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THE RELATIVE ABUNDANCE OF OPOSSUM SHRIMP, MYSIS RELICTA, IN TWIN LAKES, COLORADO, USING A BENTHIC TRAWL

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16. ABSTRACT

The study of the opossum shrimp (*Mysis relicta* Loven) at Twin Lakes, Colo., is part of an investigation into the potential impacts of pumped-storage power generation on the two lakes. Since 1974, large and small benthic sled-type trawls have been used monthly to determine relative abundance of the shrimp. A comparison of the two trawls based on replicate sampling indicated that the mean shrimp density for the large trawl was 68 percent of the small trawl estimate. This difference was not statistically significant because of a large sample variation. An off-bottom sampling bias affected by the speed of the trawl was determined in a separate study using the small trawl. Corrections for this potential bias in the small trawl data collected in 1977 and 1979 indicated that shrimp densities may have been underestimated by 22 to 77 percent. Comparison of mean shrimp densities for the two trawl sizes using corrected small trawl data showed the large trawl estimate to be only 42 percent of the small trawl estimate. Shrimp length frequency analyses concur with this difference, indicating the smaller, juvenile shrimp were missed by the large trawl because of the larger mesh size. Adjusting for trawl sampling efficiency and sampling bias, yearly shrimp densities may have ranged from 88 to 348 shrimp/m^2 in the lower lake and from 57 to 174 shrimp/m^2 in the upper lake. This sampling variability precluded all but the most general comparisons of *Mysis* densities. Monthly estimates of shrimp densities in each of 4 years sampled showed a characteristic increase from June to September with declines in October and November in the lower lake. Over the 1974 to 1979 study period, seasonal mean estimates of shrimp density and indicated an increasing abundance of *Mysis* since 1975 in the lower lake, and a fluctuating population in the upper lake.

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FOREWORD

This report is one of a series presenting data on different aspects of the ecology of Twin Lakes, Colo., collected before operation commenced at the Mt. Elbert Pumped-Storage Powerplant. Data in this report, combined with other preoperation data will be used as a baseline for analyzing postoperation data in order to quantify the effects of pumped-storage powerplant operation. The overall objectives of this research are two-fold: (1) to maximize ecological resources at Twin Lakes while meeting the demands of water and power projects, and (2) to learn the effects of pumped-storage operation on lakes and reservoirs, especially oligotrophic lakes in montane situations. Studies similar to those at Twin Lakes, Colo., are being conducted at other locations with periodic workshops being held for the purpose of presenting and discussing the results obtained. The exchange of information results in a better understanding of pumped-storage effects, which in turn, leads to a more efficient planning process and greater protection of environmental features.

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PURPOSE

The data contained in this report are a significant part of the baseline pumped-storage operations information on the ecology of Twin Lakes, Colo., to which findings during the postoperative phase will be compared. Opossum shrimp make up a significant part of the zooplankton population and are an important element of the Twin Lakes food chain, particularly for the lake trout fishery. Significant alteration of the shrimp population should be reflected in populations of other plankton, and of the young lake trout. The information in this report will be useful to those interested in the limnology and fisheries of other cold-water lakes where opossum shrimp are found. In addition, those interested in methods of sampling opossum shrimp will find the information in this report useful.

INTRODUCTION

Twin Lakes are two montane lakes of glacial origin, located within the drainage of the Upper Arkansas River, 24 km south of Leadville in central Colo. (fig. 1). The lakes lie at an elevation of 2802 m. The maximum surface area of the upper lake is 263 ha and the maximum depth is 28 m. The maximum surface area of the lower lake is 736.5 ha and the maximum depth is 27 m. The lakes are dimictic, fluctuating water storage reservoirs with maximum surface temperatures of 14 to 18 °C. Depletion of hypolimnetic oxygen may occur during thermal stratification. A detailed description of the limnology of Twin Lakes is provided by Sartoris *et al.* (1977) [1].[1]

Mysis relicta were introduced into Twin Lakes in 1957 (Klein, 1957 [2]) in an attempt to establish an additional food source for the lake trout (*Salvelinus namaycush* Walbaum (fig. 2). By 1969, the population had expanded to the point where *Mysis* were collected in the lakes for introductions elsewhere (Finnell, 1977 [3]). Griest (1977) [4] determined that the shrimp were the primary food item for the lake trout in Twin Lakes by 1974.

The development of Twin Lakes for pumped-storage power generation prompted investigations to determine the potential impacts of power generation on the various aspects of the life history of *Mysis*. Gregg and Bergersen (1980) [5] determined that the major impact upon the shrimp would probably be mortality via turbulence following entrainment. Significant mortality to the *Mysis* population from powerplant operation would likely have adverse effects on the lake trout population and fishery.

Studies of the spatial and temporal distribution of the shrimp were initiated by the Colo. Div. of Wildlife in 1974 to determine their relative abundance. Two sizes of benthic sled-type trawls and two photographic techniques have been utilized to estimate *Mysis* densities. The majority of *Mysis* density data were generated using the two trawls, while photographic techniques developed by Finnell (1977 [6]) and Bergersen and Maiolie (1981) [7] were used to evaluate the sampling efficiencies of the trawls. Further studies were conducted to determine the relative sampling efficiencies between the two trawls. These studies provided a comparative evaluation of the relative abundance of *Mysis* using all available data collected during the preoperational study period.

This report presents *Mysis* density data collected during 1977–79, but utilizes data collected in 1974–75 for comparisons between the different-size trawls and between years sampled. Details of the 1974–75 shrimp data may be found in Finnell (1977) [6].

CONCLUSIONS AND RECOMMENDATIONS

1. The relative differences in *Mysis* abundance over time and depth may be adequately determined using a benthic sled-type trawl. The dynamics of *Mysis* distribution, as influenced by their extensive vertical and horizontal migrations, make estimations of the real or absolute density from benthic trawl data unlikely.

2. The comparison of *Mysis* density estimates from different lakes, and collected with various types and sizes of sampling gear, must account for size-selective differences in capture efficiencies, eliminate variability in *Mysis* distribution over time and depth, and consider differences in lake productivity. The difference in shrimp density estimates

[1]Numbers in brackets refer to entries in the Bibliography.

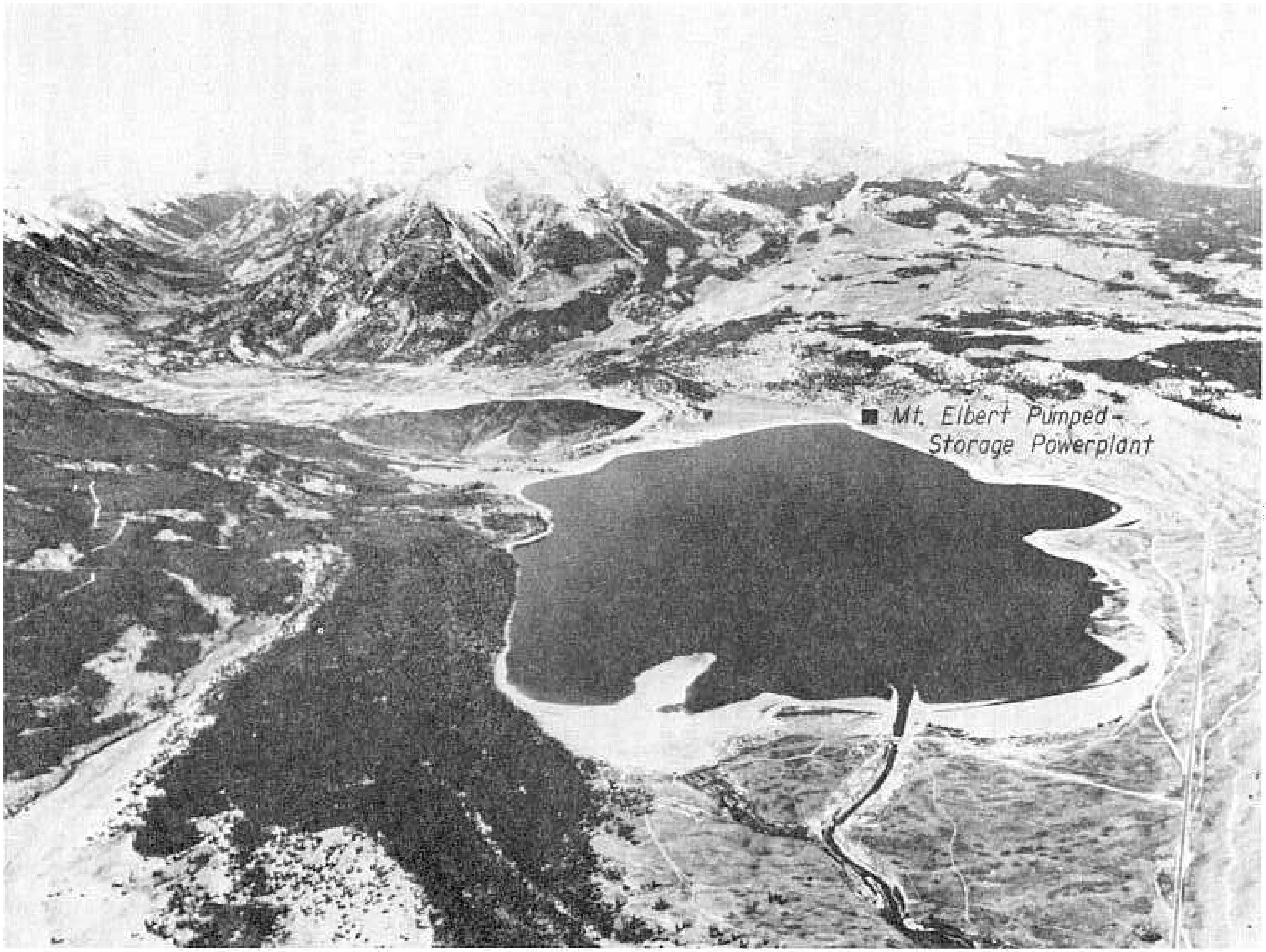


Figure 1.—Aerial view of the lower lake. Mt. Elbert is in the background, and the outlet works in the foreground. Photo P-915-D-79401

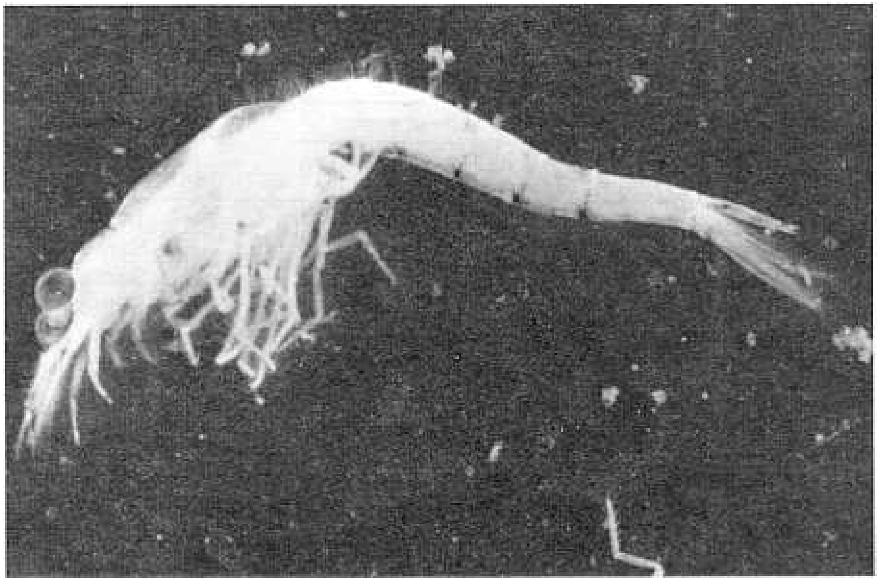


Figure 2.—Opossum shrimp (*Mysis relicta*). Photo P-915-D-79400

provided by the two trawls used was a result of the larger mesh size in the large trawl, which allowed a selective escapement of the small, juvenile shrimp.

Yearly differences in the relative abundance of *Mysis* in Twin Lakes are influenced by limnological factors affecting lake productivity and zooplankton abundance. This assumes a consistent sampling bias between years sampled.

4. Monthly differences in *Mysis* density estimates are influenced by the shrimp's migratory behavior relative to the sampling limitations of the trawl and also by specific limnological factors that predominate Twin Lakes in certain years.

5. Use of the *Mysis* density estimates generated by the benthic trawl for the evaluation of powerplant impacts is possible if increased mortality results in a reduced *Mysis* abundance below the range of preoperational estimates. Precautions concerning sampling consistency must be considered.

METHODS

A standardized scheme for sampling *Mysis*, using a benthic sled-type trawl, was developed in 1974 and used in 1975, 1977, and 1979 (fig. 3). Only limited sampling was accomplished in 1978. *Mysis* sampling at Twin Lakes was conducted from 1974 to 1975 by Finnell (1977) [6] and Gregg (1976) [8]. The sampling design for all studies combined systematic and stratified-random elements. Traverse lines were constructed through the middle of both lakes using permanent sampling stations 2, 3, and 4 as directional guiding points. In the lower lake, this line ran from the lake outlet, through stations 2 and 3, ending near the powerplant outlet. This line was divided equally into eight sampling sections, each approximately 0.4 km long. In the upper lake, the traverse line ran from inlet to outlet using station 4 as a midpoint, forming two sampling sections approximately 0.8 km in length.

Monthly sampling was conducted within each of these traverse line sections from June through November (table 1). Additionally, six stations in the lower lake and one in the upper lake were sampled monthly from depths greater or less than 15 m (fig. 3). Locations of these seven permanent stations were selected randomly for each of the six sampling months in 1974, 1975, 1977, and 1979. In the lower lake, three stations were located at depths greater than 15 m and three at depths less than 15 m. In the upper lake, the one station was located at a depth greater than 15 m. In 1978, only the traverse

Table 1.—*Mysis sampling stations for Twin Lakes*

Month	Lower lake			Upper lake	
	Traverse line stations	Random stations		Traverse line stations	Random stations
		> 15 m	< 15 m		
June	I thru VIII	$B_{1,2,3}$	$B_{1,2,3}$	IX, X	B_1
July	Same	$C_{1,2,3}$	$C_{1,2,3}$	Same	C_1
August	Same	$D_{1,2,3}$	$D_{1,2,3}$	Same	D_1
September	Same	$E_{1,2,3}$	$E_{1,2,3}$	Same	E_1
October	Same	$F_{1,2,3}$	$F_{1,2,3}$	Same	F_1
November	Same	$G_{1,2,3}$	$G_{1,2,3}$	Same	G_1

line stations were sampled, and only in 2 months—August and September. On a yearly basis, 85, 17, and 103 samples were obtained in 1977, 1978, and 1979, respectively.

The sampling procedure consisted of lowering the trawl down through the water at the desired location while moving slowly forward in the boat to make sure the trawl settled on the lake bottom in an upright position. Line was stripped from the winch drum to maintain adequate slack and prevent unwanted movement once the trawl touched bottom. Approximately 90 m of line was used for deep stations (18 to 24 m) to ensure that the trawl remained on the lake bottom. At shallower stations (2 to 16 m), approximately 45 m of line was let out. The tubular aluminum frame of the trawl was weighted with 6.8 kg of lead from 1977 to 1979 to add stability and further promote bottom sampling. Sampling runs were conducted for 2 minutes, during which the mean speed of the towing vessel was determined by timing the passage of a float over the length of the vessel. Three float passages were timed for each run. Using the mean boat speed in meters per second over the 2-min sampling period, the distance traveled by the trawl was estimated. From 1977 to 1979, the mean boat speed was maintained within a range of 0.26 to 1.09 m/s and averaged 0.63 m/s (± 20 pct coefficient of variation) over 205 samples taken.

At the end of the 2-min period, the boat was stopped and reversed in direction to minimize further sampling by the trawl, which was rapidly winched to the lake surface. At the surface, the trawl net was washed to concentrate the shrimp into the metal bucket forming the cod end. The shrimp samples were then preserved in 10 to 15 percent formalin. Sampling was normally conducted between 0800 and 1100 hours. This time was selected because Gregg (1976) [8] found that 90 percent or greater of the shrimp were at the bottom of Twin Lakes by sunrise.

To facilitate counting samples of very large numbers of *Mysis*, an electric subsampler described by Gregg (1976) [8] was used. Preliminary chi-square analysis of *Mysis* density estimates based on subsample numbers were performed by Gregg (1976) [8] and no significant differences ($P \leq 0.05$) were found. Equality of subsamples was assumed for the years 1977–79. The density of *Mysis* at each station was determined by dividing the total number of shrimp per sample by the area of lake bottom sampled by the trawl. The area sampled was determined to be the product of the distance traveled by the trawl and the width of the trawl mouth.

Two different size trawls were used during the study period (figs. 4, 5, 6, and 7). In 1974–75, a large trawl with a 60- by 150-cm mouth and 3- to 6.4-mm-mesh net was used. In 1977–79, a smaller trawl with a 27- by 45-cm mouth and 0.7- to 1.0-mm-mesh net was used. During sampling with the large trawl in 1979, *Mysis* were observed escaping through the mesh as the trawl was held at the surface, and it was postulated that the larger trawl was not sampling small shrimp effectively, thus resulting in lower density estimates relative to the smaller trawl. Twenty-eight replicate samples using the two trawls at given stations were made in July, August, September, and October 1979, with the objectives of determining relative sampling efficiencies and a conversion factor to make the data sets for 1974–75 (Finnell, 1977 [6]) and

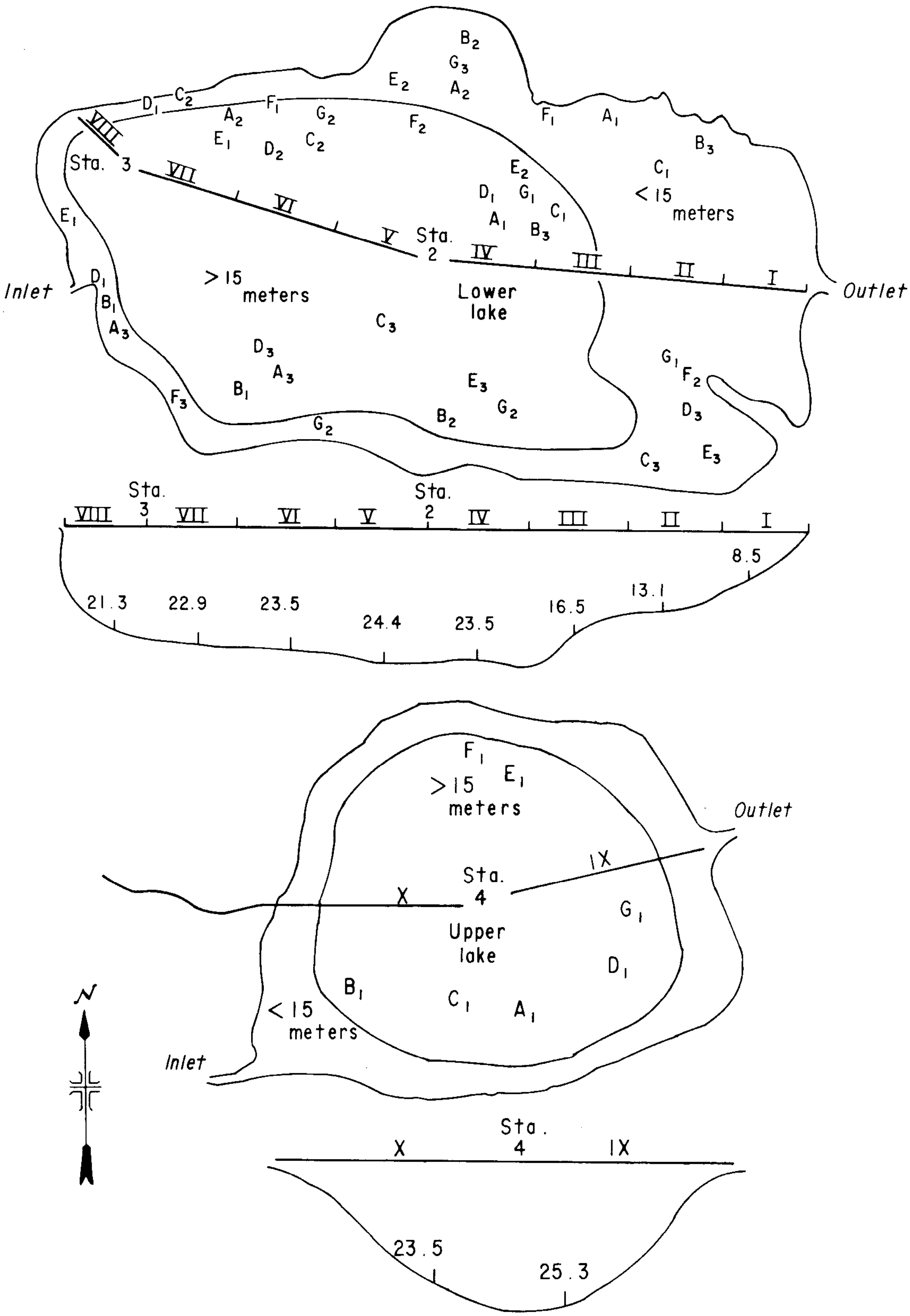


Figure 3.—*Mysis* sampling stations for Twin Lakes.

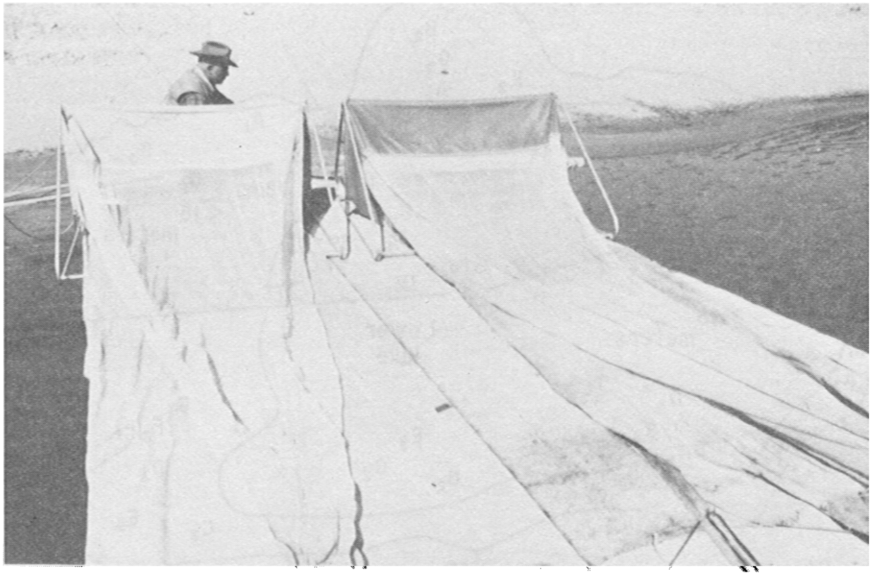


Figure 4.—Large benthic sled-type trawl used in 1974–75. Photo P-801-D-79722

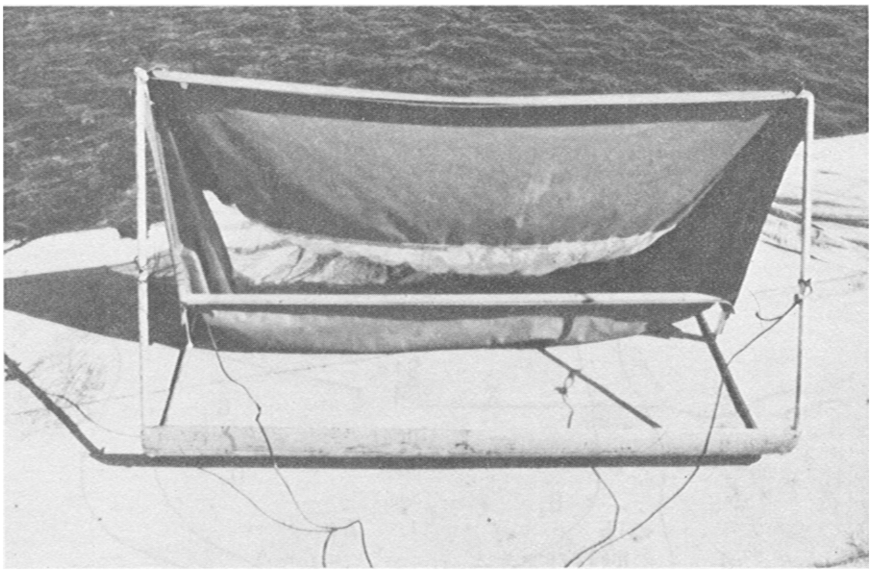


Figure 5.—Front view of large trawl. Photo P-801-D-79723

1977–79 comparable. To increase the representativeness of the comparison, stations where replicate sampling was conducted were divided monthly among lower lake-deep stations, lower lake-shallow stations, and upper lake stations on a 4:3:1 ratio. A lost sample and limiting weather conditions altered this ratio in August (3:3:1) and October (4:1:0), respectively. Each sample was conducted according to the procedure described earlier. Once the boat was positioned at the desired location, a marker buoy was used to identify the starting point. At the completion of one sample, the boat would be returned to the same position, and another sample would be taken in the same direction with the other trawl. Given the method of placing the trawl on the lake bottom, it was assumed that the two trawls never followed the same path exactly. The two trawls were also alternated on which was used first in a replicated sample.

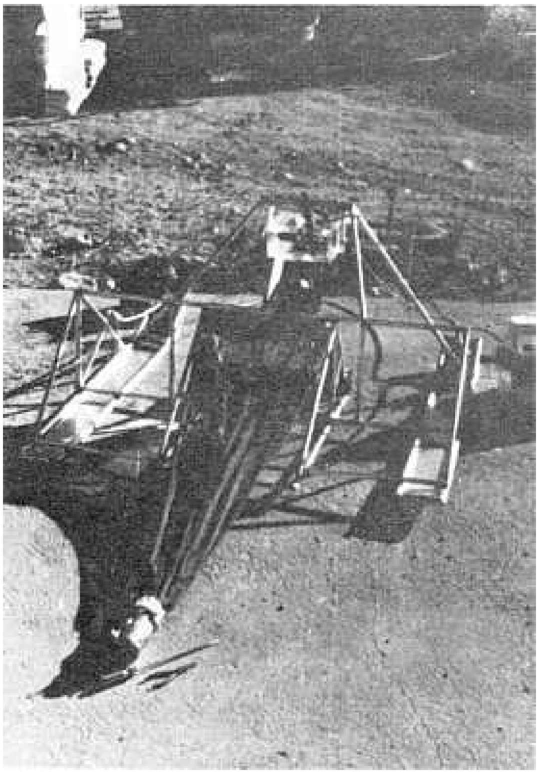


Figure 6.—Small benthic sled-type trawl used in 1977–79. Photo P-801-D-79724

These *Mysis* samples were processed in the same manner as described earlier for density estimation and were further processed for length frequency measurements. Following density estimation on a given sample, the entire sample would be subsampled again to obtain approximately 400 shrimp. All shrimp within this subsample would be measured for length to the nearest millimeter (i.e., 14.5 to 15.4 = 15 mm) from the tip of the rostrum to the tip of the telson, disregarding setae. Sample sizes for the length frequency analyses for the large and small trawls were 10 389 and 10 934 shrimp, respectively.

RESULTS

Small Trawl Samples—1977–79

Mysis shrimp densities varied considerably over the 205 samples collected from 1977 to 1979, ranging from 0 to 355 shrimp/m^2 (tables 2 and 3). Categorizing the sample stations as deep (> 15 m) or shallow (< 15 m), monthly *Mysis* density estimates appeared greater in the deep stations of the lower lake for both 1977 and 1979 (table 4). Using the *t*-distribution for comparisons ($P < 0.05$), these differences between deep and

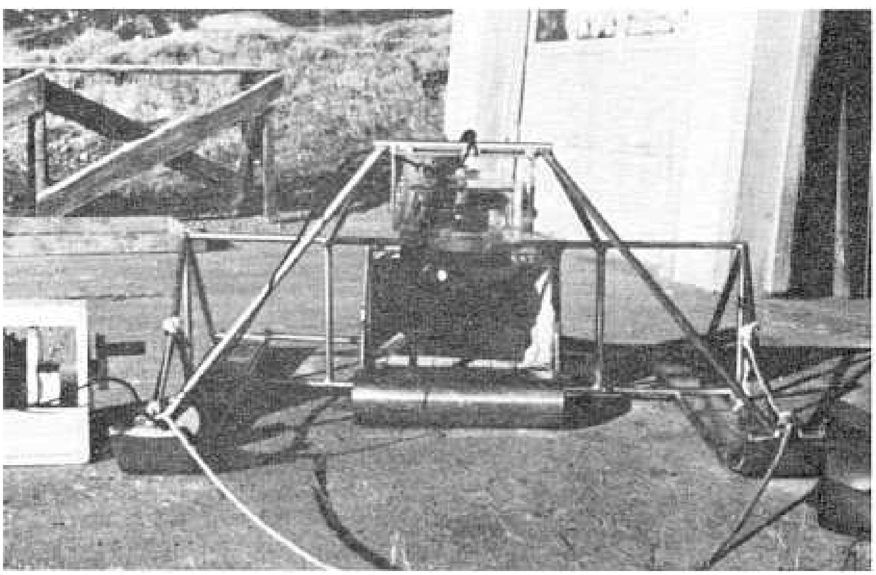


Figure 7.—Front view of small trawl. Photo P-801-D-79725

Table 2.—Mysis *density estimates for the lower lake, 1977–79.*

Month and year	Shallow or deep	Station	Estimated density No./m²	Trawl speed m/s	Estimated lift-off %	Corrected density No./m²
June 1977	Shallow	I	10	0.47	—	—
		II	5	.66	—	—
		$B_1 < 15$	40	.63	—	—
		$B_2 < 15$	19	.60	—	—
		$B_3 < 15$	3	.58	—	—
	Deep	III	8	.70	—	—
		IV	14	.63	—	—
		V	35	.66	—	—
		VI	22	.63	—	—
		VII	29	.63	—	—
		VIII	72	.66	—	—
		$B_1 > 15$	64	.66	—	—
		$B_2 > 15$	22	.63	—	—
		$B_3 > 15$	125	.63	—	—
July 1977	Shallow	I	0	.65	—	—
		II	0	.59	—	—
		$C_1 < 15$	4	.54	—	—
		$C_2 < 15$	168	.51	—	—
		$C_3 < 15$	2	.76	—	—
	Deep	III	159	.46	0	—
		IV	157	.42	0	—
		V	68	.40	0	—
		VI	35	.44	0	—
		VII	51	.26	0	—
		VIII	62	.31	0	—
		$C_1 > 15$	156	.51	9	171
		$C_2 > 15$	163	.49	3	168
		$C_3 > 15$	83	.48	1	84
August 1977	Shallow	I	22	.46	—	—
		II	18	.51	—	—
		$D_1 < 15$	11	.57	—	—
		$D_2 < 15$	25	.65	—	—
		$D_3 < 15$	14	.54	—	—
	Deep	III	160	.51	9	176
		IV	49	.40	0	—
		V	205	.57	24	270
		VI	156	.51	9	171
		VII	171	.57	24	225
		VIII	101	.61	34	153
		$D_1 > 15$	25	.76	72	89
		$D_2 > 15$	107	.65	44	191
		$D_3 > 15$	90	.54	16	107
September 1977	Shallow	I	0	0.42	—	—
		II	30	.54	—	—
		$E_1 < 15$	1	.48	—	—
		$E_2 < 15$	0	.34	—	—
		$E_3 < 15$	20	.54	—	—
	Deep	III	90	.51	9	99
		IV	1	.55	19	1

Table 2.—Mysis *density estimates for the lower lake, 1977–79.*—Continued

Month and year	Shallow or deep	Station	Estimated density No./m²	Trawl speed m/s	Estimated lift-off %	Corrected density No./m²
		V	0	.48	1	0
		VI	0	.57	24	0
		VII	98	.54	16	117
		VIII	168	.76	72	600
		$E_1 > 15$	47	.76	72	168
		$E_2 > 15$	49	.46	0	—
		$E_3 > 15$	150	.54	16	179
October 1977	Shallow	I	51	.51	—	—
		II	45	.42	—	—
		$F_1 < 15$	34	.57	—	—
		$F_2 < 15$	58	.42	—	—
		$F_3 < 15$	6	.52	—	—
	Deep	III	137	.54	16	163
		IV	154	.48	1	156
		V	126	.51	9	138
		VI	67	.40	0	—
		VII	54	.57	24	71
		VIII	45	.46	0	—
		$F_1 > 15$	113	.48	1	114
		$F_2 > 15$	286	.48	1	289
		$F_3 > 15$	88	.59	29	124
August 1978	Shallow	I	16	1.02	—	—
		II	39	0.76	—	—
		II	18	.95	—	—
	Deep	III	40	.87	—	—
		IV	148	.78	—	—
		V	152	.78	—	—
		VI	104	.54	—	—
		VII	41	.71	—	—
		VIII	83	.73	—	—
September 1978	Shallow	I	101	0.61	—	—
		II	105	.69	—	—
	Deep	III	127	.95	—	—
		IV	141	.82	—	—
		V	144	.82	—	—
		VI	127	.78	—	—
		VII	151	.78	—	—
		VIII	140	.76	—	—
June 1979	Shallow	I	6	.68	—	—
		II	44	.85	—	—
		$B_1 < 15$	35	.87	—	—
		$B_2 < 15$	15	.87	—	—
		$B_3 < 15$	0.3	.76	—	—
	Deep	III	10	1.09	—	—
		IV	91	0.90	—	—
		V	59	.59	—	—
		VI	157	.61	—	—
		VII	78	.65	—	—
		VIII	88	.80	—	—

Table 2.—Mysis *density estimates for the lower lake, 1977–79.*—Continued

Month and year	Shallow or deep	Station	Estimated density No./m²	Trawl speed m/s	Estimated lift-off %	Corrected density No./m²
		$B_1 > 15$	16	.82	—	—
		$B_2 > 15$	27	.71	—	—
		$B_3 > 15$	34	.76	—	—
		III	23	.71	—	—
July 1979	Shallow	I	8	.55	—	—
		II	94	.62	—	—
		$C_1 < 15$	91	.67	—	—
		$C_2 < 15$	16	.99	—	—
		$C_3 < 15$	177	.76	—	—
	Deep	III	90	.64	42	155
		IV	114	.62	37	181
		V	239	.58	26	323
		VI	195	.67	49	382
		VII	209	.70	57	486
		VIII	33	.67	49	65
		$C_1 > 15$	170	.72	62	447
		$C_2 > 15$	14	.68	52	29
		$C_3 > 15$	66	.70	57	153
August 1979	Shallow	I	0.2	0.68	—	—
		II	4	.67	—	—
		$D_1 < 15$	9	.52	—	—
		$D_2 < 15$	2	.61	—	—
		$D_3 < 15$	19	.72	—	—
	Deep	III	—	—	—	—
		IV	136	.76	72	486
		V	48	.67	49	94
		VI	157	.68	52	327
		VII	58	.65	44	104
		VIII	311	.63	39	510
		$D_1 > 15$	143	.66	47	270
		$D_2 > 15$	214	.64	42	369
		$D_3 > 15$	137	.62	37	217
September 1979	Shallow	I	12	.64	—	—
		II	81	.65	—	—
		$E_1 < 15$	21	.64	—	—
		$E_2 < 15$	46	.61	—	—
		$E_3 < 15$	83	.62	—	—
	Deep	III	179	.64	42	309
		IV	44	.61	34	67
		V	355	.62	37	563
		VI	278	.64	42	479
		VII	235	.67	49	461
		VIII	63	.62	37	100
		$E_1 > 15$	178	.64	42	307
		$E_2 > 15$	101	.64	42	174
		$E_3 > 15$	135	.65	44	241
October 1979	Shallow	I	2	.68	—	—
		II	32	.63	—	—
		$F_1 < 15$	12	.67	—	—

Table 2.—Mysis *density estimates for the lower lake, 1977–79.*—Continued

Month and year	Shallow or deep	Station	Estimated density No./m²	Trawl speed m/s	Estimated lift-off %	Corrected density No./m²
		F_2 < 15	0.4	.64	—	—
		F_3 < 15	0.1	.71	—	—
	Deep	III	188	.62	37	298
		IV	36	.63	39	59
		V	134	.67	49	263
		VI	192	.63	39	315
		VII	198	.64	42	341
		VIII	95	.61	34	144
		F_1 > 15	160	.58	26	216
		F_2 > 15	54	.64	42	93
		F_3 > 15	184	.61	34	279
November 1979	Shallow	I	27	0.78	—	—
		II	29	.72	—	—
		G_1 < 15	10	.83	—	—
		G_2 < 15	30	.63	—	—
		G_3 < 15	37	.64	—	—
	Deep	III	116	.54	16	138
		IV	92	.61	34	139
		V	327	.57	24	430
		VI	63	.58	26	85
		VII	122	.57	24	161
		VIII	48	.65	44	86
		G_1 > 15	62	.61	34	94
		G_2 > 15	84	.55	19	104
		G_3 > 15	44	.57	24	58

shallow stations were found to be significant in July, August, and October of 1977, and August, September, and October of 1979. *Mysis* density estimates in the lower lake-deep stations also appeared greater than those in the upper lake in each month for both years with the exception of June and September 1977. These differences between upper and lower lake-deep stations were significant for July 1977, and August, September, and October of 1979.

On a seasonal mean basis (June–November mean), *Mysis* densities in the deep basin of the lower lake were four times greater than those estimated for the shallow area of the lower lake in both 1977 and 1979. This difference was significant for both years. The seasonal estimate of *Mysis* density for the lower lake-deep stations was 1.5 times greater than the upper lake estimate in 1977 and five times greater than the upper lake estimate in 1979. Only the difference in 1979 was statistically significant. Comparing the lower lake seasonal estimates only, the 1979 deep-station estimate was significantly greater than that for 1977, while the shallow-station estimates for 1977 and 1979 were similar. In the upper lake, the 1977 estimate was significantly greater than that for 1979. The 95-percent confidence intervals for these estimates indicate that the greatest variation in *Mysis* densities was associated with the upper lake stations and shallow stations of the lower lake.

Large/Small Trawl Comparisons

Replicate samples, using the large and small trawls, involved 15 samples from the deep basin of the lower lake, 10 samples from the shallow areas of the lower lake and three samples from the upper lake (table 5). The mean *Mysis* density of the large trawl samples was 66 shrimp/m²

(95 pct confidence interval ± 47 pct) versus 97 shrimp/m² (95 pct confidence interval ± 39 pct) for the small trawl, but these means were not significantly different ($P>0.05$). The lack of a significant difference was attributed to the sample design, which incorporated the variability in *Mysis* distribution between the upper and lower lakes, deep and shallow stations, and within upper lake and shallow-station samples. Given the limited number of trawl samples possible per category (month, lake, and depth), pooling of all samples into a general mean was necessary. The smaller sample sizes for each category caused a slight decrease in the width of the above confidence intervals for the lower lake-deep station estimates for both trawl sizes. Considerable increases (± 70 to 293 pct), however, were found in the width of the confidence intervals for both trawl sizes for the lower lake-shallow and upper lake estimates. Sampling bias within the small trawl sample also contributed to the lack of statistical significance.

Length frequency distributions of the samples from the two trawls were both bimodal, and

Table 3.—Mysis *density estimates for the upper lake, 1977–79.*

Month and year	Station	Estimated density No./m²	Trawl speed m/s	Estimated lift-off %	Corrected density No./m²
1977					
June	IX	114	0.66	—	—
	X	112	.66	—	—
	B_1	59	.63	—	—
July	IX	26	.51	9	29
	X	21	.57	24	28
	C_1	39	.70	57	91
August	IX	46	.57	24	61
	X	80	.51	9	88
	D_1	50	.51	9	55
September	IX	71	.61	34	108
	X	140	.59	29	197
	E_1	13	.54	16	15
October	IX	29	.45	0	—
	X	101	.47	0	—
	F_1	6	.55	19	7
1979					
June	IX	7	.78	—	—
	X	5	.80	—	—
	B_1	18	.76	—	—
July	IX	19	.78	77	83
	X	18	.72	62	47
	C_1	72	.58	26	97
August	IX	13	.73	65	37
	X	6	.68	52	13
	D_1	47	.72	62	124
September	IX	10	.59	29	14
	X	7	.58	26	9
	E_1	15	.58	26	20
October	IX	41	.62	37	65
	X	17	.61	34	26
	F_1	48	.64	42	83
November	IX	38	.57	24	50
	X	30	.65	44	54
	G_1	56	.57	24	74

Table 4.—Mysis *shrimp densities (No/m²) by month, year, and depth for Twin Lakes, 1977 and 1979*

		June	July	August	September	October	November	Seasonal mean
					Lower lake			
1977	Deep[1]	43 (67)[4]	104 (40)	118 (39)	67 (73)	119 (47)	—	90 (21)
	Shallow[2]	15 (127)	35 (263)	18 (39)	10 (170)	39 (64)	—	23 (61)
	Mean[5]	33 (59)	79 (50)	82 (48)	47 (71)	90 (45)	—	66 (26)
1979	Deep	63 (56)	126 (49)	151 (46)	174 (45)	138 (35)	106 (63)	126 (19)
	Shallow	20 (117)	77 (111)	7 (134)	49 (83)	9 (188)	27 (46)	32 (55)
	Mean	46 (60)	109 (56)	96 (53)	129 (48)	92 (40)	78 (65)	92 (24)
					Upper lake			
1977[3]	Mean	95 (82)	29 (79)	59 (78)	75 (211)	45 (273)	—	60 (38)
1979	Mean	10 (174)	36 (213)	22 (248)	11 (91)	35 (115)	41 (81)	26 (48)

[1]Mean of 9 stations: III, IV, V, VI, VII, VIII, and monthly random stations 1, 2, and 3 > 15.
[2]Mean of 5 stations: I, II, and monthly random stations, 1, 2, and 3 < 15.
[3]Mean of 3 stations: IX, X, and monthly random station > 15.
[4]95% confidence intervals expressed as ± percent of mean.
[5]Weighted mean of 14 lower lake stations.

Table 5.—Mysis *density estimates for the large and small trawl comparisons of replicated stations.*

Month and year	Upper or lower lake	Station	Large trawl No./m²	Small trawl No./m²	Corrected small trawl No./m²
1979					
July	Lower	IV	29	114	181
		$C_1 > 15$	49	170	447
		$C_2 > 15$	112	14	29
		$C_3 > 15$	108	66	153
		$C_2 < 15$	16	16	—
		$C_3 < 15$	2	177	—
		$C_1 < 15$	29	91	—
	Upper	$C_1 > 15$	11	72	97
August	Lower	V	2	48	94
		VII	8	58	104
		VIII	138	311	510
		I	0.4	0.2	—
		II	5	4	—
		$D_1 < 15$	0.4	9	—
	Upper	X	6	6	13
September	Lower	V	135	355	563
		VII	107	235	461
		$E_1 > 15$	355	178	307
		$E_2 > 15$	115	101	174
		I	10	12	—
		II	1	81	—
		$E_2 < 15$	14	46	—
	Upper	$E_1 > 15$	6	15	20
October	Lower	III	120	188	298
		IV	131	36	59
		VI	147	192	315
		VIII	140	95	144
		$F_1 < 15$	44	12	—
Mean			66	97	158

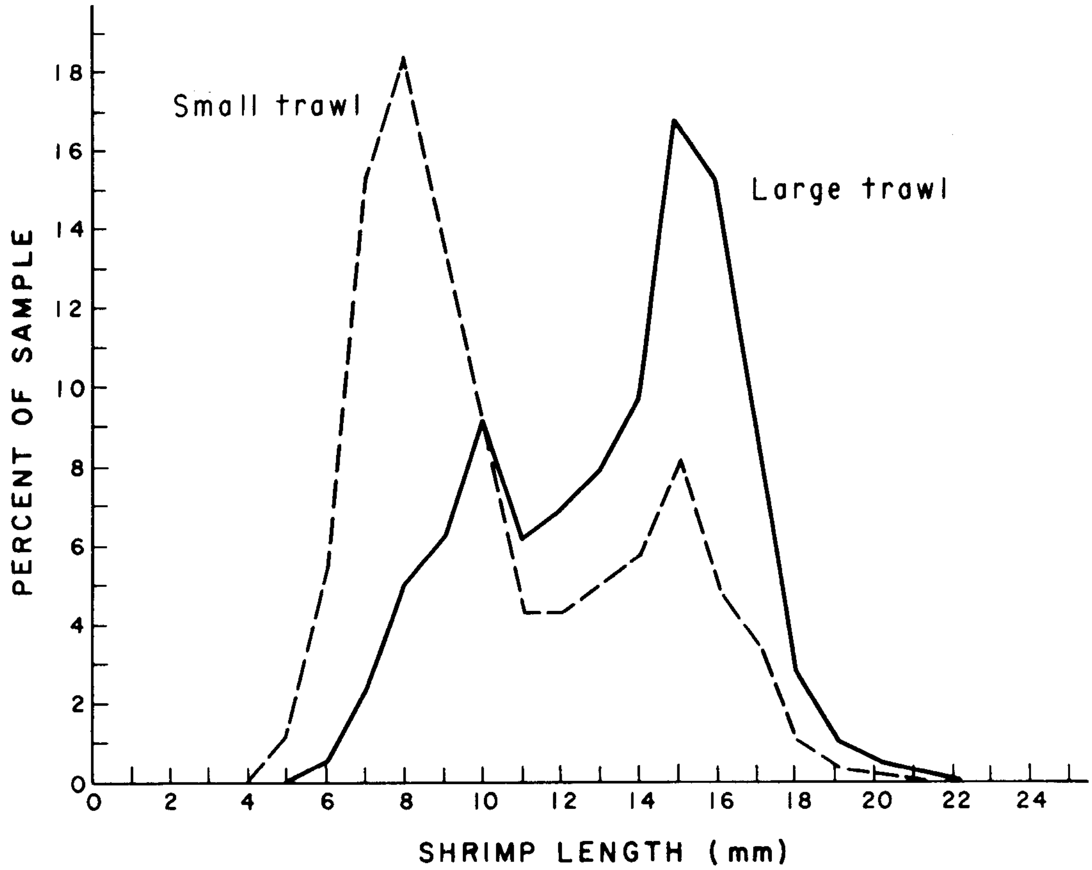


Figure 8.—Length frequency distributions of replicated *Mysis* samples for the large and small trawls.

nearly mirror reflections of each other, suggesting that the two trawls were sampling different *Mysis* populations (fig. 8). The peaks observed at 8 and 10 mm represent young-of-the-year shrimp, and the peaks observed at 15 mm represent yearling and adult shrimp. The curve from the large trawl data demonstrates a sample population dominated by yearling and adult shrimp, and reflects the escapement of the smaller-size shrimp through the mesh of the large trawl. The small trawl mesh size eliminated this possibility, and the curve shows a sample population dominated by young-of-the-year or juvenile shrimp. The other possibility indicated by figure 8 is a greater escapement of large shrimp from the small trawl relative to the large trawl, which might be a possible condition resulting from the different mouth dimensions of the two trawls. However, the relative difference in this avoidance between the two trawls is uncertain.

Photographic/Trawl Comparisons

An evaluation of the sampling efficiency of the small trawl was made by Bergersen and Maiolie (1981) [7] using the results of photographic sampling conducted simultaneously with the net trawl. Their analyses of the photograph samples indicated that the speed of the trawl had a major effect on sample results, and that a large sampling bias may exist in a portion of the 1977 and 1979 data. The bias was caused by the use of a floating towrope, which caused the small benthic sled-type trawl to lift off the lake bottom during the first part of the sampling tow. From eight samples taken in the lower lake in a limited area (sta. VIII), the trawl was off the lake bottom 0 percent of the time at 0.48 m/s, 24 percent of the time at 0.57 m/s, and 57 percent at 0.70 m/s (Bergersen and Maiolie, 1981 [7]). Errors in the computed distance the trawl moved on the bottom because of lift-off may apply to many of the estimates for the deep stations in 1977 and 1979, resulting in underestimation of *Mysis* densities. The June samples in both years and all the 1978 samples were collected using steel cable as a towline, and the sled is presumed to have remained on the lake bottom. Bergersen and Maiolie (1981) [7] indicate that the small trawl remained on the lake bottom when using steel cable until speeds exceeded 1 m/s. The off-bottom sampling bias probably did not occur in the shallow-station samples. Despite the correlation between lift-off and speed, no significant correlations between estimated *Mysis* densities and speed were found for either deep- or shallow-station categories in any year. The lack of correlation resulted from the station-to-station variability in shrimp abundance at a given speed within a depth category. Using the above relationship between speed and off-bottom sampling time, corrections were made in the *Mysis* density estimate for each deep-station sample for July through November in 1977 and 1979 using their respective trawl speeds (tables 2 and 3). No corrections were made in the June 1977 and 1979 samples nor in any 1978 samples. Based on these corrections, seasonal estimates of *Mysis* density for 1977 and 1979 (table 4) may have been underestimated by 24 and 59 percent, respectively, for the lower lake and 22 and 77 percent, respectively, for the upper lake.

This sampling bias may have also affected the comparison of the large and small trawls. Making corrections in the same manner for the small trawl density estimates used in the replicated samples (table 5), the corrected small trawl mean density of 158 shrimp/m^2 was significantly greater than the large trawl mean density estimate of 66 shrimp/m^2 ($P < 0.05$).

Assuming this comparison is the real difference in the sampling efficiency between the two trawls, it may also account for the apparent differences in the respective shrimp length frequency distributions. Modifying the large trawl curve in figure 8 to adjust for the large trawl's lesser sampling efficiency relative to the small trawl (large trawl = 0.42 small trawl), the large trawl curve falls within the small trawl curve (fig. 9). The 15-mm peaks for the two trawls become approximately equal. This suggests that the conversion factor for the two trawls accounts for the juvenile segments of the *Mysis* population missed by the large trawl, and that the sampling efficiency of the two trawls for the larger shrimp is about the same. The percent difference between the length frequency peak corresponding to juvenile shrimp and the peak for yearling-adult shrimp for the small trawl curve in figure 8 is 44, which is very similar to the 42-percent difference between the mean density estimate for the large trawl and the small trawl estimate corrected for sampling bias (66 vs. 158 shrimp/m^2). This supports the conclusion that the large trawl was essentially missing the smaller, juvenile shrimp. This escapement of juvenile shrimp would be a function of the larger mesh used in the large trawl.

Adjustments for the off-bottom sampling bias of the small trawl were necessary to correct the shrimp density estimates generated by the small trawl, allowing for a more accurate comparison between the large and small trawl data. In addition to this bias was the evaluation of the sampling efficiency of the small trawl while the sled was on the lake bottom. Results from 12 phototrawl comparisons indicated that the small trawl collected only 42 percent of the shrimp observed in the photo samples during the times when the sled was actually on the lake bottom (Bergersen and Maiolie, 1981 [7]). The difference in their two mean estimates (174 vs. 73 shrimp/m^2) was highly significant ($P < 0.05$). A similar result was observed by Finnell (1977) [6] in which the large trawl collected only 38 percent of the shrimp observed in photographs taken by a stationary, single-photo mechanism.

Population Trends

An objective of the previous analyses was to permit the comparative evaluation of the 1974–75 shrimp density data of Finnell (1977) [6] with the 1977–79 data that was collected under the same sample design and method, but with dissimilar sampling devices. To evaluate trends in the relative abundance of the *Mysis* population over the 1974–75 and 1977–79 study periods, the use of correction factors were necessary to account for: (1) the relative sampling efficiencies between the large and small trawls, (2) the off-bottom sampling bias of the small trawl, and (3) the sampling efficiency of the small and large trawls relative to the estimates of *Mysis* densities on the lake bottom provided by the photo techniques. Figure 10 illustrates the effect of the various correction factors on the yearly estimates of *Mysis* density for both lakes for the 4 years in which complete data were collected. In all cases for both lakes, the relative trend in the seasonal estimates did not change. After correction for the sampling bias of the small trawl (line b to line c), the apparent increase in the abundance of *Mysis* in 1979 relative to 1977 became greater, and there was less difference between the 1975 and 1977 estimates in the lower lake. Assuming the sampling efficiencies of the photo techniques used by Finnell (1977) [6] and Bergersen and Maiolie (1981) [7] were similar, *Mysis* densities exhibited a much greater change (lines d and e) within the 5-year period than was indicated by the net trawl estimates, ranging from 88 to 348 shrimp/m^2 in the lower lake and 57 to 174 shrimp/m^2 in the upper lake.

The yearly trend in *Mysis* abundance in the lower lake exhibited an early decline in 1975, and suggests a steady increase in numbers of shrimp to the maximum abundance observed in 1979 (fig. 11). Monthly trends exhibit a characteristic increase in the relative abundance of *Mysis* over the summer months to an August or September peak, followed by declines in October through November. The only major deviation from this pattern, a dramatic decline in the numbers of shrimp sampled in September 1977, was the result of an apparent absence of *Mysis* at the deepest stations. This absence of shrimp was attributed to a hypolimnetic depletion of dissolved oxygen below the tolerance limit of the shrimp. Bureau of Reclamation personnel recorded bottom oxygen levels of 1.0 mg/L at station 2, which was bordered on either side by shrimp sampling stations IV and V.[2] Gregg

[2]Dr. James F. LaBounty, Research Biologist, Bureau of Reclamation, Denver, Colo., personal communication.

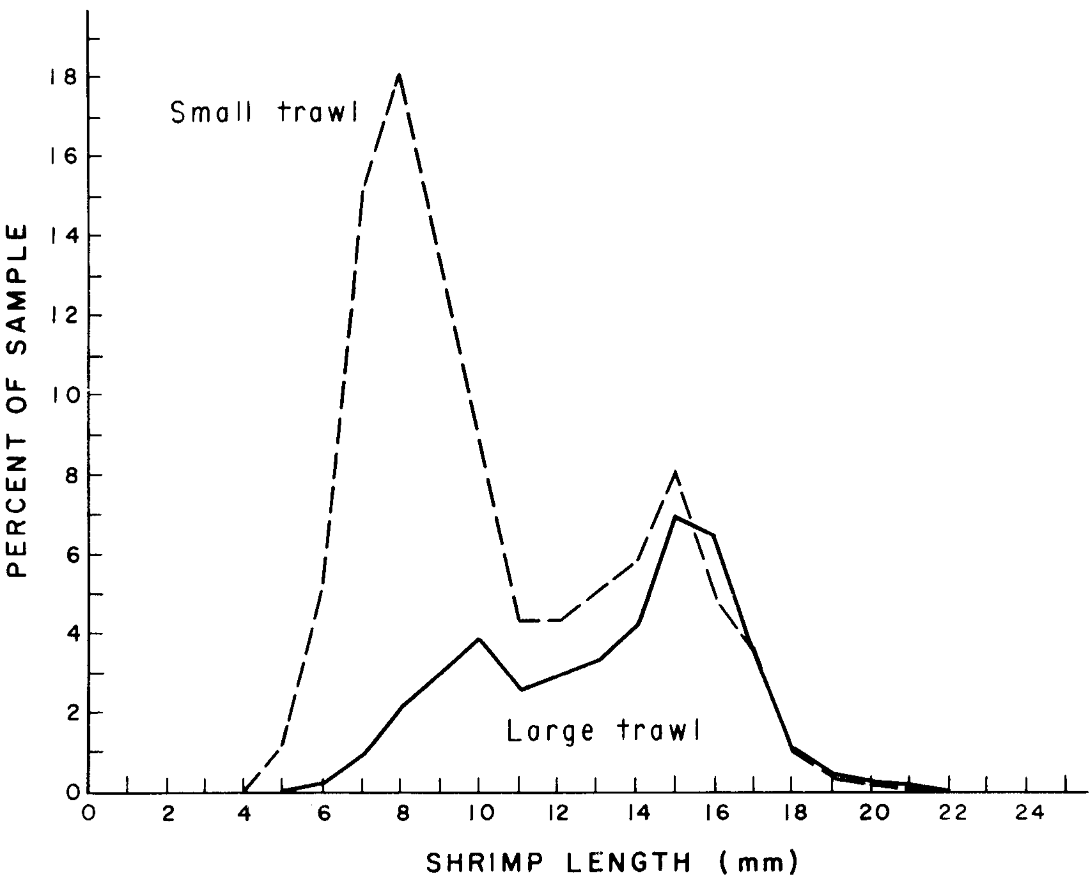
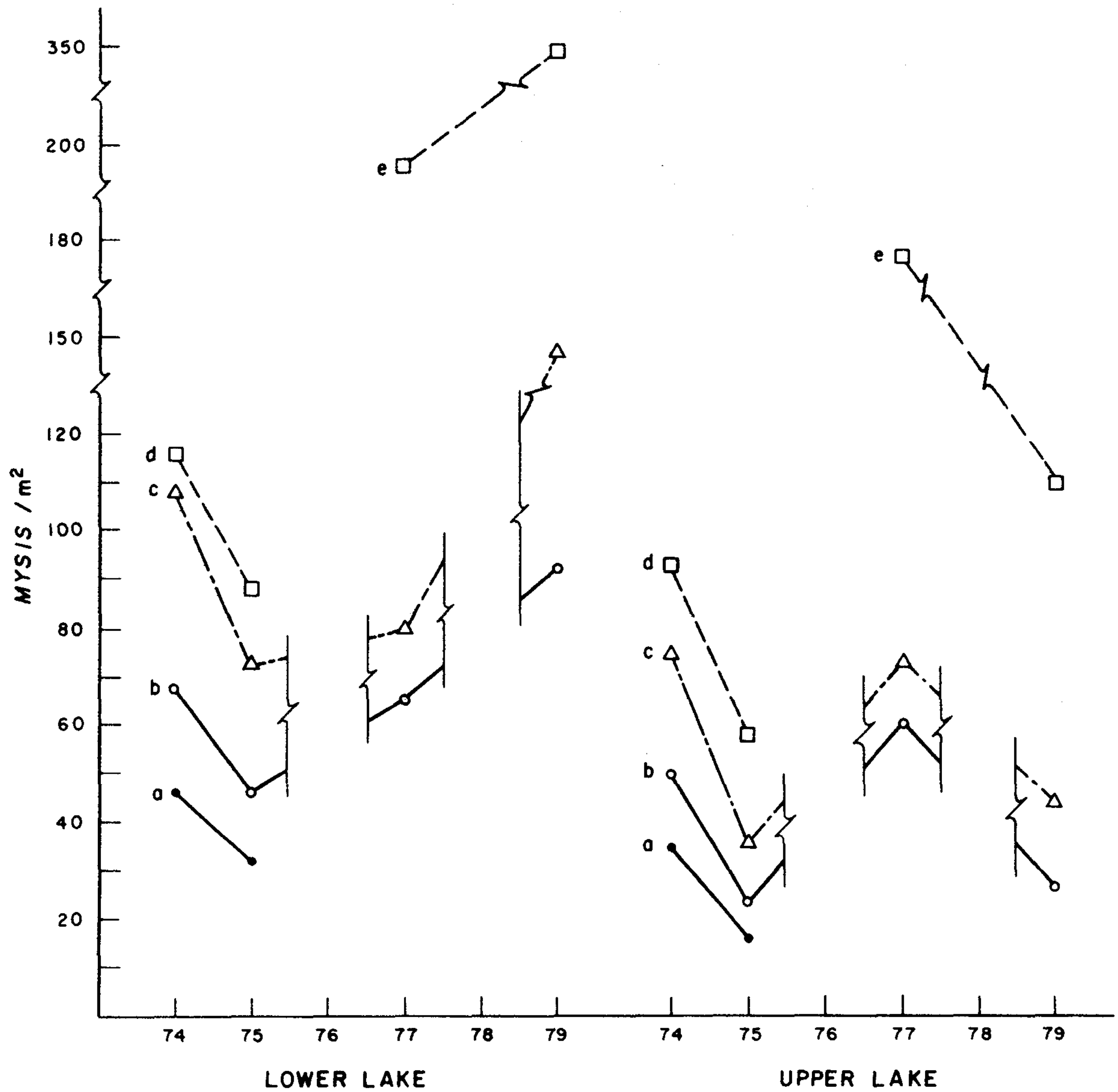


Figure 9.—Length frequency distributions of replicated *Mysis* samples for large and small trawls with the large trawl curve corrected for relative sampling efficiency.



a. large trawl samples,
b. small trawl samples with large/small conversion factor applied to 1974–75,
c. line b corrected for off-bottom sampling bias,
d. line a based on Finnell (1977) [6] photo conversion factor for large trawl capture efficiency, and
e. 1977 and 1979 estimates (line c) based on Bergersen and Maiolie (1981) [7] photo conversion factor for trawl capture efficiency.

Figure 10.—Seasonal estimates of *Mysis* density for Twin Lakes from 1974 to 1979 showing effects of correction for sampling bias and sampling efficiencies.

(1976) [8] and others have indicated 2 mg/L as the minimum oxygen concentration required by *Mysis*. The subsequent increase in *Mysis* density in October 1977 indicates that shrimp migration out of the adverse bottom area probably occurred in September rather than an increased mortality. Since the density estimates in the shallow station samples for September did not show a concomitant increase, the *Mysis* were probably above the lake bottom in the water column where dissolved oxygen concentrations achieved satisfactory levels.

The seasonal and monthly trends in *Mysis* abundance in the upper lake demonstrated a more varied pattern lacking the consistency of the lower lake (fig. 12). In all years except 1977, the seasonal mean density of shrimp in the upper lake is much less than the density estimated for the lower lake. Only in 1975 was the lower lake pattern of monthly increases in shrimp density observed in the upper lake. Notable declines in *Mysis* density occurred in July, August, September, or October of most other years. Similar to the situation occurring in September 1977 in the lower lake, subsequent increases in *Mysis* density following these declines indicate shrimp had temporarily migrated out of the sampling zone.

DISCUSSION

The sampling bias discovered in the trawling technique used in 1977 and 1979 complicates answers to the question of how much of the variation observed in the density estimates was a result of changes in the natural abundance and distribution of *Mysis* over time and space. In spite of this bias, it is apparent that *Mysis* were more abundant in both years in the deep basin versus the shallow zone of the lower lake during the midsummer to fall period. The differences in general abundance of *Mysis* in 1979 versus 1977 in the lower lake was the result of changes in shrimp density in the deep basin. The general abundance of *Mysis* in the lower lake was greater than that in the upper lake in 1979 as a result of the significant increase in shrimp numbers in the lower lake and the significant decrease in shrimp numbers in the upper lake between 1977 and 1979. The greater variation in the monthly and yearly estimates in the lower lake shallow zone and the upper lake suggest a more uneven distribution of *Mysis* in these areas versus the lower lake-deep basin.

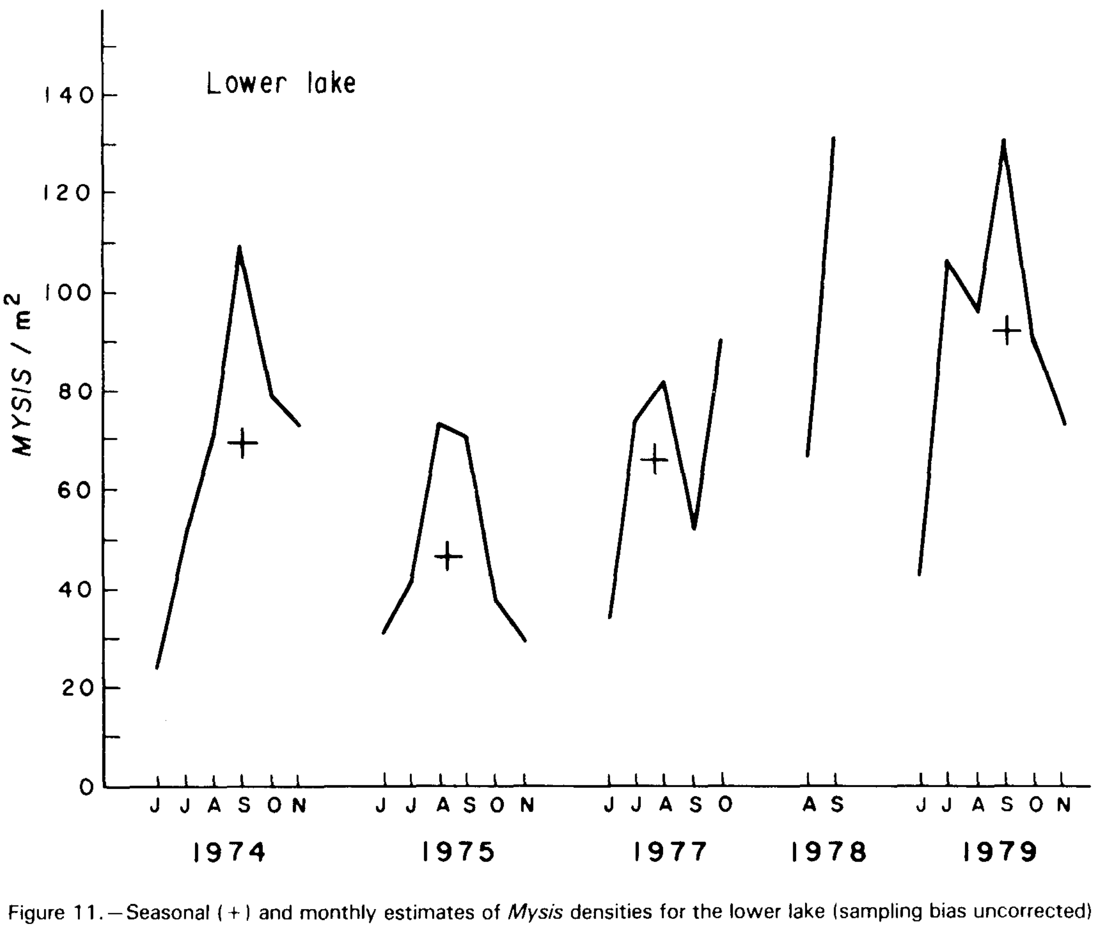


Figure 11.—Seasonal (+) and monthly estimates of *Mysis* densities for the lower lake (sampling bias uncorrected).

It is important to note again that the statistical tests were performed on the data without correcting for the sampling bias. Most of the significant differences between *Mysis* densities in table 4 were the result of relative increases in the estimates for the deepwater stations in 1979 versus 1977. It is at these stations in 1979 where the greatest source of error caused by sampling speed and the greatest underestimation of densities would have occurred relative to the 1977 estimates. So the changes indicated in the relative abundance of *Mysis* in the lower lake between the two years, therefore, appear to be real. The decrease in *Mysis* abundance in the upper lake from 1977 to 1979 may be a sampling artifact, since the depths sampled in the upper lake were greater by up to 6 m than the depth at which the lift-off/speed relationship was established. Trawl lift-off in the upper lake in 1979 may have been greater than indicated by the results because of a greater mean speed in 1979 versus 1977.

The conversion factor between estimates generated by the large and small trawls is subject to limitations imposed by the small trawl sampling bias, size-selective capture efficiencies, and natural variation in *Mysis* distribution. A lift-off sampling bias for the large trawl samples was considered negligible due to the much greater weight of the large trawl. Adjustments to the conversion over time on the basis of the reproductive state of the *Mysis* population were not considered necessary since figure 10 indicates the segment missed by the large trawl includes shrimp less than 11 mm in length. *Mysis* length frequency and growth data from Gregg (1976) [8] indicate the bulk of the juvenile

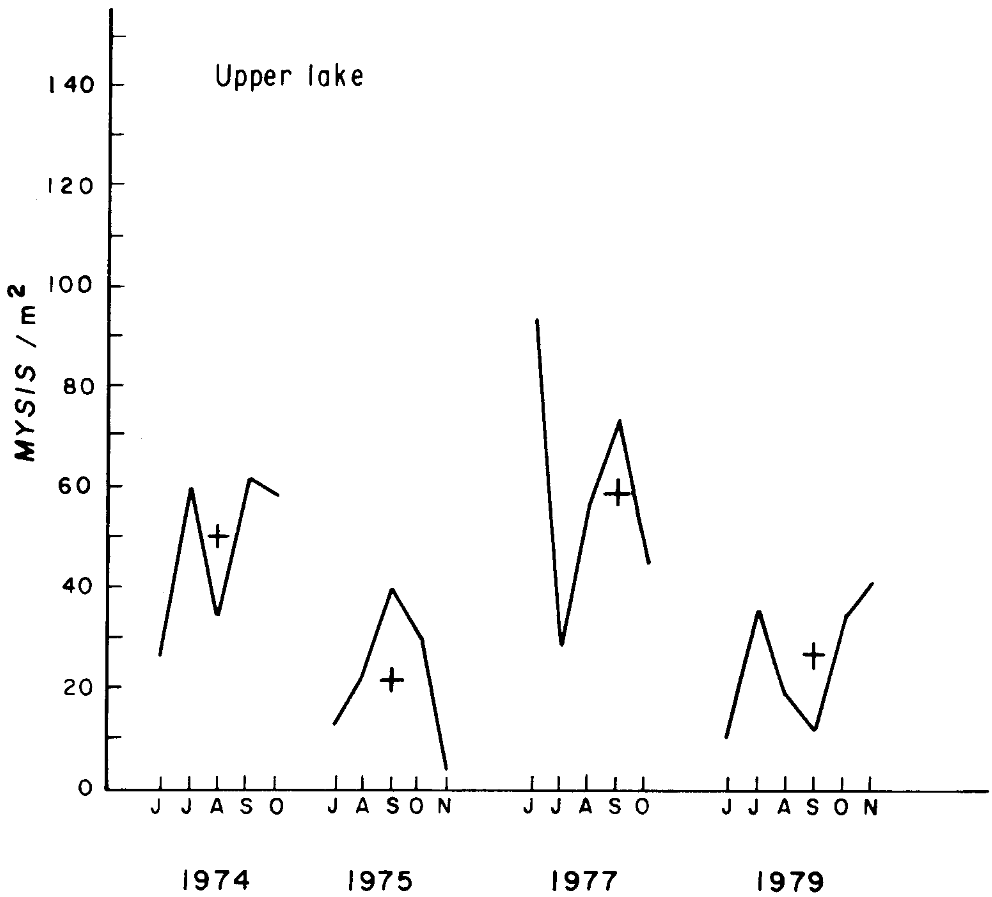


Figure 12.—Seasonal (+) and monthly estimates of *Mysis* densities for the upper lake (sampling bias uncorrected).

Mysis are present in the population by June, and are just reaching 11 mm by November. The natural variation in *Mysis* distribution was determined to be clumped by Gregg (1976) [8], with the clumping occurring in small areas. Eleven out of 28 of the large trawl estimates of *Mysis* density were greater than or equal to the corresponding small trawl estimate using the biased small trawl data, and 7 out of 28 were greater than or equal to the corrected small trawl estimates (table 5). This result could be explained by either a clumped or random distribution of *Mysis*. In a homogenous distribution of shrimp, the small trawl would always be expected to estimate a greater density than the large trawl due to the size-selective escapement associated with the large trawl.

It is difficult to determine to what extent the correction factor for off-bottom sampling bias should be applied to the shrimp density estimates for 1977 and 1979. This factor was based on a minimal sample size, and sampling was limited to depths greater than 18 m in a limited area on the west side of the lower lake. Additionally, two samples taken in the upper lake at 25 m never did sample the lake bottom. The use of an indirect quantitative method for determining bottom distance sampled and the possible capture of shrimp by the trawl during off-bottom sampling, lowering, and retrieval presents an unknown margin of error in the estimates per sampling station. The corrected yearly *Mysis* density estimates may, therefore, be conservative.

The yearly and monthly trends exhibited can be correlated to concurrent changes in other components of the limnology of Twin Lakes. The yearly relative abundance of *Mysis* closely parallels the relative abundance of zooplankton (*Keratella, Kellicottia, Diaptomus, Cyclops*) observed over the same years in the lower lake (LaBounty et al., 1980 [9], LaBounty and Roline, 1980 [10]). Finnell (1977) [6] attributed the monthly dynamics of *Mysis* numbers in the lower lake in 1974–75 to: (1) increasing capture efficiency of the large trawl as the smaller shrimp increased in length, accounting for the summer increase, and (2) the die-off of male shrimp following their reproductive effort, accounting for the fall decline. While these explanations may be true to some extent for the large trawl, increased capture efficiency of the small trawl was not an applicable explanation for the similar monthly pattern in the 1977–79 data. The die-off of reproductive males in the fall months undoubtedly contributed to a decline in the abundance of *Mysis*, but Gregg (1976) [8] demonstrated a shoreward migration of *Mysis* into the shallow zone of the lake during the fall months by using a comparison of shallow-station trawl data for summer versus fall months. This horizontal migration may be more dramatic than is evident since the sampling technique was totally ineffective for sampling *Mysis* in zones of submerged aquatic vegetation. *Mysis* densities in the shallow zones of aquatic vegetation may be greater than indicated by the trawl samples taken in the open shallow areas. This is supported by SCUBA diver reports (Gregg, 1976 [8]), in which 500 to 1000 *Mysis*/m² were observed in clumps of *Potamogeton* sp. Horizontal migration appears to be a likely explanation for the pattern of monthly *Mysis* density estimates observed at Twin Lakes. In the fall, *Mysis* migrate shoreward, and in the spring and summer they reverse direction, migrating into deeper water. Similar patterns of horizontal migration have been found for *Mysis relicta* by Reynolds and DeGraeve (1972) [11] and Morgan *et al.* (1979) [12]. The concentration of *Mysis* on the bottom of the lower lake in September appears to be an anomaly, since bottom oxygen levels are characteristically least desirable at this time. This concentration may be a feature of the thermal stratification and heating of the epilimnion as suggested by Morgan et al. (1978) [12] or a behavioral trait preceding the reproductive season of the shrimp as suggested by Reynolds and DeGraeve (1972) [11].

Vertical distribution of *Mysis* in the water column as a function of thermal stratification may also have an effect upon the monthly pattern observed. Gregg (1976) [8] has shown that the diurnal migration of *Mysis* in Twin Lakes occurred for a progressively shorter duration through the summer months, and that most of the shrimp remained on the bottom during September. It may be possible that a portion of the *Mysis* population remains suspended in the hypolimnion in a zone above the trawl, with an increasing number of these shrimp returning to the lake bottom as the summer progresses. Sartoris et al. (1977) [1] indicates that an increasing thermal stratification through the summer to a late August or early September maximum is characteristic of the lower lake.

The lesser seasonal abundance of *Mysis* in the upper lake versus the lower lake corresponds to the lower zooplankton standing crop, the lower overall productivity, and the flushing rate in the upper lake relative to the lower lake. Seasonal differences in *Mysis* abundance in the upper lake over the 4 years sampled appear to be affected by the flushing rate of the upper lake, which is normally greatest in the spring and also affects standing crops of plankton. LaBounty et al. (1980) [9] indicated the flushing rate in the upper lake was greatest in 1975 and 1979 relative to 1974 and 1977, and correlated very low plankton abundance in the upper lake to the high flushing rate. They determined a flushing rate of 7 days for the upper lake in 1979 when inflows reached 68 m^3/s in mid-June. A reduced springtime plankton production affecting the growth and survival of *Mysis* in the upper lake and potential flushing of the shrimp into the lower lake appear to be probable factors controlling shrimp abundance in the upper lake.

The upper lake has also demonstrated a tendency toward winter stagnation, resulting in anoxia at the lake bottom and release of heavy metals (Sartoris et al., 1977 [1]). This condition occurred in 1974–75, and was suspected of affecting the lake's biota. The authors suspected direct toxicity and removal of algal nutrients from the water column via precipitation of metals during spring turnover as causative mechanisms. This would contribute to lower *Mysis* abundance in 1975, since the shrimp were probably affected by not only direct toxicity, but also a reduction in food availability.

The inconsistent monthly pattern of shrimp abundance in the upper lake may be attributed to a combination of the lower and more variable production of food sources within the lake and a small sample size. The variable feeding habits of *Mysis*, and their capability for adaptive omnivory have been documented by Lasenby and Langford (1973) [13], and Cooper and Goldman (1980) [14]. Since only three samples were taken in the upper lake per month, and all three were generally located in the deepest part of the basin, it is possible the shrimp were missed by this limited effort due to their concentration in areas of the lake with the greatest food availability.

In summary, the trawl sampling method provided estimates of *Mysis* density that demonstrated relative differences over depth, time, and limnology, but problems concerning sampling bias and different trawl capture efficiencies make the estimates corrected for underestimation only indirect approximations of *Mysis* abundance. The relative differences in the seasonal mean estimates correlate well with differences in lake productivity and zooplankton abundance. Monthly differences in *Mysis* densities were influenced by the shrimp's migratory behavior relative to the sampling limitations of the benthic sled-type trawl, and by specific limnological conditions predominating Twin Lakes in certain years.

Potential Impacts of Mt. Elbert Pumped-Storage Powerplant Upon *Mysis*

The usefulness of these estimates in determining the impacts from the operation of the Mt. Elbert pumped-storage powerplant upon the *Mysis* population depends on the magnitude of the impact. It is fairly certain that the density estimates in lines a, b, and c in figure 10 are all underestimated. Therefore, reduction in the relative abundance of the shrimp below this range of estimates after daily powerplant operation begins, strongly suggests that an increased shrimp mortality has occurred. The reduction in shrimp numbers would have to persist for several years, or at least vary within a lower range of estimates, due to the variability exhibited in the 1974 to 1979 estimates.

A declining trend in *Mysis* abundance over a number of years following the initiation of regular powerplant operation would also provide evidence of an increased mortality of shrimp, regardless of the accuracy of the preoperational estimates.

Conversely, increases in *Mysis* abundance are possible as a result of possible increases in the productivity and zooplankton standing crop of the lakes. Water storage behind the new Twin Lakes Dam will increase the surface area by approximately 28 percent (Fryingpan-Arkansas Project, 1975 [15]). Much of the area inundated will result in relatively shallow-water areas, increasing the relative proportion of the shallow zone of Twin Lakes. The importance of the shallow zone to the productivity of a lake is detailed in Wetzel (1975) [16]. Bergersen and Maiolie (1981) [7] estimated the inundation of the new lake bottom will contribute approximately 4000 metric tons wet mass of organic matter to the lake. The combination of an increased productivity potential from the shallow lake area and an increased nutrient input could stimulate primary production and an increased energy flow through the zooplankton and *Mysis*. However, these conditions would also increase the potential for oxygen depletion in the hypolimnion of the lakes, resulting in possible winterkill. Water-level fluctuation could also negate much of the productive potential in the shallow zone.

The continual import of Cladocera via Turquoise Lake and the Mt. Elbert Forebay (Nesler, 1981 [17]) may also contribute to an increased abundance of *Mysis*, since these zooplankters are a preferred food item of the shrimp (Cooper and Goldman, 1980 [14]).

The combination of these conflicting influences upon Twin Lake's *Mysis* population will make the evaluation of pumped-storage power generation impacts upon the shrimp a complicated task. Detailed studies of the various aspects of the shrimp's life history will be necessary to separate the effects of these conflicting influences, and to determine the relative magnitude of their contribution to changes in shrimp abundance.

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Note: From November 1979 to May 1981, the Bureau of Reclamation was known as the Water and Power Resources Service; consider the names synonymous in this Bibliography.

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