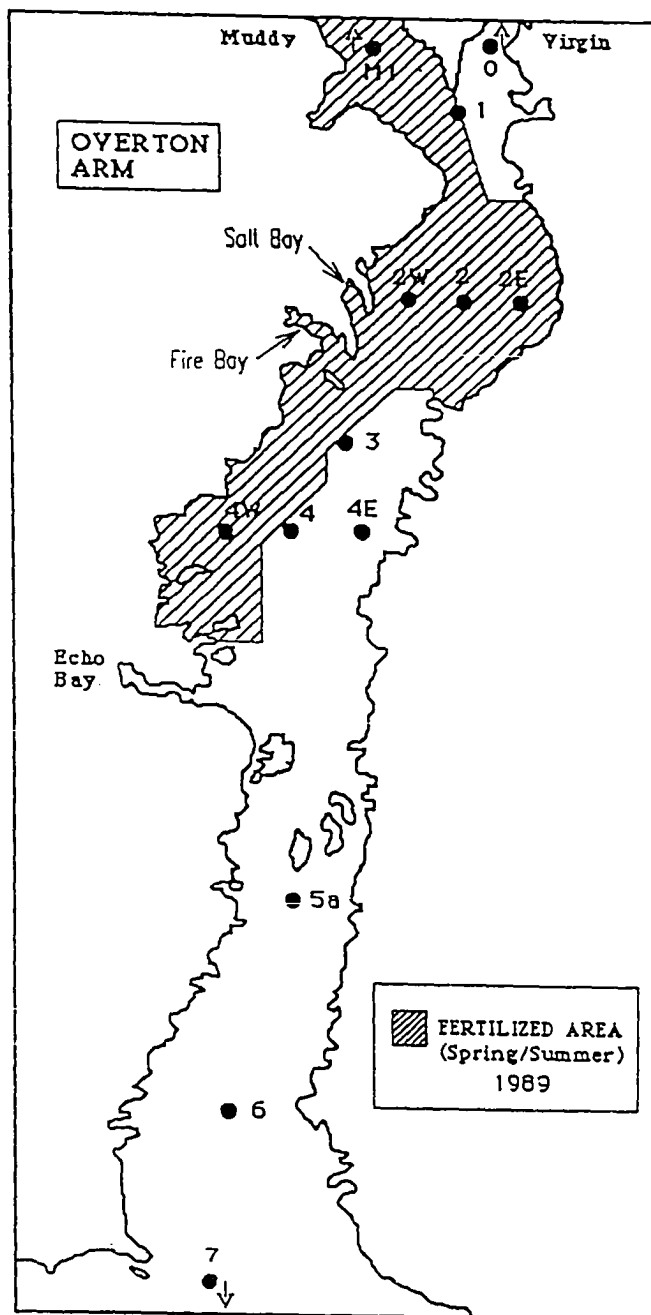


Figure 3. Sampling stations and fertilized area - 1989; not shown - east and west-side stations were also used at F3, F5a and F6.

considered more practical, as the abundance of *Daphnia spp.* in the samples taken with the 505  $\mu\text{m}$  net made separation of the young shad from the mix very time consuming. Analyses of variance were conducted on samples taken at three stations, using both nets, in order to detect possible differences in size distribution and relative number of fish caught with each net. The data were ranked to provide a nonparametric approach, as some samples were small and not all distributions appeared normal.

The depth distribution of shad was also studied, using samples collected by the Nevada Department of Wildlife with a 1 m<sup>2</sup> Tucker trawl. Three mid-channel stations (F2, F4 and F6) were sampled during the second and fourth weeks of June and the second week of July, 1989. The sampling depths were 0, 5, and 15 m for Week 2; and 0, 5 and 10 m for the two subsequent dates. Analyses of variance were performed to evaluate differences in the size of fish taken at different depths.

Plankton samples were also collected at most of the stations used for shad trawling during spring/summer 1988 and 1989. Relative phytoplankton abundances were obtained by measuring chlorophyll *a* concentrations, using the methods of Kellar *et al.* (1981). *Daphnia* egg ratios (the ratio of the number of *Daphnia pulex* eggs to adult females) were obtained, using methods described in Edmondson and Winberg (1971). This information, rather than *Daphnia* or total zooplankton abundance, is used to analyze the effects of zooplankton on shad. Egg ratios, although relative indicators of zooplankton productivity should not be directly affected by predation pressure from shad - unlike zooplankton abundance estimates.

### Analyses

Fish were counted and measurements taken of length in millimeters TL and, for some samples, weight in grams. Since the focus of this study was upon age 0 fish, the relatively few age I fish collected were not included in subsequent analyses. These obvious



outliers were > 10 mm TL longer than the age 0 fish. Length measurements were made on 40-50 randomly-selected fish when sample size was relatively large. Calculations were made of relative shad abundance, expressed as population density (no. fish/100m<sup>3</sup>), and biomass (g fish/100m<sup>3</sup>). Densities, biomass and mean lengths were plotted through time for all stations, and length frequency distributions for all samples were examined.

In order to examine the relationships between algae, zooplankton and shad, weighted means of shad density and biomass, and *Daphnia* egg ratios were calculated for samples collected between the second week of June and the second week of July. The data was time-weighted because time between samples varied between stations. Chlorophyll *a* concentrations from the first week of June to the second week of July were also averaged. Here a one week lag, relative to the period used for averaging the shad abundance data, was added to include a "feeding history" component in the shad abundance models.

The time-weighted means were log-log transformed and used in regression models to assess effects of resource availability upon shad abundance. In these models, shad density and biomass were the dependent variables. Chlorophyll *a* concentrations and *Daphnia* egg ratios were the independent variables.

The models took the general form:

$$(1) \quad S = Y + XR$$

where S = shad abundance (density or biomass); R = resource (chlorophyll *a* concentration, [Chla] or *Daphnia* egg ratios, [Daph]); and X and Y were the regression coefficients.

More complex models that included geographic factors were also tested, to evaluate large-scale geographic effects, independent of chlorophyll *a* influence. *Daphnia* egg ratio data were not complete enough to be included in these analyses. The basic form of these models was:

$$(2) \quad S = Chla \text{ Dist Pos}$$

The variable [Dist], the north-south factor, is the distance to each station from the inflow of the Virgin River; distance from Muddy River inflow was used for station M1. This factor was included in these models to determine if young shad abundance may be correlated with proximity to inflow for reasons other than resource availability. The variable [Pos] is the east-west factor; the levels being West, Mid-channel and East side). This factor was included to detect variance in young shad abundance across Overton Arm that could not be explained by resource availability. The General Linear Models procedure (for unbalanced designs) in Minitab (1989) was used to test the models, with [Chla] and [Dist] as covariates and [Pos] as a fixed effect. The data were ranked to provide nonparametric tests, as variance was not homogenous between the [Pos] elements. The effects were assumed to be additive. Interaction terms could not be included, as there were empty cells in the experimental design.

## RESULTS

### Sampling Program

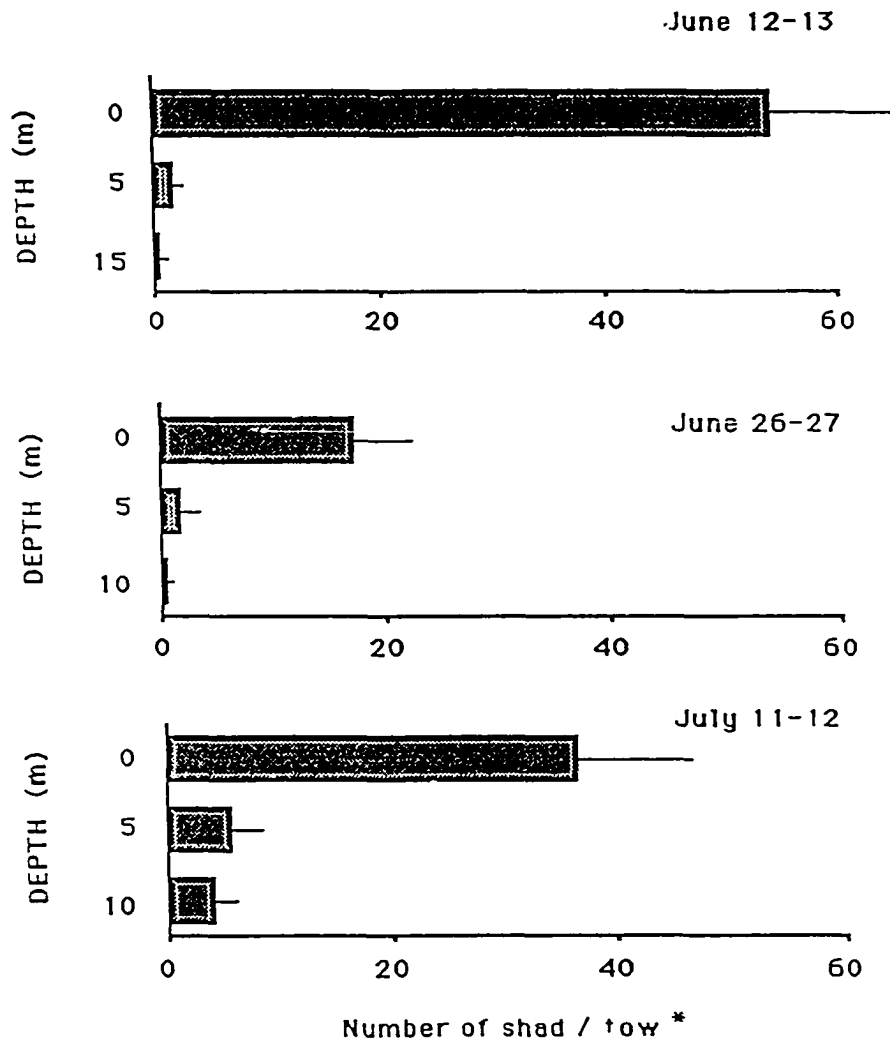
Non-parametric analysis of variance showed that there were no significant differences between samples of shad caught with the 505 and 1600  $\mu\text{m}$  nets in either size ( $p = 0.470$ ) or number ( $p = 0.795$ ). Therefore, data from both nets were weighted equally, in all subsequent analyses.

The depth distribution of shad taken in 1989 with the Nevada Department of Wildlife Tucker trawl at station F2 is shown in Figure 4. It appeared that generally  $> 75\%$  of the shad were in the top 1 meter of the water column and that relative density of shad decreased exponentially with depth. Examination of the size distributions of fish taken at 0, 5 and 10 m (Figure 5) reveals size range decreasing with depth, and the distribution of fish taken at 10 m appeared somewhat bimodal. However, there were no significant difference between these non-normal distributions in either shape (Kolmogorov-Smirnoff,  $p = 0.586$ ) or central tendency (Kruskal-Wallis,  $p = 0.093$ ).

### Chlorophyll *a*

The synoptic distribution of chlorophyll *a* on May 26, 1988, following fertilization on May 21, is shown in Figure 6. The highest chlorophyll *a* levels (6.0 - 8.9  $\mu\text{g/liter}$ ) were in Virgin Bowl (F0). Relatively high concentrations of 3.0 - 5.9  $\mu\text{g/liter}$  were also found in Muddy Arm (M1), the upper west-side and main channel.

On June 15, 1989, following fertilization on June 5 and 8, chlorophyll *a* was highest ( $> 9.0 \mu\text{g/liter}$ ) in Muddy Arm and Rogers Bay (F4W) (Figure 7). In 1988 and 1989, chlorophyll *a* was generally  $< 3.0 \mu\text{g/liter}$  throughout Overton Arm, one week before and



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

Figure 4. Depth distribution of shad in trawl samples from station F2 - 1989.

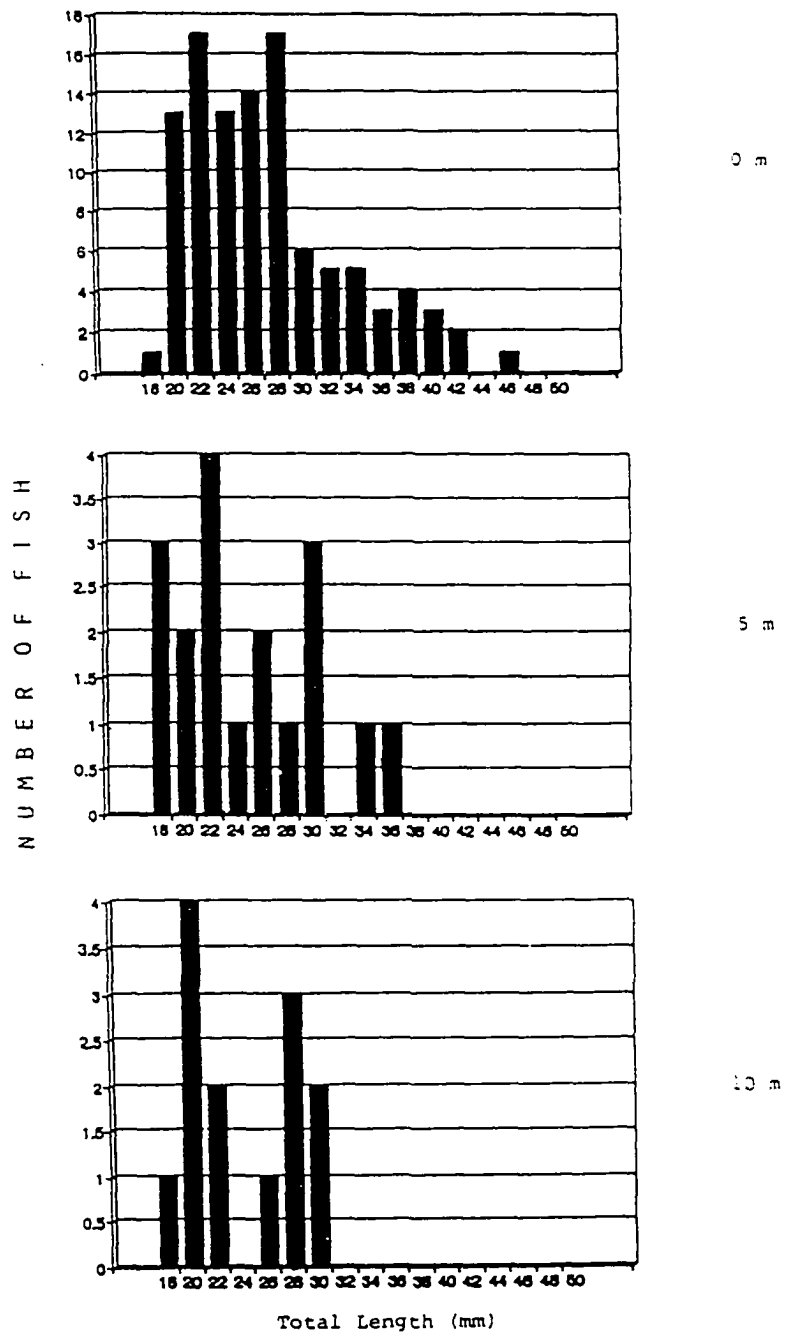


Figure 5. Size distribution of shad in trawl samples from three depths at station F2 - 1989.

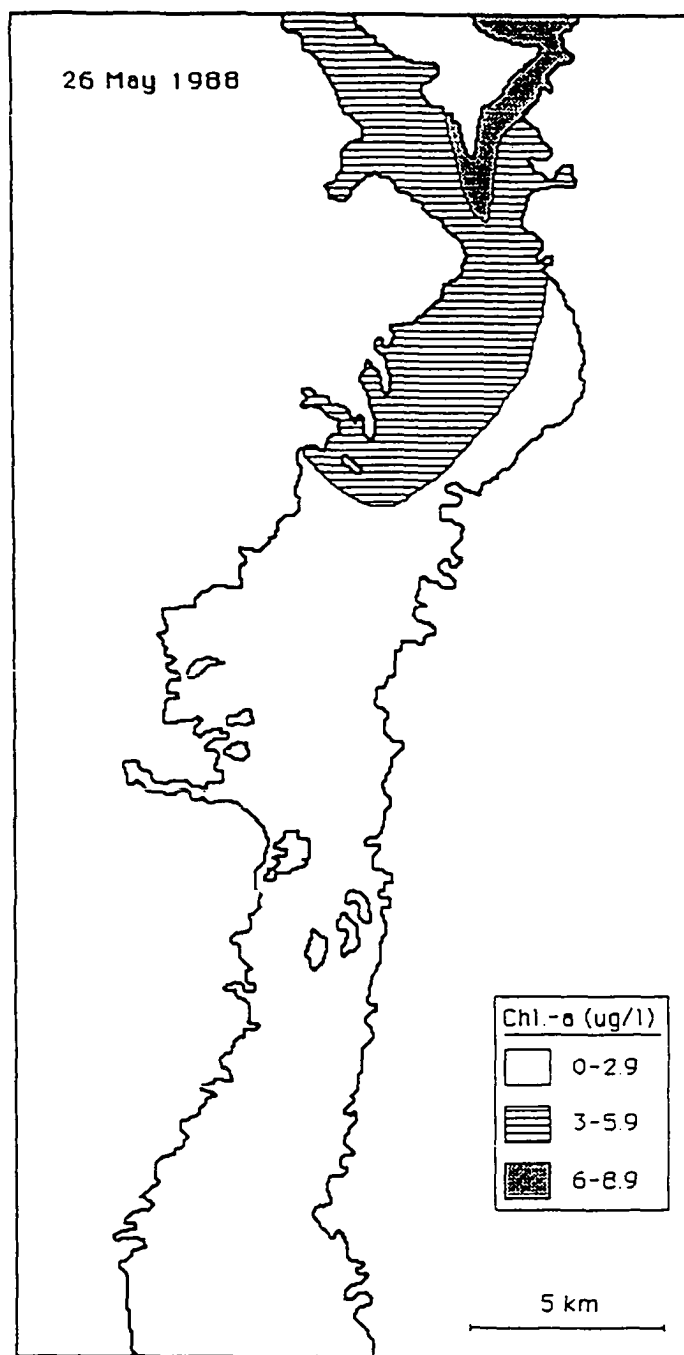


Figure 6. Synoptic distribution of chlorophyll *a* concentrations - May 26, 1988.

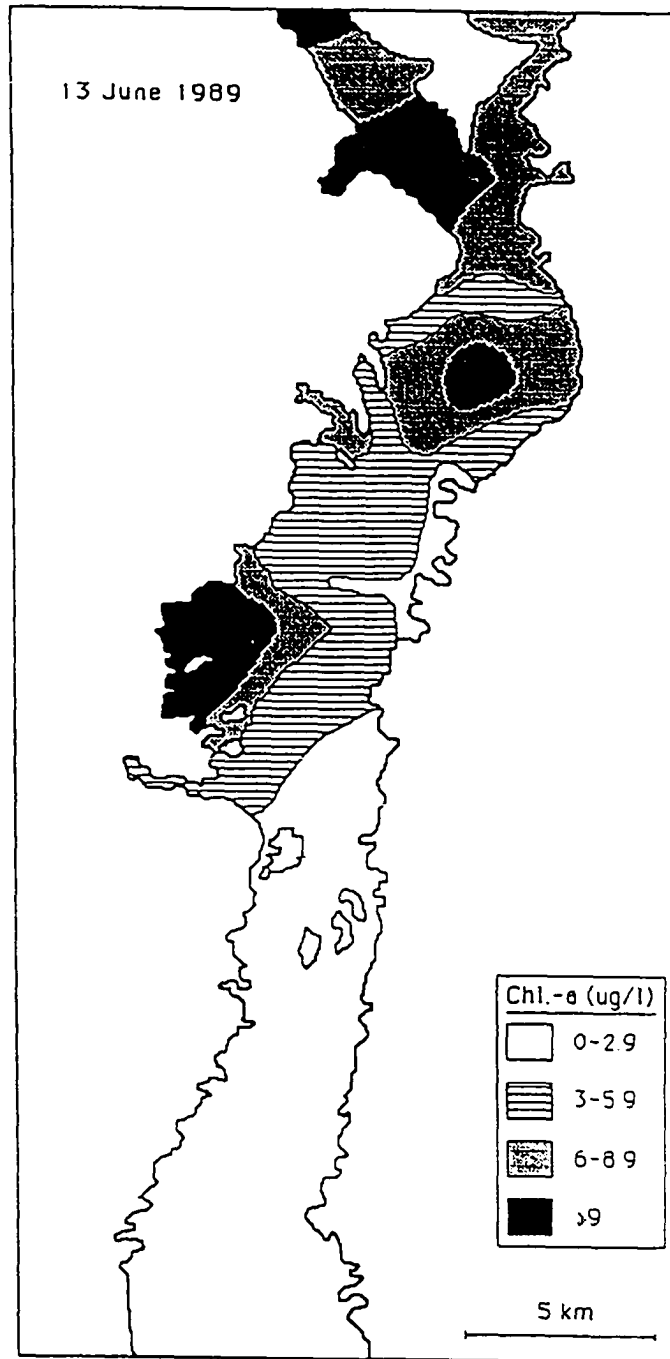


Figure 7. Synoptic distribution of chlorophyll *a* concentrations - June 13, 1989.

after fertilizer applications (Paulson and Vaux, unpubl.). In Virgin Bowl, however, concentrations remained at  $> 6.0 \mu\text{g/liter}$  throughout the spring/summer of both years.

#### *Daphnia* Egg Ratios

Only the 1989 *Daphnia* egg ratios are presented as synoptic distributions, since relatively few stations were sampled for this factor in 1988. Highest *Daphnia* egg ratios ( $> 4.0$ ), following the 1989 fertilizer application, were found in Muddy Arm, Virgin Bowl and Rogers Bay (Figure 8). In other fertilized regions of upper Overton Arm, egg ratios were also relatively high (1.0 - 3.0). Egg ratios in the southern half of Overton Arm were  $< 1.0$ . Like chlorophyll *a* levels, egg ratios also peaked one week following fertilization, with baseline levels at  $< 1.0$ , before and after fertilization peaks (Paulson and Vaux, unpubl.).

#### Shad Abundance

Young shad densities through time at four main-channel, and associated lateral stations, in Overton Arm are presented in Figures 9-11. Biomass through time for the main channel stations is shown in Figure 12. In 1988 there were peaks of abundance in Virgin Bowl (98 fish/100 m<sup>3</sup>), during the second week of June, and in Rogers Bay (195 fish/100 m<sup>3</sup>), during the third week of June. Abundance also peaked at station F4 (29 fish/100 m<sup>3</sup>) during the third week of June in 1988. In 1989 shad abundance throughout the season was generally highest in Virgin Bowl. Peaks in abundance here occurred on the second and fourth weeks of June, and the third week of July. Abundance in Virgin Bowl appeared generally higher in 1989 than in 1988. During the fourth week of June, 1989, peaks of abundance also occurred in Rogers Bay (97 fish/100 m<sup>3</sup>) and at stations F4 (40 fish/100 m<sup>3</sup>) and F2W (25 fish/100 m<sup>3</sup>). Patterns of shad abundance through time were similar for both density and biomass.



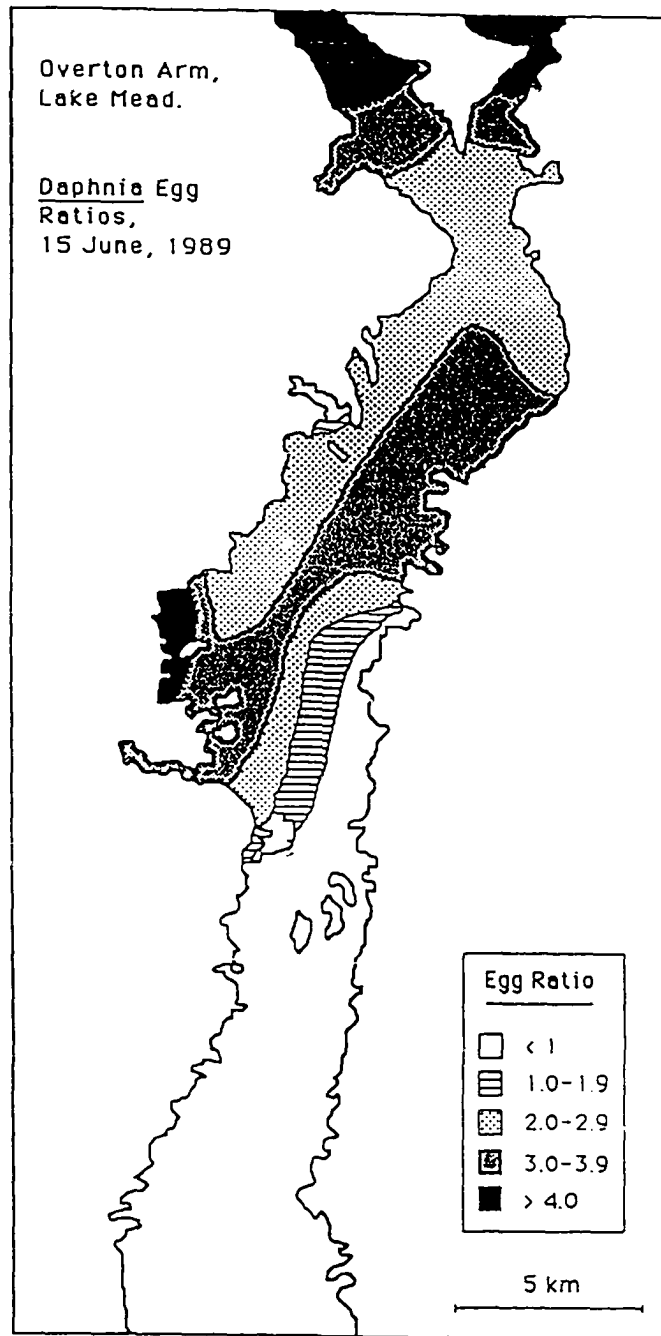


Figure 8. Synoptic distribution of *Daphnia pulex* egg ratios - June 15, 1989.

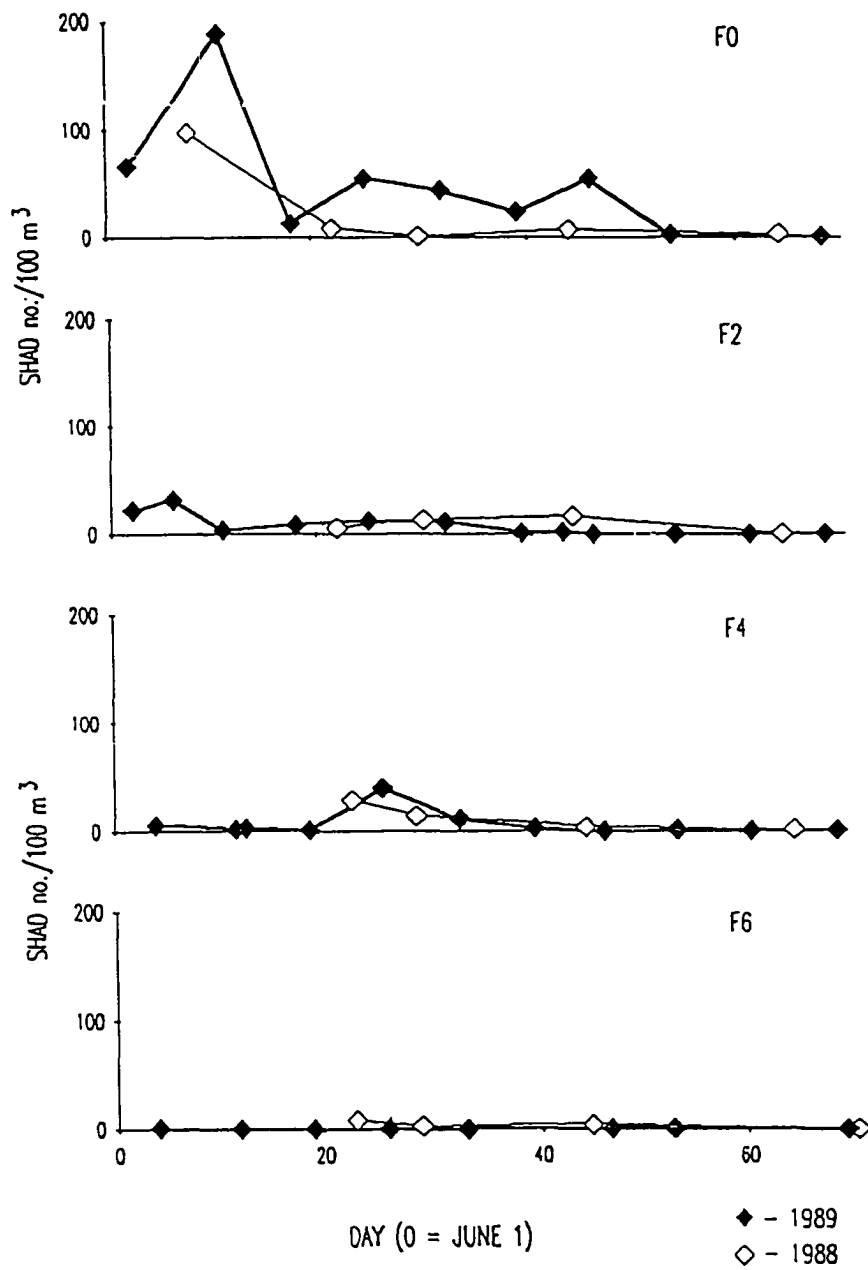


Figure 9. Shad densities through time; mid-channel stations - 1988, 1989.

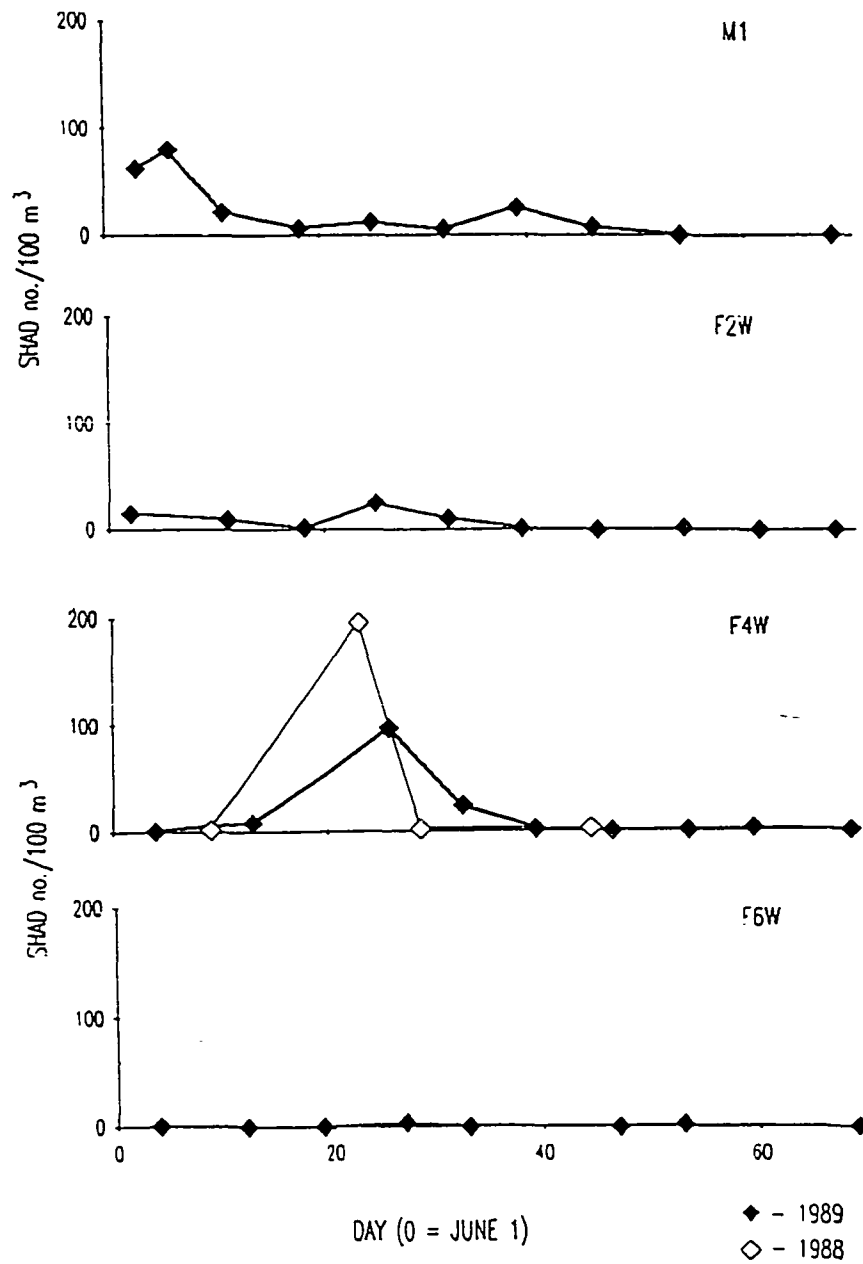


Figure 10. Shad densities through time; west-side stations and Muddy Arm, M1 - 1988, 1989.

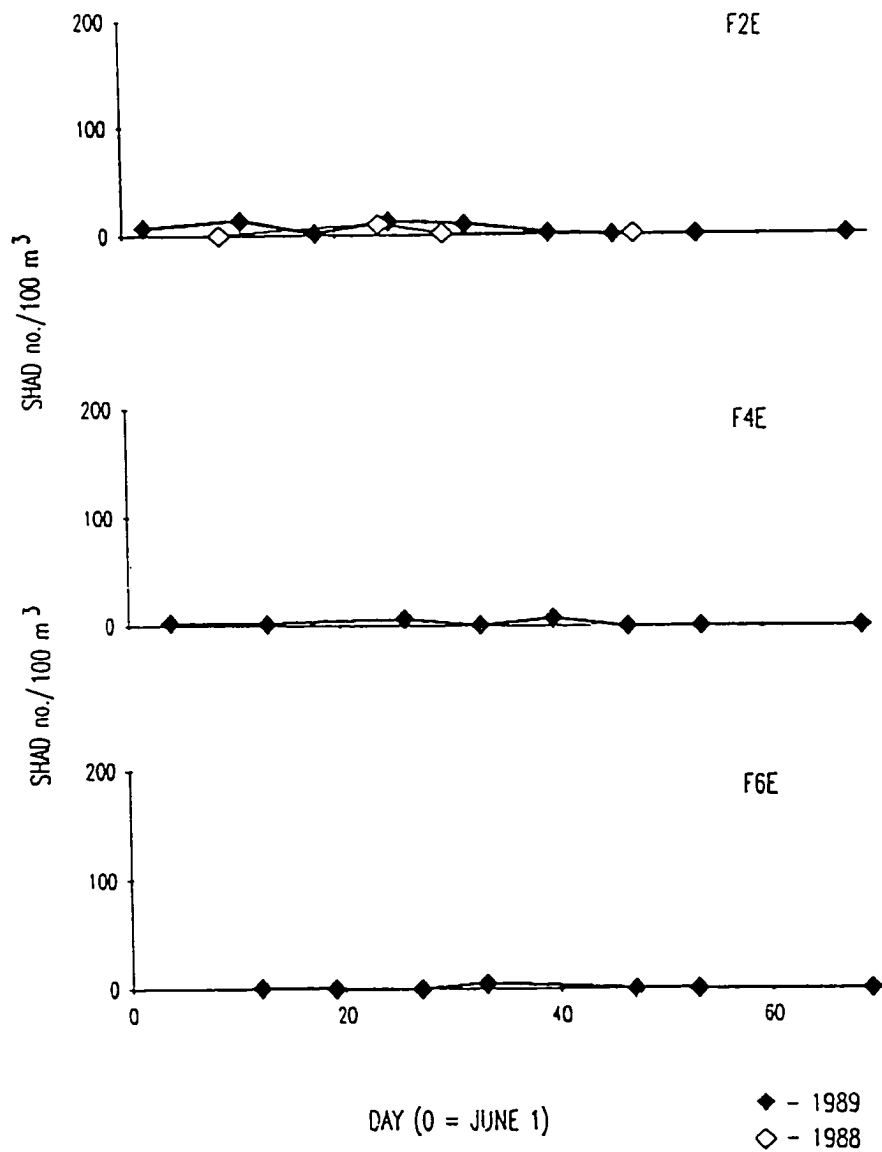


Figure 11. Shad densities through time; east-side stations - 1988, 1989.

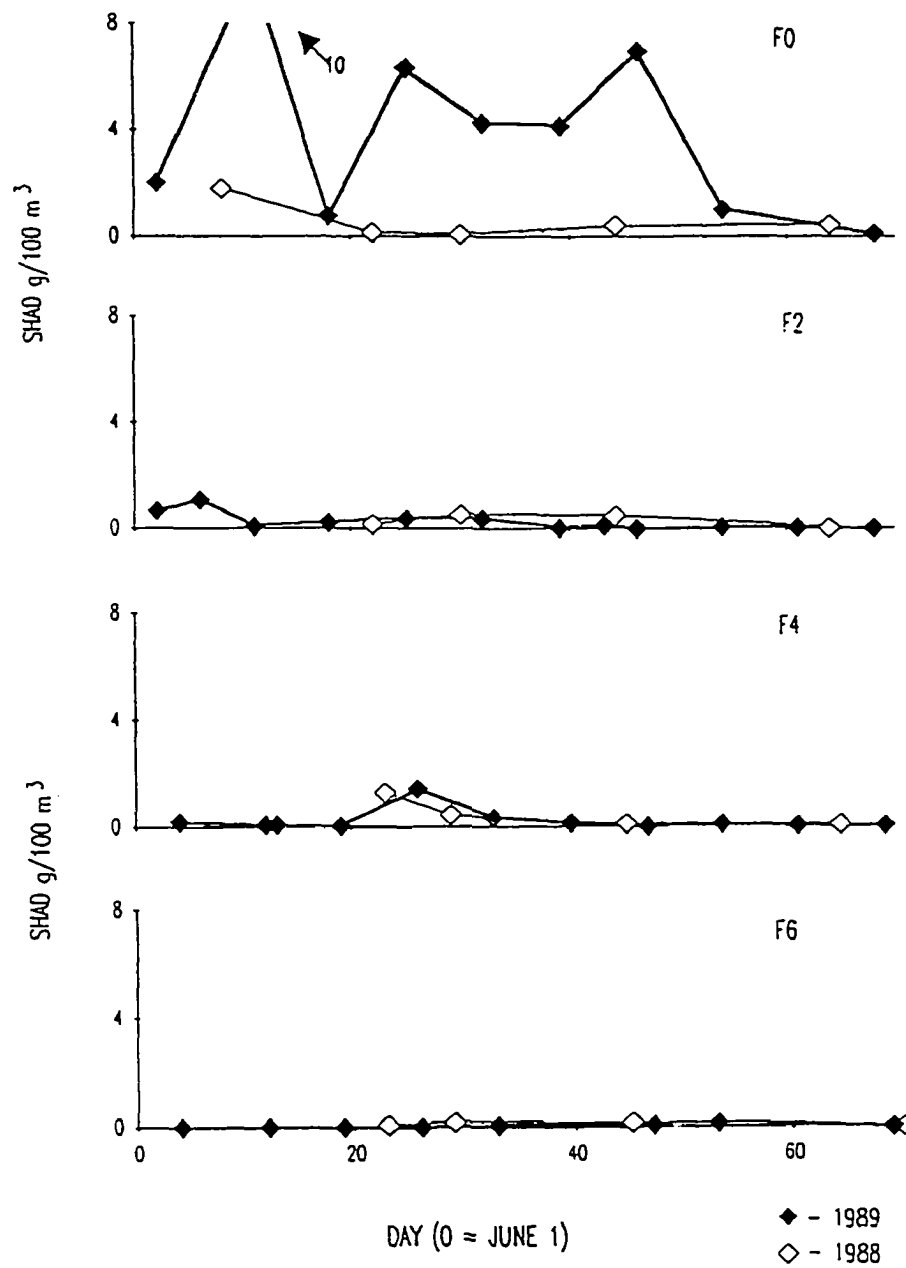


Figure 12. Shad biomass through time; mid-channel stations - 1988, 1989.

From the June - July 1988 synoptic distribution of mean shad densities (Figure 13), it was evident young shad were most numerous ( $>30$  fish/100 m<sup>3</sup>) in west-side coves. Mean density was also relatively high in Virgin Bowl (21-30 fish/100 m<sup>3</sup>). In 1989, mean shad densities were  $>30$  fish/100 m<sup>3</sup> in the west-side coves and Virgin Bowl (Figure 14).

#### Shad Abundance Models

The log-log regressions of shad abundance on resource availability reveal that during mid-June to mid-July in 1988 chlorophyll *a* did not correlate significantly ( $p < 0.05$ ) with young shad density or biomass (Figure 15 and Table 1). Conversely, during this same period in 1989, chlorophyll *a* correlations were significant in both shad density ( $r^2 = 0.771$ ;  $p < 0.000$ ) and biomass ( $r^2 = 0.476$ ;  $p = 0.003$ ) regressions.

*Daphnia* egg ratios did not correlate significantly with shad density or biomass in 1988 (Figure 16 and Table 1). In 1989, however, egg ratios did correlate significantly with shad density ( $r^2 = 0.34$ ;  $p = 0.018$ ), but not with biomass. Figure 16 reveals high positive residuals for the Fire Bay observations in both 1989 regressions, there being no data for 1988. In addition, the range of egg ratios was larger in 1989 than 1988, although the sample size in 1989 ( $n = 16$ ) was also larger than in 1988 ( $n = 8$ ).

Analysis of variance for the more complex, geographic models is summarized in Table 2. The east-west position [Pos] effect was significant, with the west-side ranking highest, in the 1988 density ( $p = 0.010$ ) and biomass ( $p = 0.011$ ) models. The effect of distance from inflow [Dist] was insignificant for both geographic models of shad abundance for this year. Chlorophyll *a* effect was insignificant, although relatively strong, in both 1988 geographic models.

[Pos] and [Dist] effects in 1989 were found insignificant in both geographic shad abundance models. Chlorophyll *a* effect, however, was strongest in both of these models (density,  $p = 0.053$ ; biomass,  $p = 0.117$ ), although insignificant at the 5 % level.

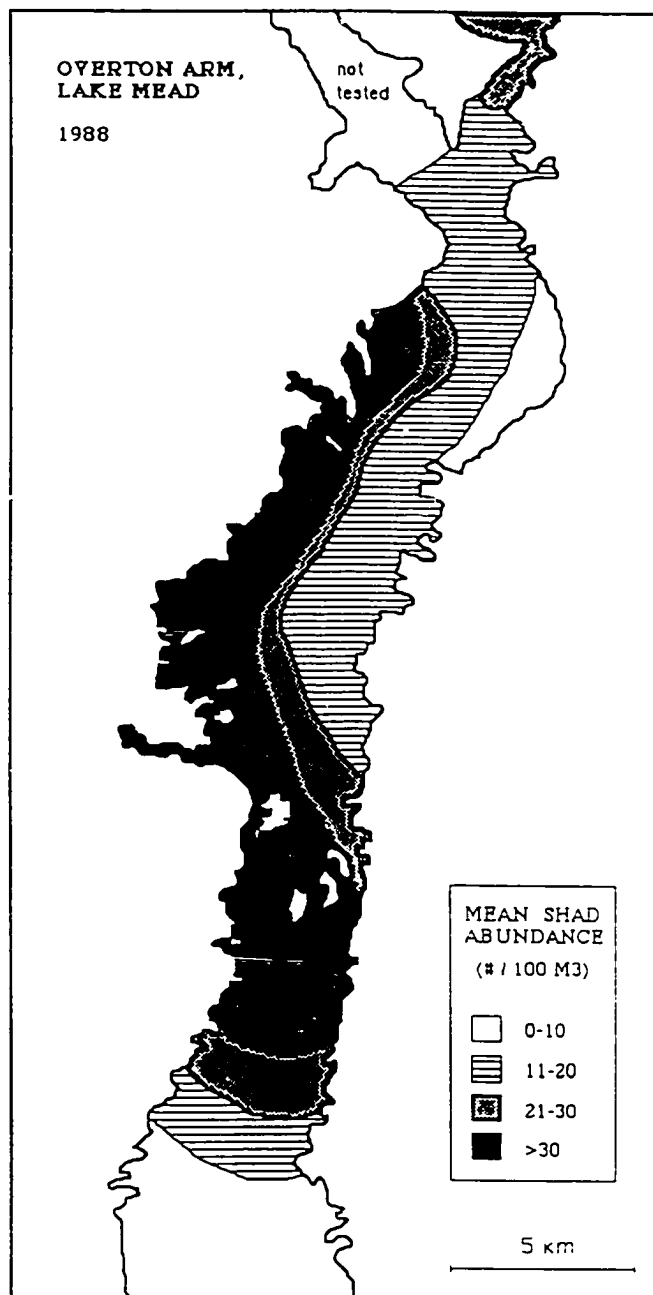


Figure 13. Synoptic mean shad densities; June, 2nd week - July, 2nd week, 1988.

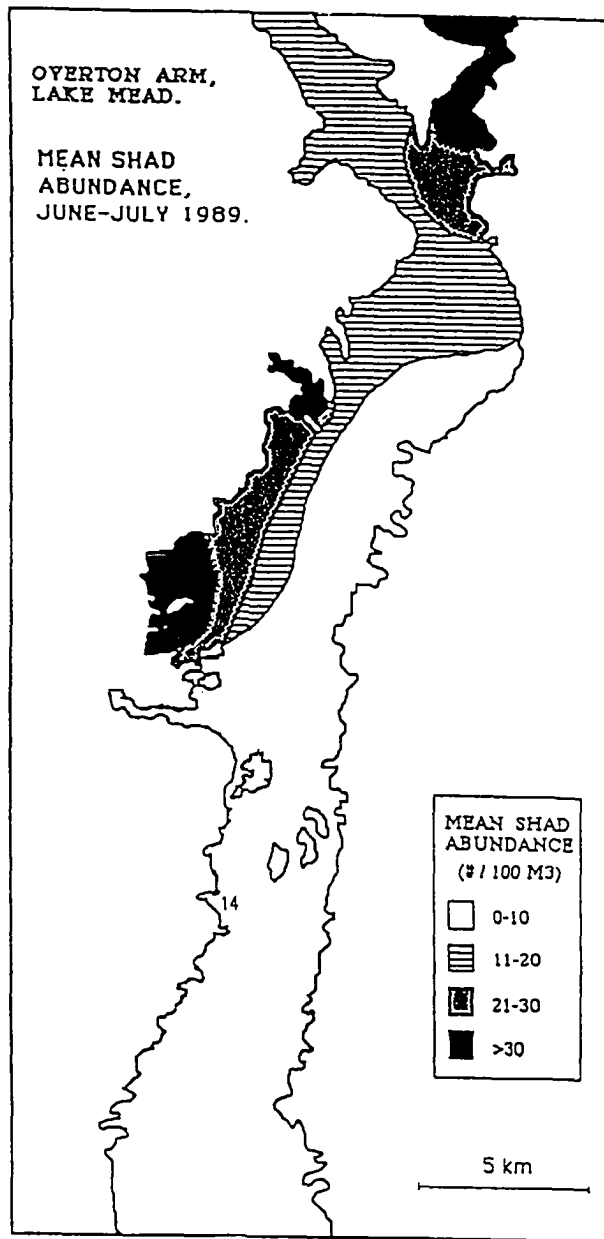


Figure 14. Synoptic mean shad densities; June, 2nd week - July, 2nd week, 1989.



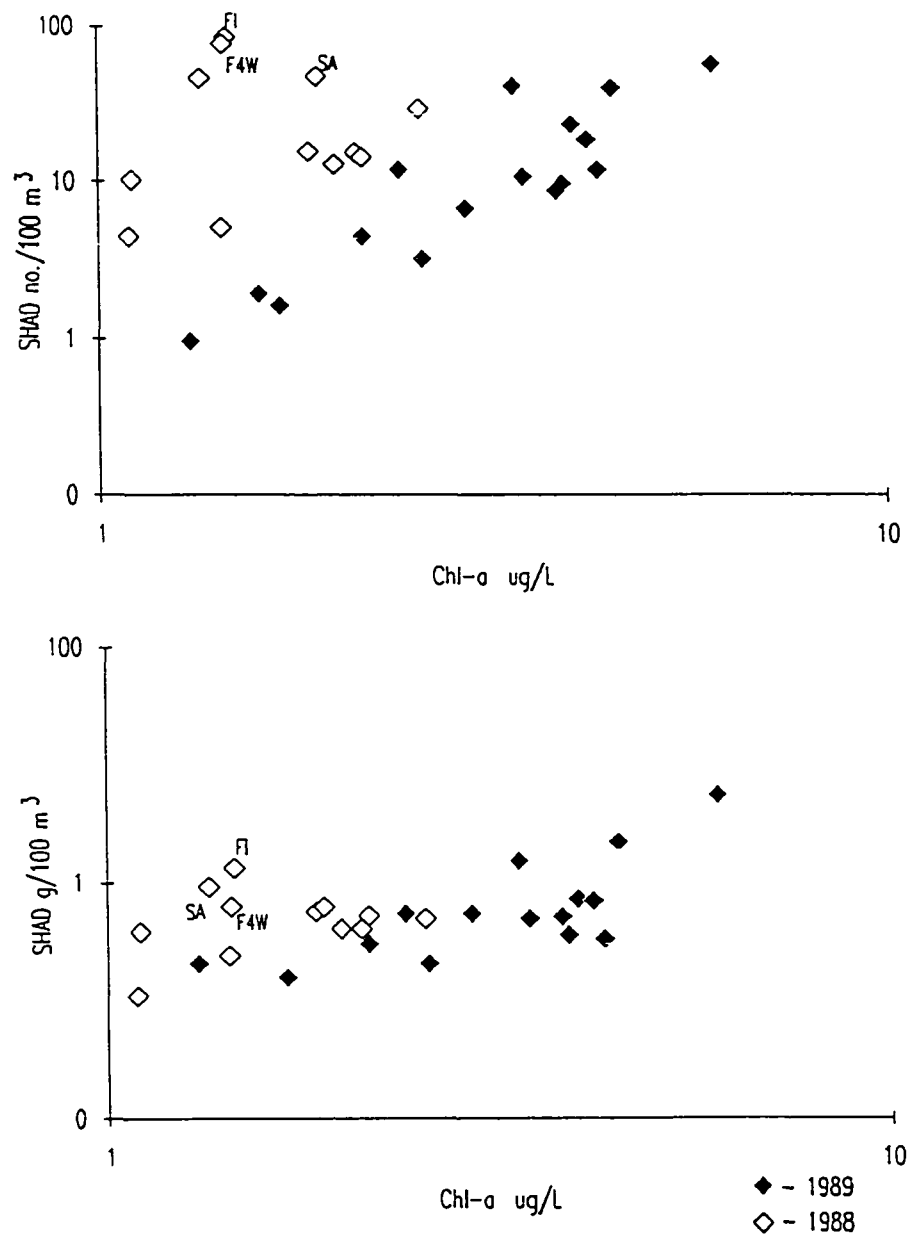


Figure 15. Chlorophyll *a* - shad abundance regressions; 1988, 1989.

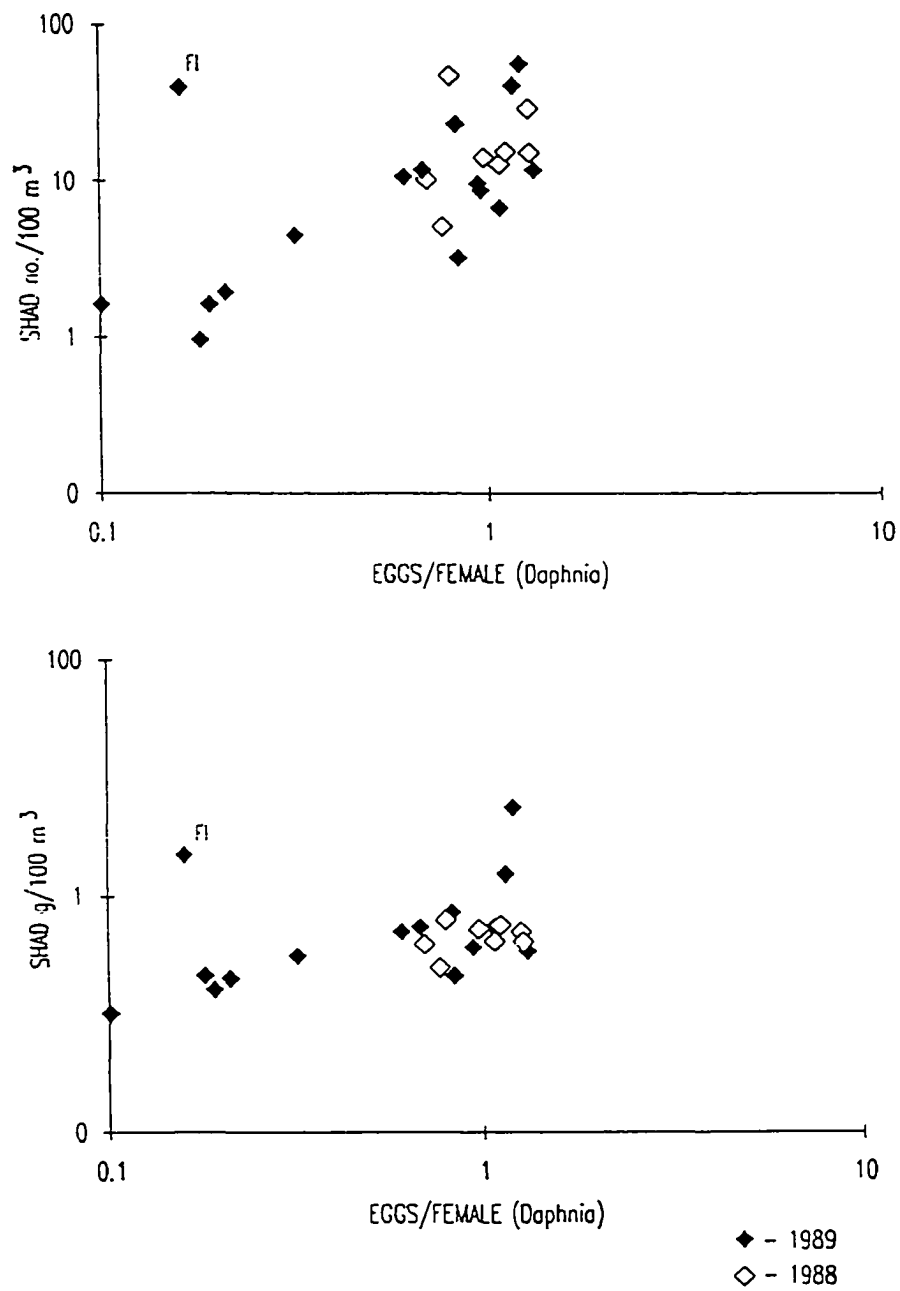


Figure 16. *Daphnia pulex* egg ratio - shad abundance regressions; 1988, 1989.

Table 1. Analysis of variance summary for log-log resource availability - shad abundance regressions.

SHAD YEAR ABUND.		RESOURCE	$r^2$	p
1988	Density	Chl $a$	0.023	0.636
1988	Density	Chl $a$	0.377	0.059
1988	Biomass	Chl $a$	0.005	0.822
1988	Density	Daph	0.084	0.487
1988	Biomass	Daph	0.064	0.547
1989	Density	Chl $a$	0.771	0.000
1989	Biomass	Chl $a$	0.476	0.003
1989	Density	Daph	0.337	0.018
1989	Biomass	Daph	0.125	0.178

Chl $a$  = chlorophyll *a*

Daph = *Daphnia* egg ratio

Table 2. Analysis of variance summary for shad abundance models with geographic factors.

YEAR	SHAD ABUND.	Pos	FACTORS (p values)	
			Dist	Chla
1988	Density	0.010	0.725	0.121
1988	Biomass	0.011	0.965	0.276
1989	Density	0.491	0.648	0.053
1989	Biomass	0.651	0.622	0.117

### Shad Size Distribution

Length frequency distributions for samples taken from four mid-channel stations (F0, F2, F4 and F6), during the first week of July, 1989, are given in Figure 17. Although the distributions were found to be generally unimodal, a second mode appeared at station F-0. This second mode, however, was only evident in the sample taken on July 2. Figure 18 shows that mean length for the primary mode remained at about 20 mm at all stations throughout the main spawning season, with a relative increase at most stations after the third week of July. Temporal and spatial variances appeared minimal and random, therefore no resource or geographic effects were tested. The relatively minor changes in size distribution also did not allow estimation of growth rates.

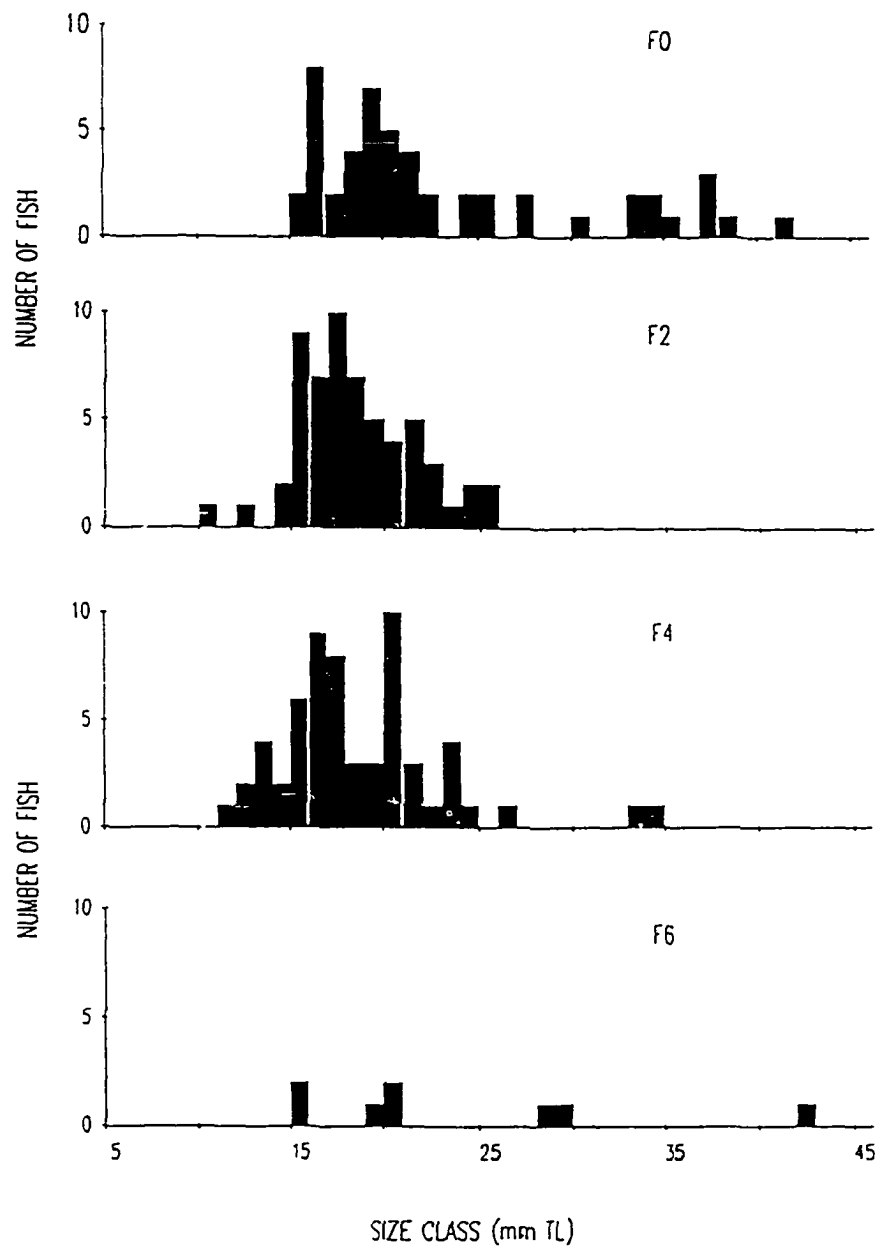


Figure 17. Shad size distributions; mid-channel stations - July, 1st week, 1989.

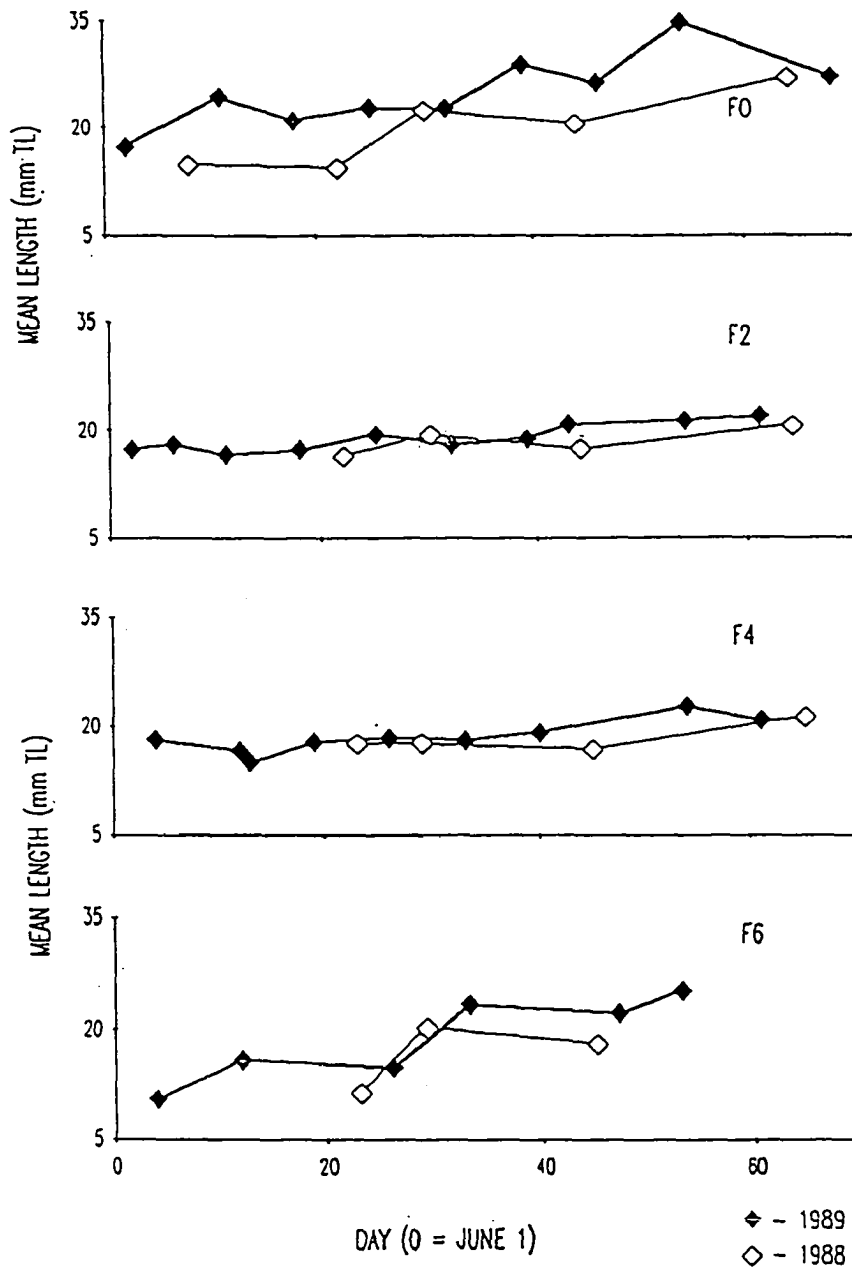


Figure 18. Shad mean lengths through time; mid-channel stations - 1988, 1989.

## DISCUSSION

### Sampling Program

Lack of temporal or spatial variation in mean length of fish caught with the meter net may be at least partially due to net bias. The range of shad caught with this net (8 - 45 mm TL) indicated that fish larger than 20 mm TL could be captured. However, the mean length of fish caught with Tucker trawl on July 12, 1989 (27 mm TL) was significantly larger (t test,  $p < 0.000$ ) than for fish taken with the meter net (20 mm TL) on the same date. This indicates there was net bias. Since actual distribution of the shad population was not known, it is impossible to quantify the effects of net bias, however, relative shad abundance was standardized for this bias, as the meter net was used for all sampling. Tucker trawl samples were analyzed independently.

Lack of variance in mean young shad length may be also be partially due to size-selective mortality for larger fish - recruitment at one end of the size distribution approximating mortality at the other. The proportion of this mortality attributable to starvation, versus predation, cannot be ascertained, although striped bass diet analyses (Paulson and Vaux, unpubl.) show that shad smaller than 30 mm TL are not generally taken. This supports predation as a factor in size-selective mortality. The extent to which starvation mortality may be size-selective for larvae cannot be determined, as the data reveal only the net effects of larvae mortality and recruitment.

### Evaluation of the Resource Availability - Shad Abundance Relationship

Fish abundance has been found highly correlated with chlorophyll *a* concentration in other studies. Using mean chlorophyll *a* concentrations and an index of shad abundance



from echograms, Wilde (1989) found a positive correlation in Lake Mead of  $r_s = 0.533$  ( $p < 0.000$ ). This was a lake-wide study. Ogelsby (1974), using data from 46 lakes on four continents, reported an  $r^2$  of 0.84 ( $n = 19$ ) in a regression of total fish harvest on chlorophyll  $a$  concentration. In addition, there were strong positive correlations found between total fish abundance and chlorophyll  $a$  in midwestern lakes and reservoirs ( $r = 0.91$ ; Jones and Hoyer, 1982), and in central Arizona reservoirs ( $r = 0.85$ ; Rinne *et al.*, 1981). The fish in the latter study were primarily threadfin shad. In a study of southern Appalachian reservoirs, Yurk and Ney (1989) reported a relatively weak correlation between total fish abundance and chlorophyll  $a$  ( $r^2 = 0.31$ ;  $p = 0.007$ ), however, the relationship between planktivore abundance and total phosphorous concentration was found to be quite strong ( $r^2 = 0.84$ ;  $p = 0.01$ ).

It appears safe to assume causality in resource availability - shad abundance correlations, and although shad abundance was not found to correlate significantly with chlorophyll  $a$  in 1988, this does not necessarily mean there was no influence from the chlorophyll  $a$  in that year. Further examination of Figure 15 reveals that the 1988 observations for the west side coves are clustered, all having relatively high, positive residuals. In the models that included geographic variables, the west-side effect upon shad abundance was significant. Possibly some geographically-associated factor(s) confounded evaluation of the chlorophyll  $a$  effect in 1988. This type of situation is not uncommon when dealing with complex sets of environmental variables.

Significantly higher shad abundance seen in the west-side coves in 1988 may reflect lower predation pressure from striped bass. Predation pressure may vary with the size of the sub-adult striped bass population. Coutant (1986) found that adult ( $>3$  years) striped bass are incapable of foraging in warm, epilimnetic waters, due to thermoregulatory constraints. A thermal prey refuge from adult stripers then exists for shad during the

spring/summer in areas where depth is less than the thermocline, which is about 13 m deep during the summer in Lake Mead. However, subadult stripers ( $< 400$  mm fork length FL in Lake Mead) can spend more time than adults in the warm, epilimnetic waters, because they are more efficient at thermoregulation, owing to their greater surface/volume ratio. In this case, the effect of this prey refuge would be inversely proportional to the density of subadult striped bass. Gustaveson *et al.* (1985) have suggested that such a thermal prey refuge results in a three year cycle of threadfin shad abundance in Lake Powell. This coincides with the age at which striped bass reach sexual maturity.

When densities of sub-adult striped bass are small, the west-side coves of Overton Arm are ideal thermal refuges, as they are relatively large, shallow and geographically well-defined (Figures 2 and 3). Less habitat is provided for adult striped bass, which must reside in the hypolimnion. Subadult striped bass were less abundant in 1988 than in 1989 (Paulson and Vaux, unpubl), suggesting that this prey refuge may have had a relatively stronger influence upon shad abundance in 1988. Less predation pressure in that year could have then resulted in higher densities of young shad in the west-side coves than in other areas. More adult shad may have survived in and/or moved into these coves, resulting in higher spawning rates in these areas. Lower predation pressure may also have lead to increased survivorship of the young.

Another explanation for high young shad abundance in the west-side coves is that these areas are preferred for spawning, because they are sheltered from prevailing southwest winds and wave action. This may partially explain the absence of a refuge effect in the east-side coves, although the Meadows (F2E) was the only east-side station studied in 1988, making it difficult to evaluate influences on east-side abundance in that year. If adult shad are selective for the west-side coves during the spawn, for reasons other than resource availability, evaluation of the effects of fertilizer treatment are further confounded, as these

coves were also all fertilized in both years.

*Daphnia* egg ratios are of no use in evaluating the interannual variance in relative shad abundance in the west-side coves, as samples were not taken at lateral stations in 1988.

Because factors other than resource availability did have a significantly stronger effect in the west-side coves, than in the rest of Overton Arm in 1988, it seems reasonable to also run the chlorophyll *a* - shad abundance regressions without the west-side cove observations. In this case, the strength of both models is greatly improved (density  $r^2 = 0.377$ ;  $p = 0.059$ )(biomass  $r^2 = 0.471$ ;  $p = 0.041$ ).

That *Daphnia* egg ratios did not correlate as well with shad abundance as did chlorophyll *a* suggests three possibilities: a.) egg ratios did not accurately represent abundance of zooplankton as food; b.) phytoplankton concentration is more influential in determining young shad abundance; c.) the efficiency of energy conversion between the zooplankton and shad trophic levels was poor. Sample size was also quite small in 1988 ( $n = 8$ ). The egg ratio effect may have been stronger in 1989 than indicated by the egg ratio - shad abundance regression. Because of low *Daphnia* densities in Fire Bay, egg ratios for this area had to be calculated using relatively few animals. As the accuracy of these data are therefore questionable, perhaps the Fire Bay observations should not be included in the regression. As residuals for these observations were very high, egg ratio -shad abundance correlations would undoubtedly improve if these observations were not included in the analyses. And so, although evidence is not conclusive, resource availability may have influenced young shad abundance in both years, with abundance in the west-side coves having been also affected by lowered predation pressure in 1988.

#### Further Study

Trawling for threadfin shad in Overton Arm will continue at least one more season

(1990), to provide a temporal control for the fertilization project test data. Information gathered will allow analyses of chlorophyll *a* effects upon shad abundance, attributed solely to natural nutrient levels.

In future evaluations of the effects of nutrient enhancement on young shad, analyses of some physiological indices of growth and condition might prove helpful. Preliminary work with otoliths from young shad suggests it is possible to detect differences in growth rates between populations in different areas of Lake Mead, by comparing otolith/somatic size ratios (Paulson and Vaux, unpubl.). Morphological indices of nutritional condition may be of use. Yin and Blaxter (1986) used ratios of different body measurements to detect starvation in larval cod (*Gadus morhua* L.) and flounder (*Platichthys flesus* L.). Analyses of length - weight relationships and body fat measurements could also be used to evaluate nutritional condition. It is possible some of these indices could be more sensitive to the effects of resource availability on young threadfin shad, than abundance figures.

In addition to efforts aimed at directly assessing the effects of resource availability on shad abundance, additional study of the predation effect is also needed. It is difficult to evaluate the independent effects of either resource availability or predation without knowing the other.

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