PELAGIC NEAR-SHORE ABUNDANCE OF INVERTEBRATES IN LAKE MICHIGAN COMPARED TO ENTRAINMENT AT THE LUDINGTON PUMPED STORAGE POWER PLANT

By

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ABSTRACT

PELAGIC NEAR-SHORE ABUNDANCE OF INVERTEBRATES IN LAKE MICHIGAN COMPARED TO ENTRAINMENT AT THE LUDINGTON PUMPED STORAGE POWER PLANT

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Estimates of day/night distribution, abundance, and survivorship of macroinvertebrate drift organisms cycled through a pumped storage power plant were made in 1979. Bi-weekly sampling with 351μ meter nets yielded estimates of organism abundance in adjacent Lake Michigan and at the plant site. Lake collections were dominated by *Mysis relicta*, four chironomid subfamilies, three species of amphipods and naidid oligochaetes. These groups were also collected at the plant though order of abundance was not identical. Densities were highest in night collections. *Mysis* densities peaked lakeward of the 6m contour. Highest total chironomid densities occurred shoreward of the 6m contour. Amphipod density increases were associated mainly with release of juveniles in mid-summer. Roughly 3% of entrained mysid were returned to Lake Michigan with values of 104, 55, and 20% recorded for chironomids, *Gammarus* sp. and *Pontoporeia* sp. Loss estimates were principally affected by low release rates.

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INTRODUCTION

The littoral area of Lake Michigan has been documented to be used as both a spawning site and nursery area by most fish species (Liston et al. 1980, Brazo and Liston 1979, Jude 1977) and as an area of high invertebrate production (Mozely and Garcia 1972, Robertson and Alley 1966). The literature describing macroinvertebrate fauna deals almost exclusively with depths greater than 10m. Quantitative treatment of macroinvertebrates inshore of the 10m contour is nearly nonexistent. The littoral zone of lakes occupies the interface between the terrestrial and aquatic ecosystems. Allochthonous organic inputs coupled with autochthonous production produce a diverse and dynamic community of organisms. The role of the littoral biota is significant in this respect, since organisms remove and concentrate nutrient inputs from both the terrestrial and aquatic environments as biomass. Anthropogenic activities may have a significant impact on this portion of the aquatic ecosystem via point and non-point source perturbations. Operational effects of hydroelectric power generating facilities singly, or in combination, may have a significant adverse effect on organisms using the littoral zone for either a portion or all of their developmental sequence. Macroinvertebrates provide a large portion of the forage base for fish species in eastern Lake Michigan such as yellow perch, lake whitefish, round whitefish, burbot, ninespine stickleback, trout-perch, sculpins, adult bloaters and immature salmonids (Yanusz 1979; Ligman 1978; Mikus 1978; Armstrong et al. 1977; Hauer 1975; Brazo 1973).

Impact assessment of operational effects of electric power generating facilities on macroinvertebrate populations has recently received increased attention. Environmental studies conducted at both nuclear and fossil fuel generating stations have indicated mortalities of less than 100% for organisms entrained in condenser cooling water (Cannon et al. 1977; Ginn et al. 1977; Carter 1977; Nalco 1976). Pilot studies conducted at the Ludington Pumped Storage Power Plant in 1978 indicated that mortalities incurred by macroinvertebrates entrained in the source water were below 100% (Liston et al. 1980). High survivorship was expected since water cycled through the power plant is not used for cooling purposes, nor are biocides added to the flowing water. However, turbine passage does subject organisms to increased turbulence, rapid hydrostatic pressure changes, and mechanical abrasion through contact with internal metal surfaces. Macroinvertebrate mortality evidenced is a response to the singular or combined effects of these stresses. These potential stresses coupled with the huge volumes of water (maximum of $341 m^3/s$ pumping; maximum of $358 m^3/s$ generating, per unit) cycled between the upper reservoir and Lake Michigan further underline the importance of determining survivorship for organisms passed through the turbines.

This investigation was directed towards assessment of the effects of plant operation on drifting macroinvertebrates in Lake Michigan near the Ludington Plant. The following aspects were studied:

1. Species composition and relative abundance
2. Spatial and temporal distribution of macroinvertebrates

3. Entrainment into and release of macroinvertebrates from the upper reservoir

4. Survivorship associated with turbine passage

The composition and abundance of that portion of the macrobenthic community migrating into the water column was studied by five general approaches: (1) Day-night distribution of macroinvertebrates in the water column at various depths in Lake Michigan surrounding the power plant (farfield area), (2) Macroinvertebrate withdrawal from Lake Michigan in the intake canal (entrainment), (3) Macroinvertebrates held in the reservoir, (4) Release rates of macroinvertebrates from the reservoir (extrainment), and (5) Mortalities associated with turbine passage.

Major emphasis has been placed on amphipods, mysids and chironomids due to their importance as fish forage organisms.

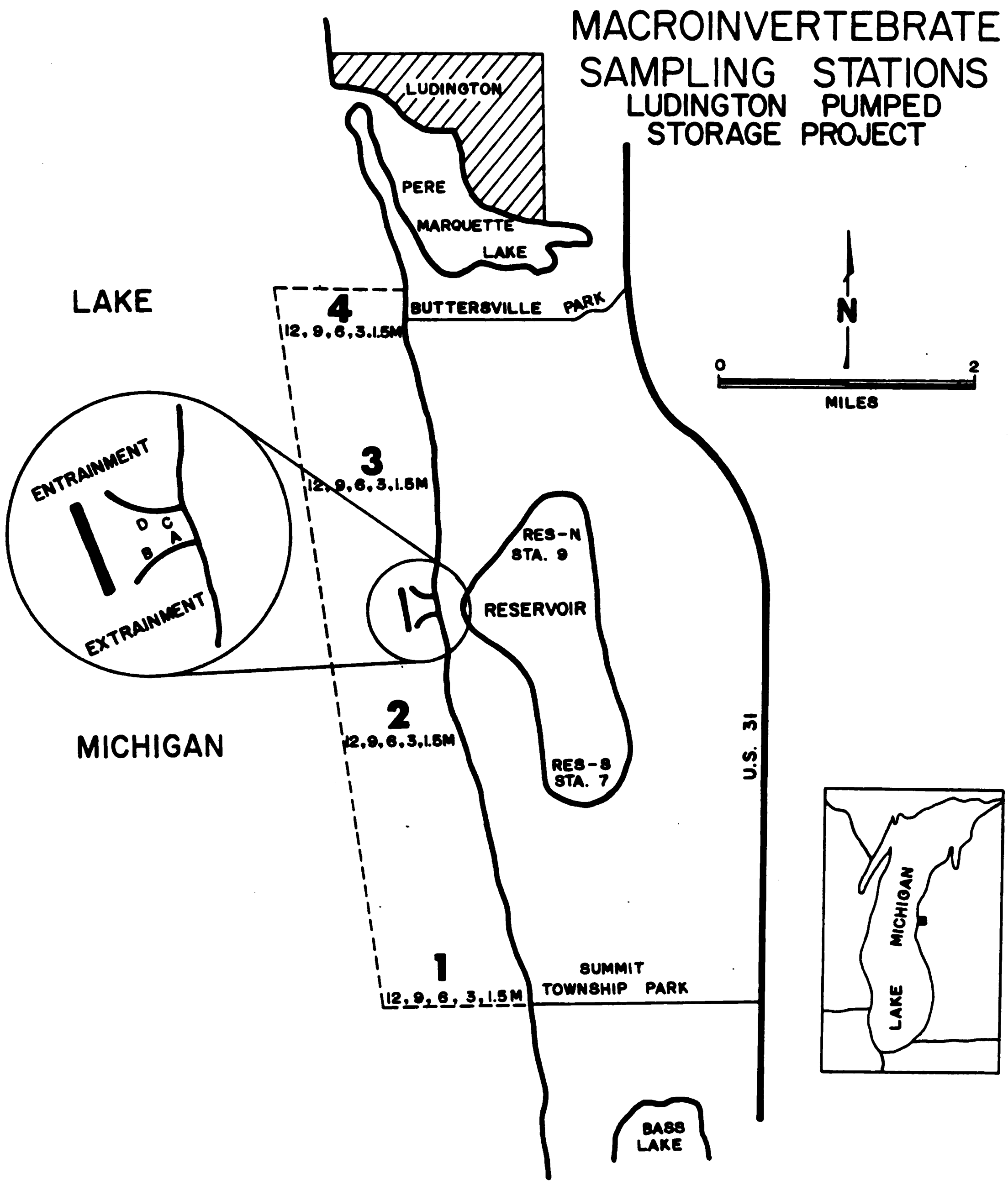
DESCRIPTION OF SITE

The Ludington Pumped Storage Facility is located approximately four miles (6.4km) southeast of Ludington, Michigan, on the eastern shore of Lake Michigan. The plant site consists of an excavated reservoir above the power house 2.5 miles (4.02km) long, .75 miles (1.21km) wide and 6 miles (9.7km) in circumference (Figure 1). The reservoir bottom is composed of 5 feet (1.5m) of compacted clay, except for a limestone scour pad 1,200 (366m) x 800 feet (244m) directly in front of the upper intake structure. Approximately 18 billion gallons ($8.04 \times 10^7 m^3$) of the 27 billion gallon ($1.02 \times 10^8 m^3$) total volume are available for daily power generation. Maximum reservoir water depths range from 97 feet (29.6m) in the south to 112 feet (34.1m) in the north end.

Protective appurtenances surrounding the power house consist of two jetties 1,600 feet (490m) long and a 1,850 foot (565m) breakwall built parallel to the shore. The breakwall, constructed of large limestone boulders, rises 10 feet (3m) above Lake Michigan and is positioned about 2,700 feet (825m) west of the power house and 1,300 feet (396m) from the jetties. The jetties, identical in construction to the breakwall, are separated by a 1,100 foot (335m) channel, dredged to a minimum depth of 28.5 feet (8.7m).

The draft tubes (2 per turbine) for the six Francis-type reversible pump-turbines, each revolving at 112 rpm, open to Lake Michigan 38 feet

Figure 1. Macroinvertebrate sampling stations, Ludington Pumped Storage Project.


MACROINVERTEBRATE
SAMPLING STATIONS
LUDINGTON PUMPED
STORAGE PROJECT
LUDINGTON
PERE
MARQUETTE
LAKE
LAKE
MICHIGAN
4
12, 9, 6, 3, 1.5M
BUTTERSVILLE PARK
3
12, 9, 6, 3, 1.5M
ENTRAINMENT
D C
B A
EXTRAINMENT
RES-N
STA. 9
RESERVOIR
2
12, 9, 6, 3, 1.5M
RES-S
STA. 7
U.S. 31
N
0
2
MILES
1
12, 9, 6, 3, 1.5M
SUMMIT
TOWNSHIP PARK
BASS
LAKE
MICHIGAN
LAKE

(11.6m) below the surface and extend to the dredged bottom at the 70 foot (21.4m) depth. No screens other than coarse trash racks are present. Six penstocks 1,300 feet (396m) long, increasing in diameter from 24 feet (7.3m) to 28.5 feet (8.7m), serve to transfer water from the turbines to the upper reservoir. Maximum velocity in the penstock is 28f/s (8.5m/s) during generation and 24.6f/s (7.5m/s) during pumping.

Data taken in 1972 - 1974 indicate that the only physical-chemical parameters modified by plant activity are turbidity and transparency. Water temperature, pH, dissolved oxygen, alkalinity, and dissolved solids are unmodified by plant operation (Liston et al. 1976). Physical-chemical parameters indicate the oligotrophic conditions of Lake Michigan near the plant site. Reported values are: pH, 7.8 - 8.5; dissolved oxygen, 9.1 - 14.0 ppm; alkalinity, 104 - 136 ppm; dissolved solids, 170 - 190 ppm; water transparency measured by secchi disc, 0.8 - 7.2m; and turbidity 0.3 - 8.70 NTU (Liston et al. 1976). Seasonally, water temperature in the near-shore area varies from 4 - 23C with temperature variations of 10 - 15 degrees within 24 hours associated with upwellings. Patterns of temperature variation are caused mainly by offshore winds.

METHODS

Macroinvertebrates were taken from tows made to capture pelagic fish larvae. All samples exclusive of mortality were taken with General Oceanics 1.0m conical plankton nets of 350μ Nitex[R] mesh. General Oceanics (Model number 2030) flowmeters equipped with low speed rotors were mounted 1/3 off-center to minimize turbulence vortices created by the tow bridles (Tranter and Smith 1968). Four kilogram brass depressors were attached to the tow bridle eye to plane the nets. A one liter, 350μ mesh windowed, collection bucket was affixed to the net end.

The sampling year was apportioned into three periods found to generally coincide with climatic changes in the study area: spring, 1 April - 1 June; summer, 2 June - 31 August; fall, 1 September - 1 November.

All entrainment, extrainment, farfield and reservoir meter net collections were preserved in the field in a solution of 10% formalin to be picked in the laboratory. All samples were picked in both black and white benthos pans. Complete removal of organisms was ensured by use of lighted magnifiers (10x). After organism removal, samples were concentrated in 121ml bottles and retained in 75% isopropyl. Approximately ten percent of these retained samples were picked a second time to gauge picking efficiency.

In the laboratory specimens were identified, sexed, counted, straightened and measured to the nearest millimeter. A random sample of a maximum of twenty individuals for a specific taxon was drawn from each field collection for analysis, with each size frequency class represented in proportion to its dominance. Mysids were measured from the tip of the rostrum to the tip of the telson. Males and females smaller than 7mm were indistinguishable. Amphipods were measured from the base of antennae 1 to the tip of the uropods. Lengths for aquatic insects were taken by measuring from the most distal portion of the head capsule (excluding antennae) to the tip of the abdomen.

Macroinvertebrates were identified with the aid of an Olympus variable power binocular microscope using either 10 or 20x oculars. Pontoporeia, Mysis and Oligochaeta were identified using keys presented in Pennak (1978). Gammarid amphipods were identified to species following Holsinger (1976). Aquatic insect identification followed Merritt and Cummins (1978) and Hilsenoff (1975). Identified invertebrates were preserved in a solution of 75% ethanol with glycerin and retained.

Farfield

Farfield sampling to determine organism abundance and species composition in Lake Michigan was accomplished by biweekly sampling at four stations (Figure 1).

Stations 1 and 4 were located approximately 4.8km south and north of the plant breakwall. Stations 2 and 3 were .8km south and north of the breakwall. Substrate type at each of the sample stations was analyzed on 30 June by making random casts with a ponar grab on a transect at stations 1 - 4 extending outward from shore to the 40 foot (12.2m) contour, coupled with scuba observations at stations 1 and 2. Substrate type was described in order of decreasing percentage dominance. Station

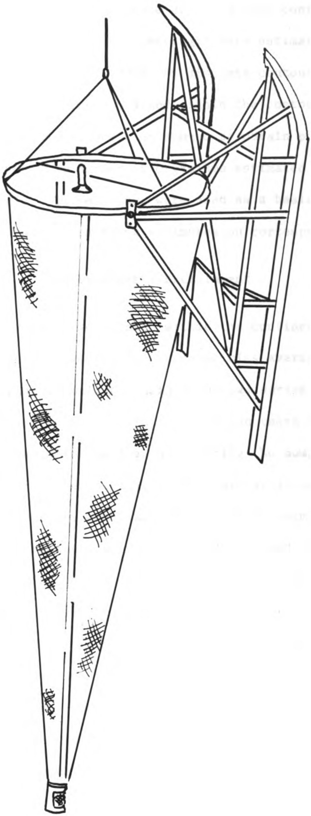
1 displayed a gravel swash step near shore followed by a band of coarse sand interspersed with gravel or cobble-sized stones extending lakeward to approximately the 10 foot (3.0m) contour. Substrate type shifted to fine sand with some gravel roughly extending to the 35 foot (10.7m) contour. Hardpan clay outcroppings with some fine sand patches were encountered lakeward of the 35 foot (10.7m) contour. Station 2 was found to be composed of coarse sand with patches of cobble to a depth of 10 feet (3.0m), followed by fine sand with some large rock beds extending to 20 feet (6.1m). Hard clay overlain with a thin layer of detritus interspersed with rock beds was encountered to 40 feet (12.2m). Station 3 substrate was composed of coarse sand and fine gravel from shore out to 15 feet (4.6m). Fine sand with scattered large boulders dominated to 30 feet (9.1m), with hard clay and sand patches encountered thereafter. Station 4 evidenced coarse sand with some fine gravel near shore, extending to the 30 foot (9.1m) contour. Hard clay outcroppings overlain with sand patches were encountered out to 40 feet (12.2m). However, the nearshore zone is a highly dynamic environment, with major substrate alterations associated with seasonal climatic variations. Bar formation and banding of sediments are a consequence of sediment sorting, which occurs primarily during summer. Fall and winter storms tend to scour the wavezone as does winter ice cover. In spring, after ice cover is removed, these coarse sediment zones and bars are much less distinct.

Day and night samples were taken consecutively beginning mid-April through October and consisted of five minute duplicate stepped oblique tows made at the 10 (3.0m), and 20 (6.1m), 30 (9.1m) and 40 foot (12.2m) contours for each series from the RV *Robert L.* Sampling commenced approximately 0930 - 1500h for day tows and between 2100 - 0130h for night tows with sampling station sequence randomized over the season. Two replicate 5-minute tows per station were made at the five foot contour using an aluminum sled mounted meter net that allowed maximum clearance of 11 inches when towed over the bottom (Figure 2). All nets were washed-down by bucket or pump. Boat speeds for all farfield tows varied as a function of ambient wind and current direction but normally approached 1 knot.

A finite area was delineated in Lake Michigan surrounding the power plant to provide a comparison with entrainment estimates. Macroinvertebrate estimates within the rectangle were based on night farfield organism densities since entrainment would only occur at night. This rectangle had a width from the shoreline lakeward to the 45 foot (13.8m) contour (approximately 2.4km) and extended three miles north and south (9.7km total) of the plant. The volume of water contained within this area was estimated to be 188,499,840m^3 which is approximately six times greater than the nightly average of water moved (approximately 35,000,000m^3) between Lake Michigan and the upper reservoir. Estimation of the volume contained within the rectangle was obtained using a navigation chart (number 14907) with soundings corrected to current lake elevations (1979), and a polar planimeter.

Contour tows made from the RV *Robert L.* were centered between contour intervals for calculation purposes. For example, tows made at the 10 foot (3.0m) contour were used to represent all water from the 5 foot (1.5m) to 15 foot (4.5m) contours; tows at the 20 foot (6.1m) contour represented all water from the 15 foot (4.5m) to the 25 foot (7.5m) contour. This technique was continued to the 45 foot (13.8m) contour. Macroinvertebrate densities from the shoreline to the 5 foot (1.5m)

Figure 2. Schematic drawing of the aluminum sled with attached plankton net used for sampling at the 1.5m contour.



contour were estimated from tows made at the 5 foot contour.

Numbers of organisms in the rectangle were estimated using combined station density estimates per $1000m^3$ at discrete contours and extrapolating to the total volume of water contained within the contour interval. These contour interval estimates were then summed to obtain point estimates for sample dates of the total number of organisms estimated to be contained within the rectangle. These values were used as a basis for comparison with macroinvertebrate entrainment estimates on corresponding dates.

Entrainment - Extrainment

Entrainment samples were taken within the confines of the power plant jetties in an area where current velocities averaged 1 knot (Figure 1). Sampling technique consisted of two series of four sequential stepped oblique tows, each of 5 minutes duration taken at 0200 and 0500h to compensate for variable pumping rates during the pumping mode. The biweekly sampling schedule was initiated in mid-April and continued through the end of October when fall storms forced termination.

Estimates of organisms pumped into and released from the upper reservoir were made in the following manner. The total number of organisms obtained for a taxon from the quadruplicate tow series was divided by the sum of the four volumes strained for that series, yielding a mean density for the time period sampled ($\#/m^3$). The volume of water passed through the plant for the sample period was calculated from reservoir elevation records provided by Consumers Power Company.

The invertebrate entrainment estimate in each time period was calculated by:

$$N_e = DV \qquad (1)$$

where N_e = estimated invertebrate entrainment in a time period

D = density of macroinvertebrates ($\#/m^3$)

V = volume of water passed through the plant (m^3)

The number of macroinvertebrates entrained or extrained during an operational mode was estimated by:

$$N_t = \sum_{t=1}^{m} N_{e,t} \qquad (2)$$

and by direct substitution from equation 1

$$N_t = \sum_{t=1}^{m} D_t V_t \qquad (3)$$

where N_t = total entrainment for the sample day

D_t = density of macroinvertebrates in the t^{th} time period

V_t = volume of water moved in the t^{th} time period

m = number of sample periods for the day

The total number of organisms entrained annually was estimated by:

$$N_{TE} = \sum_{t=1}^{P} \frac{N_t}{V_t} \left(\sum_{i=1}^{d} V_i\right) \qquad (4)$$

where N_{TE} = annual estimate of macroinvertebrates entrained

N_t = total number of macroinvertebrates entrained on a sample day from equation 3

V_t = total volume of water moved on a sample day

V_i = volume of water on the i^{th} day of the sample period

d = number of days in sample period

P = number of sample days in year

Use of this model necessitates the assumption that macroinvertebrate density and vulnerability to turbine passage are similar throughout the sample period to allow calculations. The ratio of the organisms entrained to the volume of water pumped was used as the midpoint for the interval between entrainment sample dates and was multiplied by the volume of water pumped on each date in the interval between sample periods. For example, the ratio of entrained organisms to volume of water pumped on 1 May was used to estimate entrainment for the period 15 April through 8 May. These products were summed to yield the estimate of organisms entrained during the sampling year.

Extrainment samples and estimates were made similarly on the generating mode during daylight and night to obtain data on organism release rates from the upper reservoir. Organism release rates during darkness were determined from limited tows made from 2100 - 2200h. Manpower constraints limited the number of dates sampled. Most samples were taken during 1000 - 1300h and 1500 - 1830h.

Reservoir

Reservoir sampling was initiated in an effort to obtain information on residence times and day-night distribution of organisms in the reservoir. Sampling consisted of two series of five minute duplicate stepped oblique tows made at two north-south stations in the reservoir on dates when entrainment and farfield tows were made (Figure 1).

Mortality

Survivorship of invertebrates cycled through the power plant was estimated from net tows made between the jetties and at a control station south of the plant. The sampling gear and technique employed was chosen to subject captured organisms to minimal stress inducing conditions i.e. mechanical buffeting and temperature elevation. A 2.0m 350μ mesh plankton cone net employed in a slow vertical tow appeared to give best results based on pilot studies done in 1978. In 1979 quadruplicate samples were obtained between the jetties on pumping and generating modes and at the 30 foot contour control station (south). Samples were immediately returned to the laboratory and picked, using lighted magnifiers over black and white benthos pans. Live organisms were transferred to aerated aquaria at ambient lake temperature and held 24 hours for latent mortality determination.

In 1980 sampling in the reservoir was eliminated because plant impacts were based on the number of viable organisms returned to Lake Michigan, (organisms entrained into the reservoir were assumed to be "lost" to the Lake Michigan system until released during the generating mode). A series of six samples were taken in generating currents emanating from the plant. The control samples were taken at night, three each at both a shallow (1.5m) and deep (9.1m) site to both minimize avoidance and sample when greater numbers of organisms were assumed to be concentrated at the sample site. The shallow control samples were taken with a 1.0m sled-mounted net.

A model developed to estimate ichthyoplankton losses was used to determine macroinvertebrate losses due to plant operation (Liston et al. 1981). Macroinvertebrates lost were those organisms removed from Lake Michigan either remaining in the reservoir or killed when cycled through the pump-turbines. The number of macroinvertebrates lost was estimated by:

$$N_{\ell} = N_{TE} - \{N_{TX} [1 - (M_g - M_c)]\} \qquad (5)$$

where N_{ℓ} = number of macroinvertebrates lost

N_{TE} = number of macroinvertebrates entrained from equation 4

N_{TX} = number of macroinvertebrates extrained from equation 4

M_g = mortality factor on generation mode

and M_c = mortality factor at control site

RESULTS

Farfield

Night sampling in the area of Lake Michigan immediately surrounding the power plant was initiated on 16 April and ceased 25 September. A total of 397 samples were taken on 11 dates in 1979 (Table 1). Spring storms delayed the initiation of day sampling until 15 May. A total of 342 samples were collected on nine dates.

Macroinvertebrate organisms frequently identified in sample tows were chironomids, *Mysis relicta* Loven, *Pontoporeia hoyi* Smith, *Gammarus pseudolimnaeus* Bousfield, *Gammarus fasciatus* Say, and the naidid oligochaetes *Stylaria sp.* and *Nais sp.* Less frequently collected taxa were Ephemeroptera, Plecoptera, Trichoptera, Ceratopogonidae, Chaoboridae and Tubificidae.

Farfield macroinvertebrate collections were dominated in order of decreasing abundance by *Mysis relicta*, *Pontoporeia hoyi*, Chironomidae, *Gammarus pseudolimnaeus*, naidid oligochaetes, Heptageniidae, Siphlonuridae, *Gammarus fasciatus*, Perlodidae, Hydropsychidae and Ceratopogonidae.

Chironomid larvae predominated in day tows in spring. Low numbers of *Mysis relicta* and naidid oligochaetes were taken during daylight, while no amphipods were collected.

Pontoporeia hoyi, *Gammarus pseudolimnaeus*, Chironomidae and *Mysis relicta* were the predominant occurrents in spring farfield night tows.

Table 1. Sampling dates, locations, and number of macroinvertebrate samples taken in 1979 at the Ludington Pumped Storage Plant.

	Lake Michigan			Reservoir			
Date	Day	Night	Entrainment	Day	Night	Extrainment	Mortality
4/16		29	5				
5/1		27	8	4		12	
5/9							12
5/15	40	39	8	4	4	4	
5/24							8
5/29	38	40	8	4	4	6	
6/5							12
6/12	26	24	8	4	2	8	
6/27							12
6/28	39	40	8	4	4	4	
7/5							4
7/10	40	40	8	4	4	8	
7/31	40	39	8	4	4	7	
8/6							11
8/15	40	39	8	4	4	4	
8/27	39	40	8	4	4	7	
8/28							12
9/25	40	40	8	4	4	8	
10/30			4				
Total	342	397	89	40	34	68	75

Perlodids, Siphlonurids and Heptageniids were infrequently collected in spring samples.

Chironomids and naidid oligochaetes were the most frequently collected taxa in summer day tows. Mysis dominated night collections, followed by Chironomidae, Pontoporeia hoyi, naidid oligochaetes and Gammarus spp.

Fall collections were dominated by Chironomidae, Mysis relicta, Pontoporeia hoyi, Naididae, Gammarus spp. and Heptageniidae.

Entrainment

A total of 89 biweekly collections were made from mid-April through October to outline macroinvertebrate entrainment during field sampling in 1979 (Table 1). Taxa encountered in entrainment samples in order of decreasing abundance were Mysis relicta, chironomid larvae, Amphipoda (Gammarus sp., Pontoporeia sp.), Oligochaeta (Naididae, Tubificidae), chironomid pupae, Ephemeroptera (Siphlonuridae, Heptageniidae, Ephemeridae), Chaoboridae, Isopoda, Plecoptera (Perlodidae) and Trichoptera (Hydropsychidae) (Table 2). Mysis relicta composed nearly 81% of the estimated total macroinvertebrates entrained during sampling in 1979. Chironomids, amphipods and oligochaetes composed approximately 12, 4 and 2% of total macroinvertebrate entrainment, respectively.

Entrained amphipods were identified as Pontoporeia hoyi Smith, Gammarus pseudolimnaeus Bousfield and Gammarus fasciatus Say. Oligochaetes identified in entrainment samples were the naidid oligochaetes Nais sp. and Stylaria sp. and occasionally members of the family Tubificidae. Taxa encountered sporadically in samples were Ephemeroptera (Isonychia sp., Heptagenia sp., Ephemera sp.), Plecoptera (Isoperla sp.),

Table 2. Estimated numbers of macroinvertebrates entrained in the Ludington Pumped Storage Reservoir on sample dates during 1979.

	4/16/79	5/1/79	5/15/79	5/29/79	6/12/79	6/28/79	7/10/79	7/31/79	8/15/79	8/27/79	9/25/79	10/30/79
Mysis relicta	239,403	191,210	30,941	1,874,471	645,562	3,651,061	14,020,628	37,613,133	2,619,164	14,021,452	1,686,345	814,748
Chironomids	165,944	2,122,569	1,724,487	684,540	815,614	279,304	139,377	338,538	533,428	1,383,116	551,110	250,958
Pontoporeia hoyi	118,772	61,708	0	25,359	37,159	39,253	0	426,815	607,474	0	263,878	153,522
Gammarus fasciatus	0	0	0	0	91,544	0	40,505	42,313	0	365,732	106,638	0
Gammarus pseudolimnaeus	77,657	0	0	109,555	37,396	40,736	0	0	61,755	93,731	147,243	0
Hydropsychidae	31,779	75,870	0	0	45,772	0	0	0	0	0	0	0
Siphlonuridae	198,866	21,809	0	0	37,396	0	0	0	63,904	0	0	0
Isopoda	0	0	0	0	0	0	0	0	0	0	47,698	0
Heptageniidae	0	30,132	0	0	0	0	0	0	0	0	0	90,803
Naididae	0	23,929	0	410,855	344,724	82,270	0	0	1,461,605	51,913	0	0
Perlodidae	31,779	21,809	0	0	0	0	0	0	0	0	0	0
Chaoboridae	0	0	70,327	4,852	49,253	39,253	0	0	0	0	0	0
Ephemeridae	31,779	0	0	0	0	0	0	0	0	0	0	0
Chironomid pupae	0	0	0	0	86,984	11,903	214,271	37,812	0	209,016	240,048	0
Tubificidae	0	0	0	48,374	0	0	0	0	0	0	0	0
Total Entrainment	895,979	2,549,036	1,825,755	3,158,006	2,191,404	4,143,780	14,414,781	38,458,611	5,347,330	16,124,960	3,042,960	1,310,031

Isopoda (Asellus sp.) and Trichoptera (Hydropsyche sp.)

Nearly all taxa were captured in higher numbers during the first sample period (0200h) throughout spring, except on 15 May when all taxa were collected during the second (0500h) sample period (Table 3). With the exception of Mysis all taxa continued to be collected in higher numbers during the first sample period throughout summer and fall (Table 3).

Macroinvertebrate entrainment ranged from the low on 16 April (895,979) to a peak occurring on 1 August (38,458,611; Table 2). The 1 August peak was caused by a marked increase in entrained mysids which comprised nearly 66% of the total entrainment value.

Total macroinvertebrate entrainment increased during summer sampling. Peak total entrainment occurred on 1 August, with secondary modes on 10 July and 27 August (Table 2). High entrainment estimates on these dates were mainly due to marked increases in numbers of entrained Mysis.

Fall samples indicated a decline in total entrainment. All taxa entrained during fall sampling appeared to be decreasing with the exception of heptageniid mayflies (Table 2). Over 60% of entrained macroinvertebrates in fall samples were indicated by the peak value for entrained chironomid pupae occurring on 25 September.

Reservoir

A total of 74 collections were made in the Ludington Pumped Storage Reservoir in 1979 (Table 1). Night sampling resulted in 34 samples on 9 dates. Day collections totaled 40 samples on 10 dates. Major taxa encountered in order of decreasing abundance were Chironomidae (larvae),

Table 3. Number of macroinvertebrates entrained inthe Ludington Pumped Storage Reservoir during the 0200 (1) and 0500 (2) sample periods in 1979.

Date	Sample Period	*Mysis relicta*	*Pontoporeia hoyi*	Chironomids	*Gammarus pseudolimnaeus*	*Gammarus fasciatus*	Hydropsychidae	Siphlonuridae	Isopoda	Heptageniidae	Naididae	Perlodidae	Chaoboridae	Ephemeridae	Chironomid pupae	Tubificidae
4/16/79	1	239,403	118,772	165,944	77,657	0	31,779	198,866	0	0	0	31,779	0	31,779	0	0
	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5/1/79	1	120,368	61,708	1,572,699	0	0	75,870	21,809	0	30,132	23,929	21,809	0	0	0	0
	2	70,841	0	549,870	0	0	0	0	0	0	0	0	0	0	0	0
5/15/79	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	30,491	0	1,724,467	0	0	0	0	0	0	0	0	70,327	0	0	0
5/29/79	1	1,700,946	0	684,540	104,702	0	0	0	0	0	410,855	0	0	0	0	48,374
	2	173,525	25,359	0	4,852	0	0	0	0	0	0	0	4,852	0	0	0
6/12/79	1	490,158	0	566,211	0	91,544	45,772	0	0	0	344,724	0	49,253	0	49,825	0
	2	155,404	37,159	249,403	37,396	0	0	37,396	0	0	0	0	0	0	37,159	0
6/28/79	1	1,374,344	39,253	201,007	40,735	0	0	0	0	0	53,086	0	39,253	0	40,735	0
	2	2,276,717	0	78,297	0	0	0	0	0	0	29,183	0	0	0	78,297	0
7/10/79	1	3,590,915	0	139,377	0	40,505	0	0	0	0	0	0	0	0	47,521	0
	2	10,427,712	0	0	0	0	0	0	0	0	0	0	0	0	166,749	0
7/31/79	1	19,984,784	277,460	30,892	0	42,312	0	0	0	0	0	0	0	0	37,812	0
	2	17,628,350	149,354	29,615	0	0	0	0	0	0	0	0	0	0	0	0
8/15/79	1	2,002,556	534,558	533,428	61,755	0	0	63,904	0	0	196,106	0	0	0	0	0
	2	616,608	72,915	0	0	0	0	0	0	0	1,265,499	0	0	0	0	0
8/27/79	1	556,585	0	943,971	93,731	365,732	0	0	0	0	51,913	0	0	0	133,882	0
	2	845,560	0	439,144	0	0	0	0	0	0	0	0	0	0	75,134	0
9/25/79	1	633,497	95,978	383,209	94,158	51,796	0	0	47,698	0	0	0	0	0	141,857	0
	2	1,052,848	167,901	167,901	53,084	54,842	0	0	0	0	0	0	0	0	98,191	0
10/30/79	1	814,748	153,522	250,958	0	0	0	0	0	90,803	0	0	0	0	0	0
	2	--	--	--	0	--	--	0	--	--	--	--	--	--	--	--

Mysidacea and Naididae. Minor taxa collected in reservoir tows were *Pontoporeia hoyi*, Tubificidae, *Gammarus pseudolimnaeus*, *Gammarus fasciatus*, *Ephemerella sp.* and *Hexagenia sp.*

Generally, peak pelagic densities during day collections were recorded in tows made in the north end of the reservoir (Station 9). Highest macroinvertebrate pelagic densities during night tows were noted in collections from the south end (Station 7).

Extrainment

Sixty-nine samples were taken on ten dates during the period May through September to outline macroinvertebrate release rates from the Ludington Pumped Storage Reservoir (Table 1). Taxa encountered in extrainment samples in order of decreasing abundance were Chironomidae (larvae and pupae), *Mysis relicta*, naidid oligochaetes, gammarid amphipods, tubificid oligochaetes, *Pontoporeia hoyi*, Isopoda, Siphlonuridae (Ephemeroptera), Heptageniidae (Ephemeroptera) and Hydropsychidae (Trichoptera) (Table 4). Chironomid larvae and pupae composed 32.5 and 25.4% of extrained macroinvertebrates, respectively. Approximately 20% of the invertebrates returned to Lake Michigan from the upper reservoir were *Mysis relicta*. The amphipods *Pontoporeia hoyi* and *Gammarus spp.* contributed 2.3 and 4.8%, respectively, to the total extrainment estimate in 1979.

Table 4. Total number of macroinvertebrates estimated to be entrained and released at the Ludington Pumped Storage Reservoir during sampling in 1979.

Taxon	Entrainment	Extrainment
Mysidacea		
Mysis relicta	1,295,101,546	67,092,310
Chironomidae		
Chironomid larvae	168,992,283	109,457,724
Chironomid pupae	19,427,860	85,485,209
Amphipoda		
Pontoporeia hoyi	34,807,055	7,805,142
Gammarus spp.	29,217,664	16,230,582
Oligochaeta		
Naididae	37,437,472	32,545,127
Tubificidae	599,556	8,932,065
Ephemeroptera		
Siphlonuridae	4,817,272	3,450,751
Heptageniidae	3,604,282	1,407,312
Ephemeridae	462,243	0
Diptera		
Chaoboridae	2,435,176	0
Isopoda		
Asellus sp.	1,083,813	4,062,550
Plecoptera		
Perlodidae	739,004	0
Trichoptera		
Hydropsychidae	2,176,638	65,103
Total Invertebrates	1,600,901,864	336,533,875

Mysis relicta

Farfield

Few *Mysis* were captured in day tows during spring sampling (Figure 3). All *Mysis* were captured on 29 May at the 20 (6.1m) and 30 foot (9.1m) contours at stations 2 and 4, respectively. These individuals were all immature (1 - 5mm).

Mysis distribution during night sampling in spring exhibited a trend of lakeward increase at all stations. Lowest overall densities occurred at stations 1 and 4 (Figure 3). Greatest concentrations of mysids were noted at the 30 (9.1m) and 40 foot (12.2m) contours at stations 2 and 3. Peak concentrations of *Mysis* occurred on 16 April when densities of $344/1000m^3$ and $204/1000m^3$ occurred at the 40 foot (12.2m) contour at stations 2 and 3, respectively. Nearly 92% of the *Mysis* estimated to be contained within the rectangle were distributed at this contour (Table 5). *Mysis* captured on this date were mostly subadults, with some adults in reproductive condition noted at the 10 (3.0m) and 20 foot (6.1m) contours.

Mysis were seldom captured in day tows made during summer (Figure 3). The majority of organisms captured were collected at the 30 (9.1m) and 40 foot (12.2m) contours. Peak day collections occurred at the 30 foot (9.1m) contour at stations 1 and 2 on 31 July. Relatively few mysids were captured at the shallow contours (<30 ft) during day tows. Most of these individuals were juvenile (<11mm) instars.

Farfield night tows made during summer contained numerous mysids. Most *Mysis* captured at night were taken at the 40 foot (12.2m) contour (Figure 3). Summer sampling revealed highest densities at station 2.

Figure 3. Density (No./1000m^3) of *Mysis relicta* at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

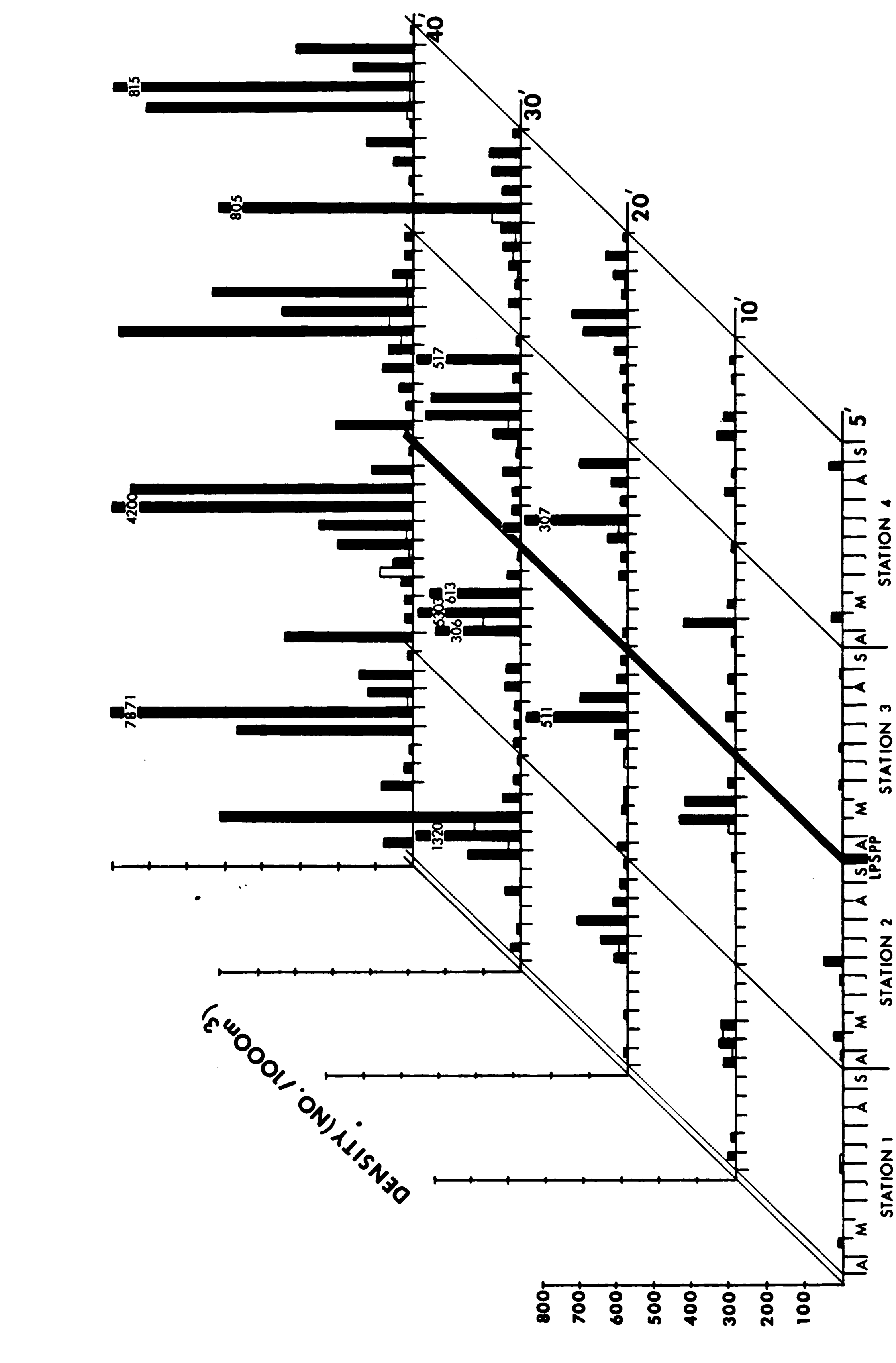

DENSITY (NO./1000m3)
800
700
600
500
400
300
200
100
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
5'
10'
20'
30'
40'
1320
7871
511
306
530
303
613
307
4200
517
805
815

Table 5. Numbers of *Mysis relicta* estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth					Total
	5	10	20	30	40	
4/16/79	958	16,723	124,758	1,698,185	19,876,530	21,717,154
5/1/79	7,586	45,961	15,617	840,562	744,149	1,653,875
5/15/79	0	0	62,789	559,453	2,925,252	3,547,494
5/29/79	1,747	21,354	111,904	2,193,785	8,021,928	10,350,718
6/12/79	905	0	256,884	1,265,426	7,144,503	8,667,718
6/28/79	3,326	139,930	816,963	6,409,823	33,976,540	41,346,582
7/10/79	0	343,886	2,772,004	28,282,150	49,976,520	81,374,560
7/31/79	0	280,348	2,709,595	101,983,600	401,714,200	506,687,743
8/15/79	0	230,497	1,005,192	11,226,530	30,340,180	42,802,399
8/27/79	4,117	31,304	799,090	9,137,802	14,846,740	24,819,053
9/25/79	0	5,918	96,758	361,310	1,386,550	1,850,536
Total	18,639	1,115,921	8,771,554	163,958,626	570,953,092	744,817,832

Figure 3 indicates marked density increases occurred at the 10, 20 and 30 foot contours on 28 June. Mysis densities peaked on 31 July when substantial increases were exhibited at the 40 foot (12.2m) contour at all stations. Nearly all Mysis collected shoreward of the 30 foot (9.1m) contour were juveniles. Few mysids were taken from the 5 foot (1.5m) contour during summer sampling.

No Mysis were collected in daylight fall tows made on 26 September (Figure 3). Low numbers of Mysis were collected at all stations in night tows with most in the 6 - 10mm length category (Figure 3; Table 5).

Entrainment

A precipitous decrease in Mysis entrainment occurred on 15 May (Table 6). However, estimates of Mysis in Lake Michigan increased on this date (Table 5). Sampling on 29 May indicated a significant increase in Mysis entrainment. Eighty-six percent of the entrained mysids were immature (<11mm), with most entering the plant during the early portion of the pumping mode (Table 3).

Entrainment estimates for Mysis continued to increase over the course of summer sampling to the peak value recorded on 31 July decreasing thereafter (Table 6). Most (>90%) of the Mysis collected during summer were immatures (<11mm), with the majority of these captured during period 1 (Table 3). Adults were captured during the second sampling period (Table 3).

Collections of entrained Mysis in fall continued to be dominated by immature instars. However, the percentage in the 6 - 10mm length category increased.

Table 6. Total number of *Mysis relicta* estimated to be entrained into the Ludington Pumped Storage Reservoir during 1979.

Sample Date	Number Entrained	Estimated Number Entrained for Interval	Interval
4/16/79	239,403	3,482,266	4/12 - 4/24
5/1/79	191,210	2,426,486	4/25 - 5/8
5/15/79	30,941	487,465	5/9 - 5/22
5/29/79	1,874,471	23,232,258	5/23 - 6/5
6/12/79	645,562	10,600,408	6/6 - 6/20
6/28/79	3,651,061	41,754,522	6/21 - 7/4
7/10/79	14,020,628	204,603,313	7/5 - 7/21
7/31/79	37,613,133	850,603,482	7/22 - 8/8
8/15/79	2,619,164	42,372,312	8/9 - 8/21
8/27/79	14,021,452	48,312,617	8/22 - 9/11
9/25/79	1,686,345	38,317,365	9/12 - 10/12
10/30/79	814,748	28,909,052	10/13 - 11/12
		1,295,101,546	4/12 - 11/12

Reservoir

Mysis relicta was not collected in day tows until 28 May when peak numbers were recorded at station 9 (Table 7). Densities recorded in day tows ranged from 0 - 908 organisms per $1000m^3$ of water. Highest daytime densities occurred at station 9, with the exception of the 28 May sample date. Mysis were collected in night tows at the inception of sampling. Densities of Mysis ranged from 3 - $1292/1000m^3$ at stations 7 and 9. Peak reservoir density occurred on 27 August. Higher pelagic densities regularly occurred at station 7 during night sampling.

Extrainment

Estimated Mysis release was highest at initiation of extrainment sampling on 1 May (1,830,218). Adult and subadult instars (6 - 10 and 11 - 16mm) dominated in collections made on this date (Table 8). Release rates of Mysis from the reservoir declined throughout the remainder of spring sampling. Extrainment estimates averaged approximately 59% of entrainment values during spring collections.

Mysis released from the pumped storage reservoir varied substantially. Interval estimates of extrained organisms ranged from 0 on 28 June to 47,647,715 on 15 August. An average of 28% of entrained mysids were estimated to be returned to Lake Michigan during summer sampling.

Mysis extrainment declined substantially in September from late summer values (Table 8). The extrainment estimate on 26 September represented .8% of the estimated number of organisms entrained during the previous night. All of the extrained Mysis released on this date were 6 - 10mm individuals.

Table 7. Mean densities of Mysis relicta (#/1000m^3) in samples from the Ludington Pumped Storage Reservoir during 1979.

	Station 7		Station 9		Total Reservoir Density	
Date	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	271	0	---	0	271
5/28/79	0	432	908	73	454	252
6/12/79	0	258	0	134	0	196
6/28/79	5	256	0	219	2	238
7/10/79	6	868	16	103	11	486
7/31/79	0	992	78	3	39	497
8/15/79	0	31	0	340	0	185
8/27/79	0	1,292	0	285	0	788
9/25/79	0	247	2	247	1	247

Table 8. Total number of *Mysis relicta* estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	1,830,218	3,710,346	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	47,560	526,786	5/23 - 6/5
6/12/79	196,023	5,420,153	6/6 - 6/20
6/28/79	0	0	6/21 - 7/4
7/10/79	408,816	5,050,069	7/5 - 7/21
8/1/79	162,822	2,854,612	7/22 - 8/8
8/15/79	3,919,013	47,647,715	8/9 - 8/21
8/27/79	99,924	1,613,883	8/22 - 9/11
9/26/79	12,856	268,747	9/12 - 10/12
		67,092,310	4/25 - 10/12

Losses to Lake Michigan

As stated previously, Mysis losses to Lake Michigan were estimated from equation 5. The entrainment estimate for the 1979 sampling year was 1,295,101,546 (Table 6). The corresponding extrainment estimate for mysids was 67,092,310 (Table 8).

Chironomidae

Farfield

Chironomid larvae dominated farfield day collections in spring. Few chironomids were captured in day tows in comparison to night collections. Chironomids were generally collected at the 10 (3.0m) and 20 foot (6.1m) contours during spring sampling (Figure 4). Highest density ($31.2/1000m^3$) occurred at the 20 foot (6.1m) contour at station 1 on 29 May. Chironomids were occasionally sampled at the 5 (1.5m) and 40 foot (12.2m) contours in daylight.

Chironomid larvae were collected at all stations when night tows were initiated on 16 April (Figure 4). Catch per effort was higher in night tows versus day tows. Peak pelagic densities occurred at the 10 foot (3.0m) contour ($5990/1000m^3$) at station 1 and the 5 foot (1.5m) contour ($2555/1000m^3$) at station 4 during May sampling (Figure 4). However, most pelagic chironomids were distributed lakeward of the 20 foot (6.1m) contour (Table 9). Numbers of chironomid larvae in the water column exhibited a general shoreward increase as spring sampling progressed until 15 May, declining thereafter. Overall, night larval chironomid densities in spring appeared to be greatest at station 2. Diamesa sp., Chironomus sp., Eukieferiella sp. and Glyptotendipes sp.

Figure 4. Density (No./1000m^3) of Chironomidae larvae at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

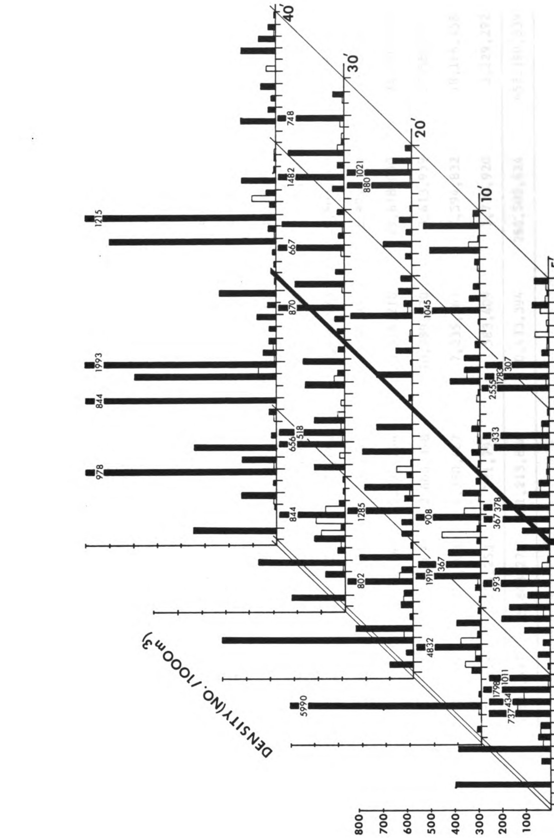

DENSITY(NO./1000 m3)
800
700
600
500
400
300
200
100
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
5'
10'
20'
30'
40'
5990
737
434
1798
1011
4832
593
1919
367
802
367
378
908
1285
844
978
656
518
844
333
2555
1783
307
1993
1045
870
667
1215
880
1021
1482
748

Table 9. Numbers of Chironomidae estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

	Contour Depth					
	5	10	20	30	40	Total
4/16/79	4,933	102,744	964,126	8,598,395	40,455,420	50,125,617
5/1/79	733,644	1,021,835	339,955	1,236,336	3,554,856	6,886,626
5/15/79	466,967	10,757,860	12,762,110	41,154,280	63,129,570	128,270,787
5/29/79	277,277	732,368	1,432,311	13,059,200	53,526,750	69,027,913
6/12/79	165,932	276,901	1,166,382	8,141,655	37,436,880	47,187,753
6/28/79	50,327	122,127	379,460	5,430,985	29,603,800	35,586,697
7/10/79	30,411	117,301	194,572	286,993	5,999,548	6,628,825
8/1/79	371,761	11,320,080	9,094,294	33,916,210	19,818,090	74,520,434
8/15/79	247,728	300,402	2,608,378	10,789,970	3,613,959	17,560,437
8/27/79	527,799	857,400	1,950,467	7,235,961	7,594,832	18,166,458
9/25/79	314,918	234,253	321,791	583,409	1,774,920	3,229,292
Total	3,191,697	25,843,271	31,213,846	130,433,394	266,508,624	457,190,839

were identified most often in spring samples. Tanypus sp., Procladius sp. and Chironomus sp. dominated collections made at the 5 (1.5m) and 10 foot (3.0m) contours. Eukieferiella sp. was most abundant at the 30 (9.1m) and 40 foot (12.2m) contours.

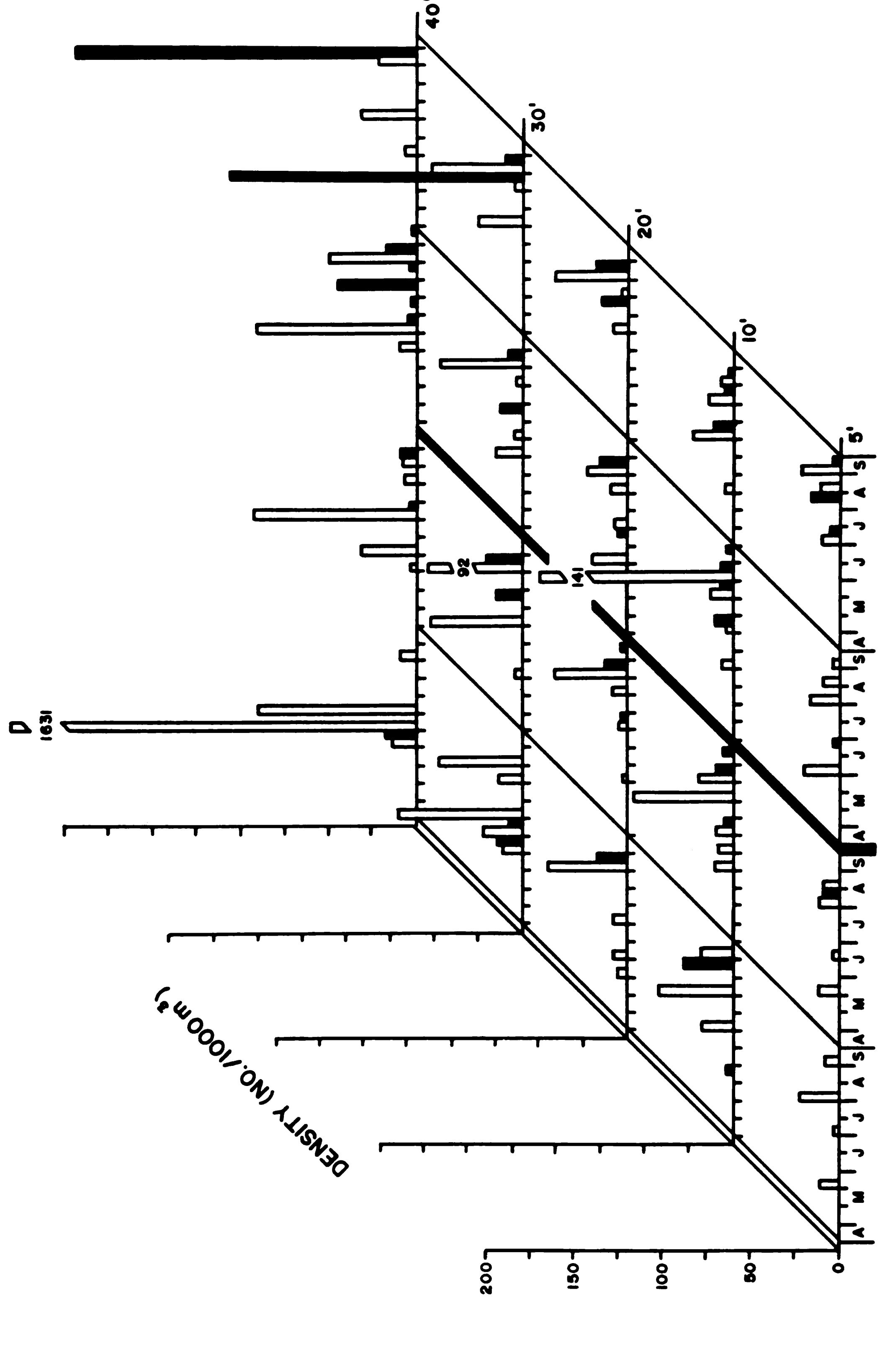
Chironomid pupae were first collected in spring day tows on 29 May. Greatest concentrations of pupae were recorded at the 5 foot (1.5m) and 10 foot (3.0m) contours (Figure 5). Farfield night tows collected chironomid pupae at station 1 at the 5 (1.5m) and 10 foot (3.0m) contours on 15 and 29 May, respectively (Table 10).

Daylight sampling in the farfield area during summer (June - August) revealed that most larval chironomids were distributed in the water column shoreward of the 30 foot (9.1m) contour (Figure 4). Overall, larval chironomid densities were greatest at station 2 during day sampling (Figure 4).

Night tows made during summer captured chironomid larvae at all stations and depths (Figure 4). Pelagic densities peaked in late July and early August shoreward of the 20 foot (6.1m) contour. Peak pelagic larval density ($1798/1000m^3$) occurred at the station 1, 5 foot (1.5m) contour on 27 August (Figure 4). Chironomus sp. and Crytochironomus sp. were most abundant in samples. Most larvae were estimated to be distributed at greater depths (>20 ft) as evidenced by collections made at station 3, 40 foot (12.2m) contour when tow densities of $1215/1000m^3$ were noted on 28 June. These samples contained many Eukieferiella sp.

Farfield day tows made during summer revealed numerous concentrations of chironomid pupae in the water column. Overall, peak chironomid pupal densities occurred at station 1 (Figure 5). Densities increased as summer sampling progressed until 31 July when no chironomid pupae were

Figure 5. Density (No./$1000m^3$) of chironomid pupae at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.



DENSITY (NO./1000 m³)
0
50
100
150
200
1631
92
141
LPSPP
40'
30'
20'
10'
5'
STATION 1
STATION 2
STATION 3
STATION 4

Table 10. Numbers of Chironomidae Pupae (Diptera) estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

	Contour Depth					
	5	10	20	30	40	Total
4/16/79	0	0	0	0	0	0
5/1/79	0	0	0	0	0	0
5/15/79	2,878	0	0	0	0	2,878
5/29/79	0	4,988	0	0	0	4,988
6/12/79	0	0	0	180,764	482,636	663,400
6/28/79	529	0	16,441	86,213	119,954	223,137
7/10/79	834	44,322	24,627	140,564	149,924	360,271
7/31/79	0	0	63,247	587,634	1,236,348	1,887,229
8/15/79	6,181	19,002	0	1,329,207	105,961	1,460,351
8/27/79	0	74,074	203,557	500,510	6,061,292	6,839,433
9/25/79	895	15,316	13,417	0	56,645	86,273
Total	11,317	157,702	321,289	2,824,892	8,212,760	11,527,960

encountered in day tows. Pelagic pupal densities increased after this date to a second peak recorded on 27 August.

Distribution of chironomid pupae in night tows was sporadic. Overall, highest densities were recorded at the 30 (9.1m) and 40 foot (12.2m) contours (Figure 5). Chironomid pupae were captured at all stations on 27 August. Greatest pelagic distribution of pupae was estimated at the 40 foot (12.2m) contour on this date (Table 10).

Chironomid larvae were captured in day tows at stations 1, 2 and 4 during fall sampling (Figure 4). Peak night density ($1011/1000m^3$) occurred on 26 September at the 5 foot (1.5m) contour. Pelagic densities of larval chironomids decreased lakeward. However, estimates of chironomids above bottom increased lakeward during fall (Table 9).

Chironomid pupae were captured only in day tows made at the 5 foot (1.5m) contour at stations 1, 2 and 4 on 26 September (Figure 5). Night tows collected pupae at stations 2, 3 and 4, all at densities below those recorded in summer tows.

Entrainment

Numbers of entrained chironomid larvae peaked in spring samples on the night of 1 May. However, the interval estimate for the period 9 - 22 May yielded the highest value as a function of larger volumes moved (Table 11). Chironomid larvae entrained declined abruptly during subsequent spring sampling. Numbers of chironomid pupae encountered were increasing in all areas (Table 10).

Entrained chironomid larvae declined steadily from the 12 June value (815,614), increasing again to a peak on 27 August (1,383,116; Table 11). Large numbers of 4th instar Cryptochironomus sp. larvae were noted in

Table 11. Total number of Chironomidae estimated to be entrained into the Ludington Pumped Storage Reservoir during 1979.

Sample Date	Number Entrained	Estimated Number Entrained for Interval	Interval
4/16/79	165,944	2,413,761	4/12 - 4/24
5/1/79	2,122,569	26,935,728	4/25 - 5/8
5/15/79	1,724,487	27,168,274	5/9 - 5/22
5/29/79	684,540	8,484,211	5/23 - 6/5
6/12/79	815,614	13,392,724	6/6 - 6/20
6/28/79	279,304	3,194,197	6/21 - 7/4
7/10/79	139,377	2,033,929	7/5 - 7/21
7/31/79	338,538	7,655,887	7/22 - 8/8
8/15/79	533,428	8,629,695	8/9 - 8/21
8/27/79	1,383,116	47,656,938	8/22 - 9/11
9/25/79	551,110	12,522,393	9/12 - 10/12
10/30/79	250,958	8,904,546	10/13 - 11/12
		168,992,283	4/12 - 11/12

samples on this date. Highest larval chironomid estimates in the farfield area during summer were recorded on 1 August (Table 9). Chironomid larvae continued to be taken in greater numbers in summer during the 0200h sample period (Table 3). Numbers of entrained chironomid pupae fluctuated inversely with values for entrained larvae during sampling.

Reservoir

Chironomid larvae first appeared in day tows on 10 May at station 9 (Table 12). Daytime densities ranged from 0 - 38 organisms per $1000m^3$ of water. Highest densities consistently occurred at station 9 during day collections. Chironomid larvae were noted in night tows on 15 May (Table 12). Night densities peaked on 12 June at station 7 ($3047/1000m^3$). Station 7 consistently exhibited higher densities throughout reservoir night sampling.

Reservoir day collections captured low numbers of chironomid pupae (Table 13). They were noted initially in tows made on 28 May. No pattern of preference was visible during day tows for chironomid pupae. Night tows in the reservoir captured chironomid pupae initially on 28 May. Tow densities ranged from 0 at station 9 on 10 July to the mode of $836/1000m^3$ which was recorded on 12 June at station 7. Two density pulses were indicated from reservoir collections, one in early June, and another in late July to early August (Table 13). On dates when chironomid pupae were taken in night tows, station 7 repeatedly had higher densities with the exception of tows made on 25 September.

Table 12. Mean densities of Chironomidae ($\#/1000m^3$) in samples from the Ludington Pumped Storage Reservoir during 1979.

Date	Station 7		Station 9		Total Reservoir Density	
	Day	Night	Day	Night	Day	Night
5/10/79	0	---	18	---	9	---
5/15/79	5	874	0	---	2	874
5/28/79	0	912	38	156	19	534
6/12/79	0	3,047	---	411	0	1,729
6/28/79	0	89	6	15	3	52
7/10/79	6	58	0	0	3	29
7/31/79	5	135	0	19	3	77
8/15/79	0	406	10	158	5	282
8/27/79	0	1,781	2	346	1	1,063
9/25/79	0	208	0	28	0	118

Table 13. Mean densities of chironomid pupae (#/1000m^3) in samples from the Ludington Pumped Storage Reservoir during 1979.

	Station 7		Station 9		Total Reservoir Density	
Date	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	0	0	---	0	0
5/28/79	0	0	4	18	2	9
6/12/79	18	836	---	234	18	535
6/28/79	11	169	0	113	5	142
7/10/79	0	12	6	0	3	6
7/31/79	0	359	0	122	0	241
8/15/79	2	679	0	219	1	449
8/27/79	5	561	8	35	6	298
9/25/79	0	8	0	14	0	11

Extrainment

Spring larval chironomid extrainment peaked on 1 May (8,588,705; Table 14). Extrainment estimates of larval chironomids averaged approximately 31% of entrainment values during spring. Peak pupal release was recorded on 15 May (Table 15).

Larval chironomid extrainment remained relatively constant over the summer until 15 August when numbers released exhibited over a ten-fold increase (Table 14). Entrainment rates of chironomids were lower but exhibited the same trend during summer (Table 11).

Release of chironomid pupae (Table 15) fluctuated markedly during summer but normally remained substantially below entrainment estimates for summer sampling (Table 2).

Extrainment of chironomid larvae in fall decreased to approximately half late summer estimates (Table 14). Release of chironomid pupae was nearly 25% of the entrainment value on 26 September (Table 15).

Gammarus spp.

Farfield

Gammarus spp. were not captured off bottom during spring farfield day collections in 1979 (Figures 6 and 7).

No clear trend was apparent in spring farfield *Gammarus pseudolimnaeus* distribution (Figure 6). No *G. pseudolimnaeus* were captured in night tows made on 15 May at stations 2 and 4 (Table 16). Peak density of *G. pseudolimnaeus* (1092/1000m^3) occurred on this date at the 5 foot (1.5m) contour at station 4. All *G. pseudolimnaeus* collected in spring tows were mature adults.

Table 14. Total number of Chironomidae estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	8,588,705	17,411,624	4/25 - 5/8
5/15/79	183,748	2,648,674	5/9 - 5/22
5/29/79	148,130	1,640,721	5/23 - 6/5
6/12/79	83,968	2,321,773	6/6 - 6/20
6/28/79	90,800	1,038,996	6/21 - 7/4
7/10/79	419,414	5,180,985	7/5 - 7/21
8/1/79	78,249	1,371,873	7/22 - 8/8
8/15/79	3,054,570	37,137,738	8/9 - 8/21
8/27/79	1,782,470	28,788,892	8/22 - 9/11
9/26/79	570,050	11,916,448	9/12 - 10/12
		109,457,724	4/25 - 10/12

Table 15. Total number of chironomid pupae estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	0	0	4/25 - 5/8
5/15/79	286,793	4,134,028	5/9 - 5/22
5/29/79	87,617	970,469	5/23 - 6/5
6/12/79	340,857	9,424,908	6/6 - 6/20
6/28/79	110,827	1,268,147	6/21 - 7/4
7/10/79	748,984	9,252,139	7/5 - 7/21
8/1/79	0	0	7/22 - 8/8
8/15/79	877,514	10,668,898	8/9 - 8/21
8/27/79	3,034,570	49,011,726	8/22 - 9/11
9/26/79	36,112	754,894	9/12 - 10/12
		85,485,209	4/25 - 10/12

Figure 6. Density (No./1000m^3) of Gammarus pseudolimnaeus at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

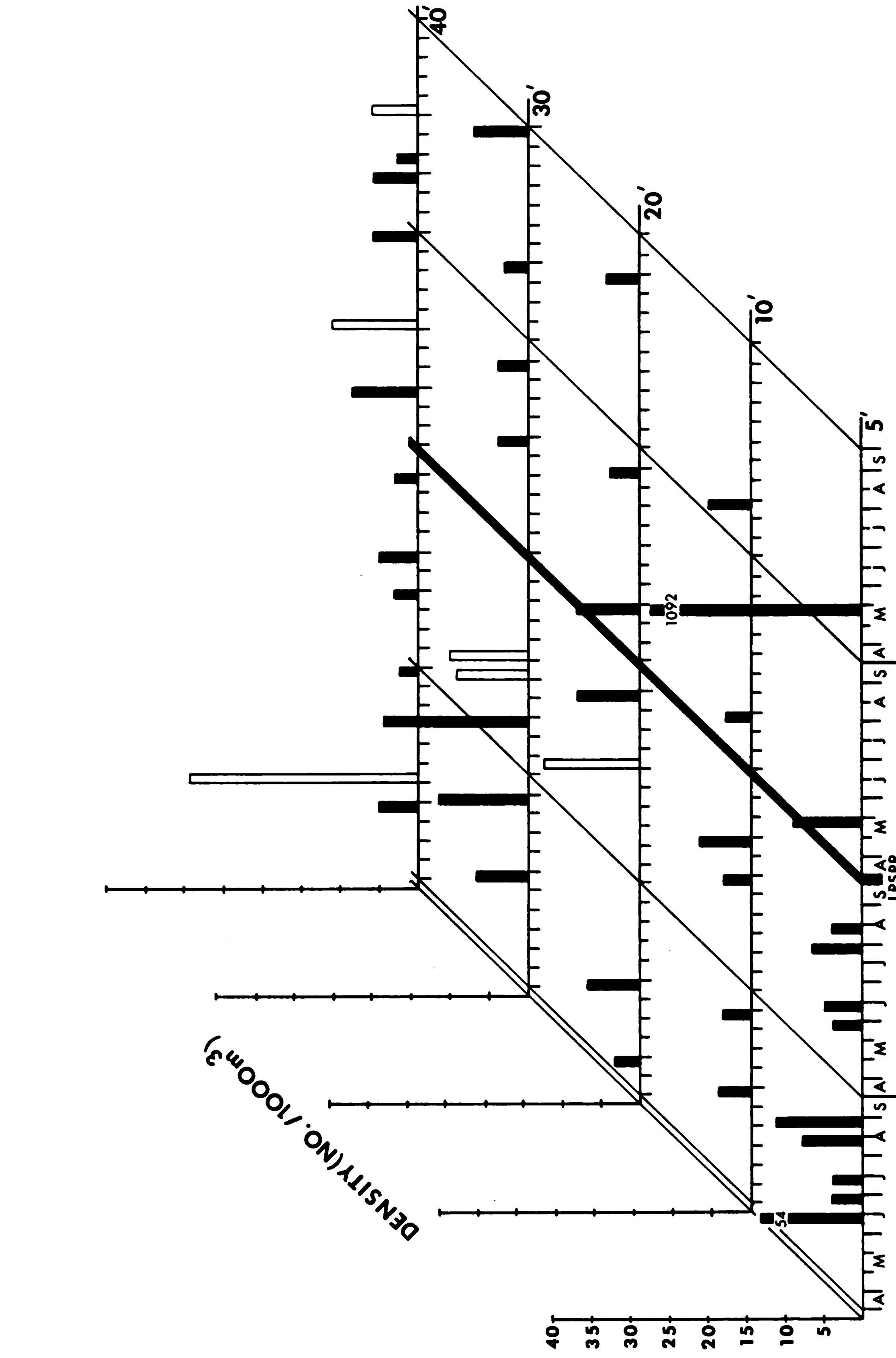

DENSITY(NO./1000m³)
40
35
30
25
20
15
10
5
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
A M J J A S
54
1092
5'
10'
20'
30'
40'

Figure 7. Density (No./1000m^3) of *Gammarus fasciatus* at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

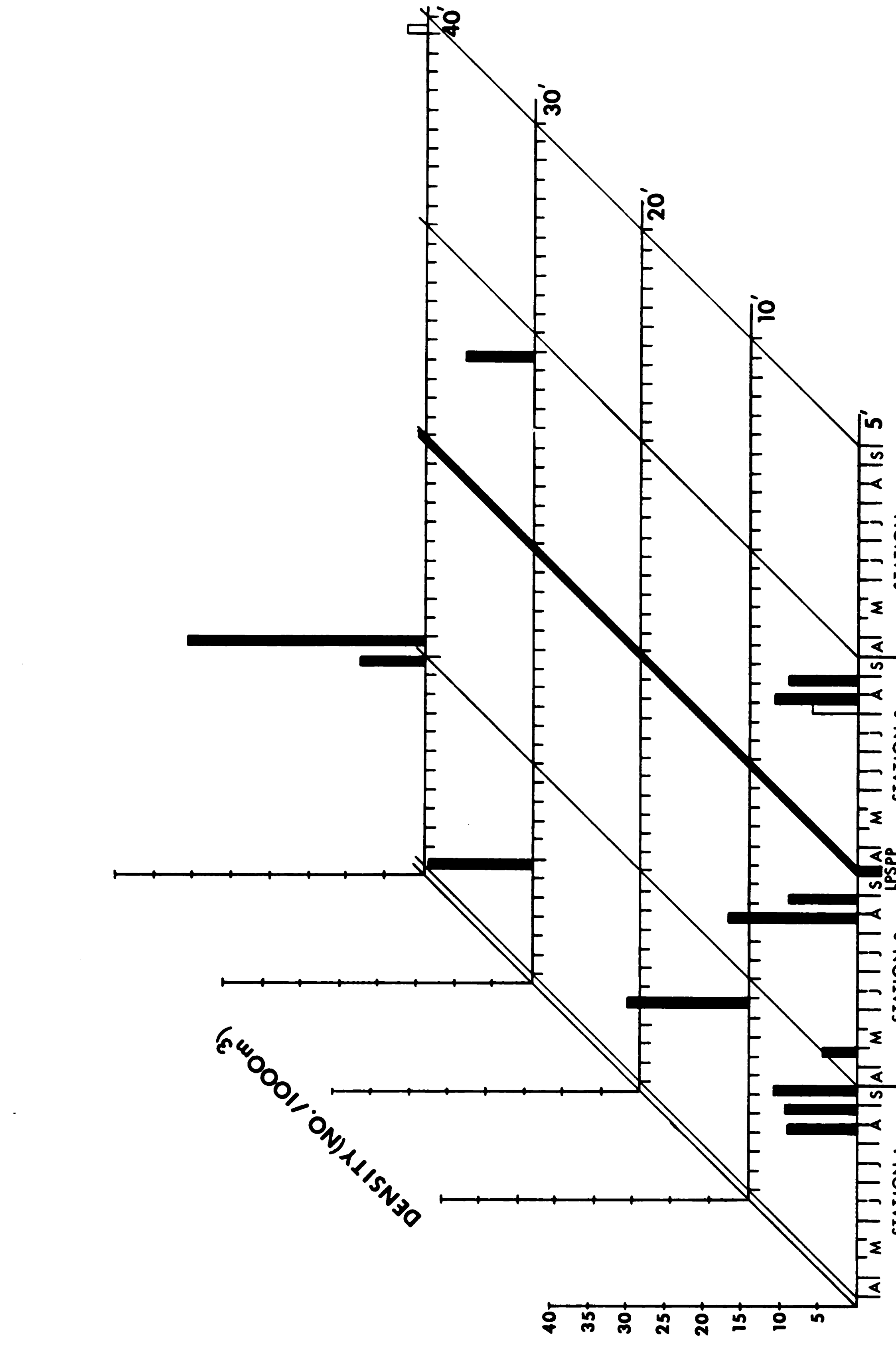

DENSITY(NO./1000m3)
40
35
30
25
20
15
10
5
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
A M J J A S
5'
10'
20'
30'
40'

Figure 7. Density (No./1000m^3) of _Gammarus fasciatus_ at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

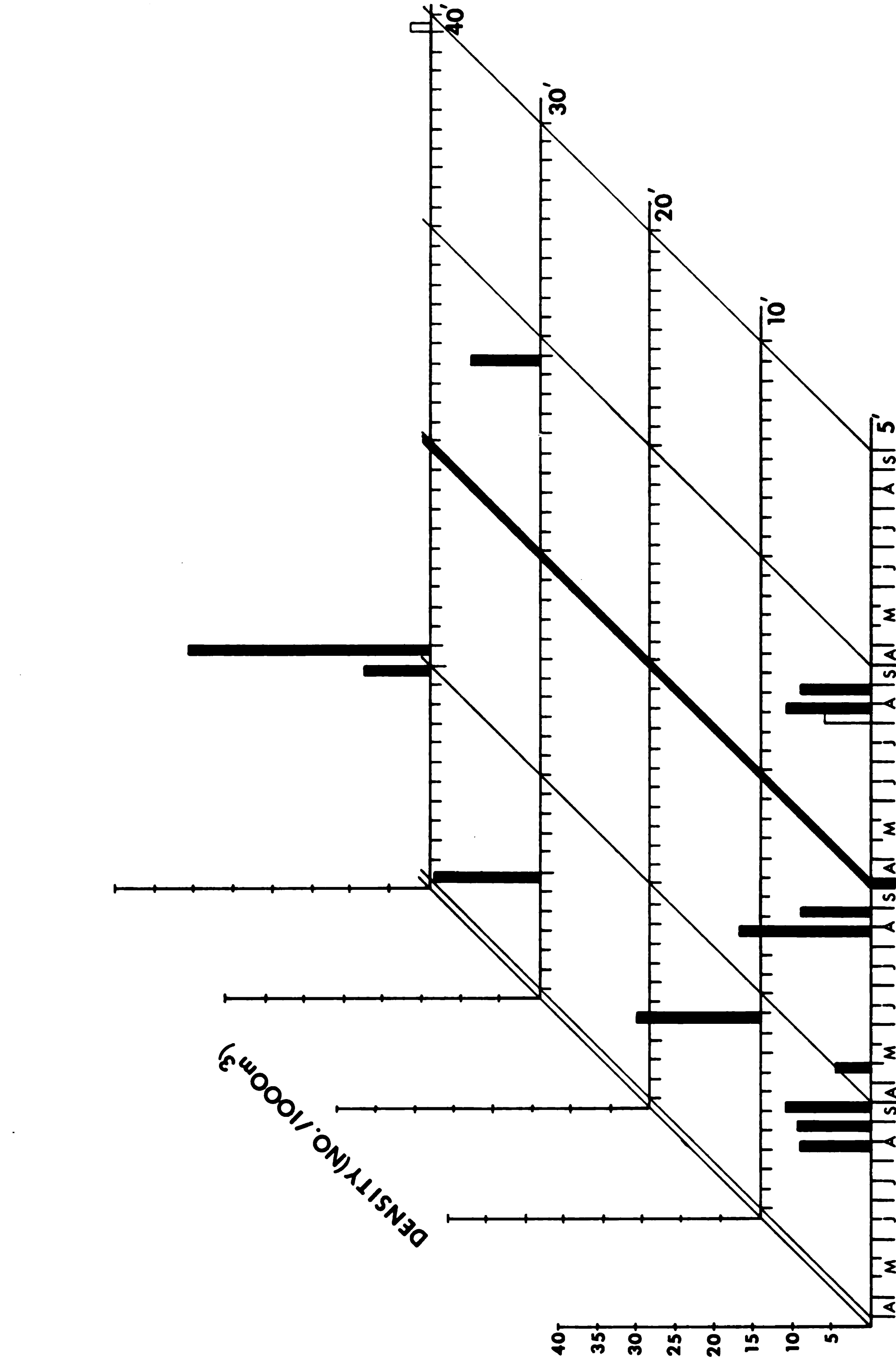

DENSITY(NO./1000m3)
40
35
30
25
20
15
10
5
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
5'
10'
20'
30'
40'

Table 16. Numbers of _Gammarus pseudolimnaeus_ estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth 5	10	20	30	40	Total
4/16/79	0	0	0	0	0	0
5/1/79	0	0	22,449	0	0	22,449
5/15/79	217,091	15,222	28,268	249,877	1,009,694	1,520,152
5/29/79	697	0	0	280,744,300	294,091	281,039,088
6/12/79	15,788	0	0	0	0	15,788
6/28/79	3,284	13,283	24,082	1,868,197	132,382	2,041,228
7/10/79	876	0	0	0	0	876
7/31/79	1,663	12,760	0	0	0	14,423
8/15/79	3,045	0	14,688	0	0	17,733
8/27/79	2,555	6,418	40,748	217,087	78,110	344,918
9/25/79	0	0	0	96,302	242,859	339,161
Total	244,999	47,683	130,235	283,175,763	1,757,136	285,355,816

Gammarus fasciatus were captured at night on 16 April and 15 May at the 40 foot (12.2m) and 5 foot (1.5m) contours, respectively (Figure 7; Table 17). All G. fasciatus were captured at station 2 during spring sampling with most estimated at 40 feet (12.2m).

Gammarus pseudolimnaeus were collected in day tows on 28 June and on 10 July (Figure 6). Most G. pseudolimnaeus were distributed at the 20 (6.1m) and 30 foot (9.1m) contours at station 2 on these dates. No G. pseudolimnaeus were captured at the 5 (1.5m) and 10 foot (3.0m) contours during summer day sampling. No G. pseudolimnaeus were collected shoreward of the 40 foot (12.2m) contour at stations 1, 3 or 4.

The majority of G. pseudolimnaeus captured in night tows were taken at station 1 (Figure 6). A general trend of decreasing northward abundance at all contours was indicated from summer sampling. Most G. pseudolimnaeus were collected on 26 June and 27 August (Table 16). All individuals collected on these dates at the 5 and 10 foot contours were immature.

Gammarus fasciatus were only collected on 31 July during daylight sampling in 1979 (Figure 7). These individuals were all juveniles. Mature G. fasciatus were collected at night on 28 June at the 30 foot (9.1m) contour at station 1. All other night collections of G. fasciatus were composed of juvenile instar organisms.

Gammarus pseudolimnaeus were only collected during fall in night tows made at the 40 (12.2m) and 30 foot (9.1m) contours at stations 1 and 4, respectively (Figure 6). Gammarus fasciatus were captured in night tows made at the station 1, 5 (1.5m) and 40 foot (12.2m) contours (Figure 7). All individuals collected were juveniles.

Table 17. Numbers of *Gammarus fasciatus* estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth					Total
	5	10	20	30	40	
4/16/79	0	0	0	0	692,703	692,703
5/1/79	1,042	0	0	0	0	1,042
5/15/79	0	0	0	0	0	0
5/29/79	0	0	0	0	0	0
6/12/79	0	0	0	0	0	0
6/28/79	0	0	0	172,427	0	172,427
7/10/79	0	0	0	0	0	0
7/31/79	0	0	0	0	0	0
8/15/79	8,407	0	0	0	0	8,407
8/27/79	5,413	25,937	0	111,484	0	142,833
9/25/79	2,284	0	0	0	248,048	250,332
Total	17,146	25,937	0	283,911	940,751	1,267,745

Entrainment

Gammarus pseudolimnaeus entrainment peaked on 29 May (Tables 2 and 18). Peak *G. pseudolimnaeus* farfield density occurred at the 30 foot (9.1m) contour on this date at station 2 (Figure 6; Table 18). *Gammarus fasciatus* were identified in Lake Michigan tows made at the 40 (12.2m) and 5 foot (1.5m) contours on 16 April and 1 May, respectively, at station 2 in the farfield area (Figure 7). However, no *G. fasciatus* were identified from entrainment samples in spring (Table 19).

Gammarus spp. entrainment exhibited marked fluctuations during summer (Tables 18 and 19). Numbers of entrained *Gammarus sp.* appeared to be increasing in late August. All amphipods were captured in greatest numbers during the 0200h sample interval (Table 3).

Numbers of *Gammarus spp.* decreased in fall entrainment collections (Tables 18 and 19). Most of these individuals were juveniles.

Reservoir

A total of 15 *Gammarus pseudolimnaeus* were captured during reservoir sampling in 1979. Most *G. pseudolimnaeus* were collected during night sampling with peak density occurring at station 9 on 28 May (Table 20). Densities were higher at station 9 on dates when *G. pseudolimnaeus* were sampled.

Nine *Gammarus fasciatus* were taken during night tows made in the reservoir in 1979. Organisms were captured on 15 May and 27 August at station 7 and 9, respectively (Table 21).

Table 18. Total number of *Gammarus pseudolimnaeus* estimated to be entrained into the Ludington Pumped Storage Reservoir during 1979.

Sample Date	Number Entrained	Estimated Number Entrained for Interval	Interval
4/16/79	77,657	1,129,575	4/12 - 4/24
5/1/79	0	0	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	109,555	1,357,824	5/23 - 6/5
6/12/79	37,396	614,060	6/6 - 6/20
6/28/79	40,736	465,864	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
7/31/79	0	0	7/22 - 8/8
8/15/79	61,755	999,064	8/9 - 8/21
8/27/79	93,731	3,229,631	8/22 - 9/11
9/25/79	147,243	3,345,678	9/12 - 10/12
10/30/79	0	0	10/13 - 11/12
		11,141,696	4/12 - 11/12

Table 19. Total number of *Gammarus fasciatus* estimated to be entrained into the Ludington Pumped Storage Reservoir during 1979.

Sample Date	Number Entrained	Estimated Number Entrained for Interval	Interval
4/16/79	0	0	4/12 - 4/24
5/1/79	0	0	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/27/79	0	0	5/23 - 6/5
6/12/79	91,544	1,503,192	6/6 - 6/20
6/28/79	0	0	6/21 - 7/4
7/10/79	40,505	591,093	7/5 - 7/21
7/31/79	42,313	956,880	7/22 - 8/8
8/15/79	0	0	8/9 - 8/21
8/27/79	365,732	12,601,753	8/22 - 9/11
9/25/79	106,638	2,423,050	9/12 - 10/12
10/30/79	0	0	10/13 - 11/12
		18,075,968	4/12 - 11/12

Table 20. Mean densities of Gammarus pseudolimnaeus (#/1000m^3) in samples from the Ludington Pumped Storage Reservoir during 1979.

	Station 7		Station 9		Total Reservoir Density	
Date	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	0	0	---	0	0
5/28/79	0	8	12	27	6	18
6/12/79	0	9	---	12	0	11
6/28/79	0	0	0	0	0	0
7/10/79	0	0	0	0	0	0
7/31/79	0	0	0	6	0	3
8/15/79	0	0	0	17	0	8
8/27/79	0	0	0	0	0	0
9/25/79	0	0	0	0	0	0

Table 21. Mean densities of Gammarus fasciatus (#/1000m^3) in samples in the Ludington Pumped Storage Reservoir during 1979.

Date	Station 7		Station 9		Total Reservoir Density	
	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	18	0	---	0	18
5/28/79	0	0	0	0	0	0
6/12/79	0	0	0	0	0	0
6/28/79	0	8	0	0	0	4
7/10/79	0	0	0	0	0	0
7/31/79	0	0	0	0	0	0
8/15/79	0	0	0	0	0	0
8/27/79	0	0	0	20	0	10
9/25/79	0	0	0	0	0	0

Extrainment

Extrainment estimates of Gammarus pseudolimnaeus peaked on 1 May declining thereafter during spring sampling (Table 22). No Gammarus fasciatus were collected in spring extrainment samples (Table 23).

Point estimates of numbers of Gammarus pseudolimnaeus extrained in summer ranged from 0 values recorded on three dates, to the summer mode on 15 August (511,498; Table 22). Percentage release of entrained Gammarus pseudolimnaeus exceeded 100% on all dates except 27 August when no G. pseudolimnaeus were estimated to be released.

Release rates of Gammarus fasciatus exhibited marked fluctuations during summer (Table 23). G. fasciatus were taken in entrainment tows on three of six dates yielding estimates ranging from 0 to 3,733,099. Approximately 31% of the G. fasciatus entrained into the pumped storage reservoir were estimated to be returned to Lake Michigan.

Extrainment tows made on 26 September collected no gammarids (Tables 4, 22 and 23).

Pontoporeia hoyi

Farfield

No Pontoporeia were captured off bottom during spring farfield day collections made in 1979 (Figure 8).

Highest night concentrations of Pontoporeia hoyi occurred at the 40 foot (12.2m) contour (Figure 8; Table 24). Most Pontoporeia appeared to be distributed at station 2, lakeward of the 10 foot (3.0m) contour (Figure 8). Overall, greatest numbers of Pontoporeia were captured on

Table 22. Total number of Gammarus pseudolimnaeus estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	595,486	1,207,211	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	39,958	442,587	5/23 - 6/5
6/12/79	72,112	1,993,947	6/6 - 6/20
6/28/79	136,201	1,558,474	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
8/1/79	0	0	7/22 - 8/8
8/15/79	511,498	6,218,842	8/9 - 8/21
8/27/79	0	0	8/22 - 9/11
9/26/79	0	0	9/12 - 10/12
		11,421,082	4/25 - 10/12

Table 23. Total number of *Gammarus fasciatus* estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	0	0	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	0	0	5/23 - 6/5
6/12/79	15,667	433,198	6/6 - 6/20
6/28/79	0	0	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
8/1/79	0	0	7/22 - 8/8
8/15/79	52,903	643,203	8/9 - 8/21
8/27/79	231,136	3,733,099	8/22 - 9/11
9/26/79	0	0	9/12 - 10/12
		4,809,500	4/25 - 10/12

Figure 8. Density (No./1000m^3) of *Pontoporeia hoyi* at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

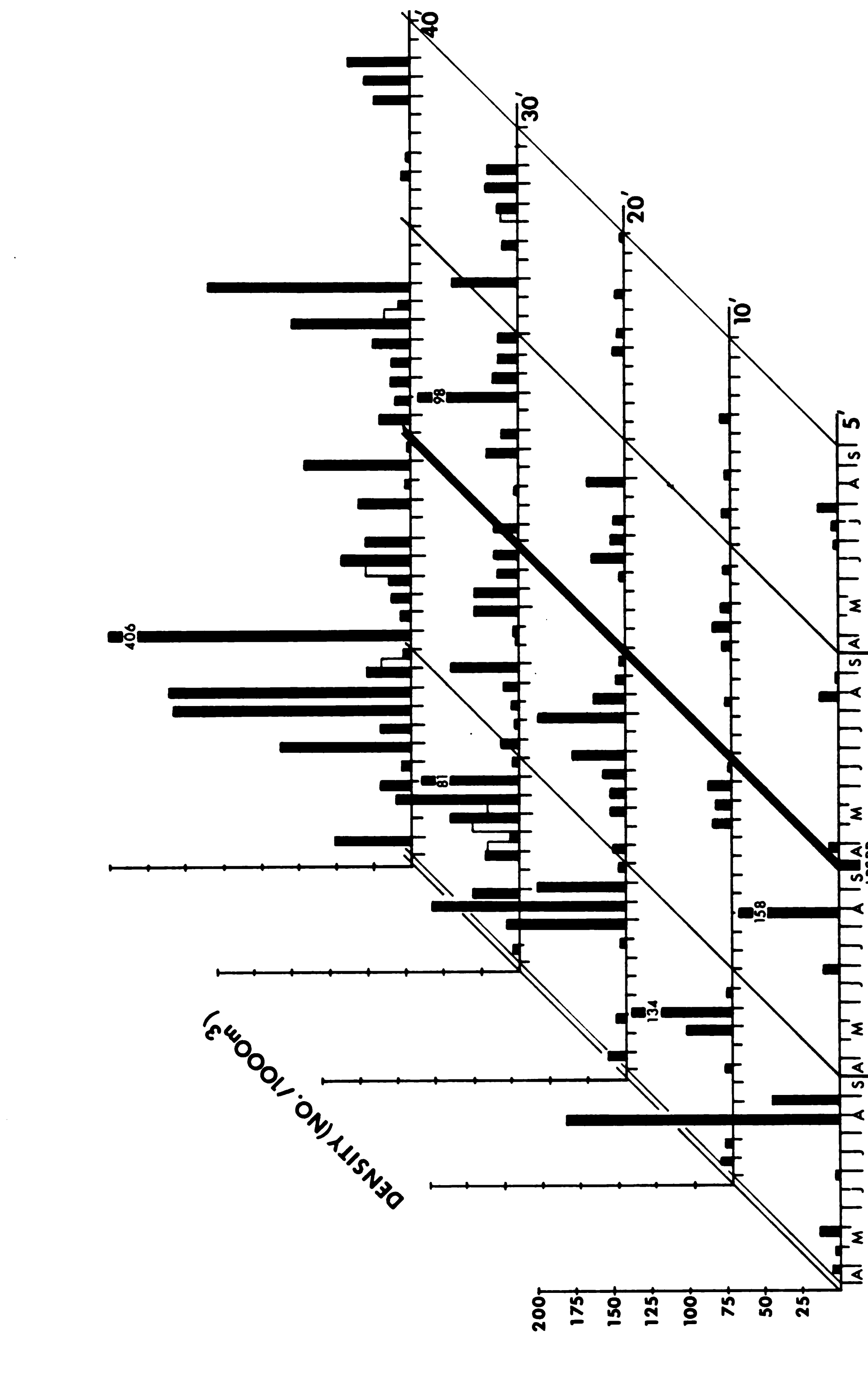

DENSITY (NO./1000m³)
200
175
150
125
100
75
50
25
STATION 1
STATION 2
STATION 3
STATION 4
LPSPP
406
98
81
158
134
40'
30'
20'
10'
5'

Table 24. Numbers of _Pontoporeia hoyi_ estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth					Total
	5	10	20	30	40	
4/16/79	2,656	17,260	100,806	545,538,400	12,964,510	558,623,632
5/1/79	795	14,462	0	138,627	355,524	509,408
5/15/79	4,403	7,704	67,612	848,843	3,226,117	4,154,679
5/29/79	0	5,112	46,491	544,490	1,785,417	2,381,510
6/12/79	0	0	172,768	1,068,823	2,264,044	3,505,635
6/28/79	3,992	14,196	165,322	3,153,112	5,085,730	8,422,352
7/10/79	1,123	33,875	42,162	568,040	1,470,453	2,115,653
7/31/79	2,289	111,780	631,936	4,373,878	10,212,110	15,331,993
8/15/79	80,369	243,549	643,655	2,194,071	5,730,863	8,892,507
8/27/79	14,473	43,948	265,210	1,551,422	2,098,589	3,973,642
9/25/79	0	4,780	75,259	521,310	230,642	831,991
Total	110,100	496,666	2,211,221	560,501,016	45,423,999	608,743,002

16 April. Mature males predominated in sample collections made on this date.

Most *Pontoporeia hoyi* captured in night tows during summer near the Ludington Plant were collected at the 40 foot (12.2m) contour (Figure 8). The majority of *Pontoporeia* were distributed at station 1. Numbers of *Pontoporeia* captured off bottom increased over summer, peaking on 31 July.

Pontoporeia were captured in day tows on 26 September at the station 1, 40 foot (12.2m) contour (Figure 8). Nearly all *Pontoporeia* collected in night tows on this date were taken from stations 1 and 2 lakeward of the 10 foot (3.0m) contour. Fall densities of *Pontoporeia* had declined to approximate spring levels.

Entrainment

A precipitous decrease in *Pontoporeia* entrainment occurred on 15 May (Table 25). However, estimates of *Pontoporeia* in Lake Michigan were increasing (Table 24). Farfield densities at the impact stations were highest at the 40 foot (12.2m) contour.

Entrainment estimates of *Pontoporeia* were extremely variable, occasionally exhibiting more than a ten-fold increase during summer sampling (Table 25). Significant increases were noted in late July and early August. The peak summer entrainment estimate of 607,474 occurred on 15 August (Table 25).

Numbers of *Pontoporeia* decreased in fall entrainment collections (Table 25). Nearly all amphipods entrained in fall were juveniles.

Table 25. Total number of *Pontoporeia hoyi* estimated to be entrained into the Ludington Pumped Storage Reservoir during 1979.

Sample Date	Number Entrained	Estimated Number Entrained for Interval	Interval
4/16/79	118,772	1,727,608	4/12 - 4/24
5/1/79	61,708	783,082	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	25,359	314,304	5/23 - 6/5
6/12/79	37,159	610,168	6/6 - 6/20
6/28/79	39,253	448,906	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
7/31/79	426,815	9,652,215	7/22 - 8/8
8/15/79	607,474	9,827,585	8/9 - 8/21
8/27/79	0	0	8/22 - 9/11
9/25/79	263,878	5,995,881	9/12 - 10/12
10/30/79	153,522	5,447,306	10/13 - 11/12
		34,807,055	4/12 - 11/12

Reservoir

Low numbers of Pontoporeia hoyi were taken in reservoir tows during both day and night sampling. The only occurrence of Pontoporeia in day tows was on 28 May at station 9 (Table 26). The initial appearance of Pontoporeia in night tow samples also occurred on 28 May. Peak pelagic density was noted on 10 July at station 7 (Table 26). Most Pontoporeia were collected in night tows made at station 9 with densities ranging from 0 - 26 individuals per $1000m^3$ of water recorded.

Extrainment

Pontoporeia were collected in extrainment samples only on 15 August during summer sampling (Table 27). Pontoporeia were collected during extrainment sampling on four of six dates during summer (Table 4).

No Pontoporeia sp. were captured in extrainment tows made on 26 September (Table 27).

Oligochaetes

Farfield

The only collections of oligochaetes during farfield day tows in spring were made on 29 May at station 1 (Figure 9). The majority of naidid oligochaetes taken at night were also captured on this date with most collected south of the power plant (stations 1 and 2). Most naidid oligochaetes were collected at station 2. At stations where oligochaetes were taken there appeared to be a trend of lakeward increase in spring (Table 28).

Peak pelagic abundance of naidid oligochaetes was evident during

Table 26. Mean densities of Pontoporeia hoyi (#/1000m^3) in samples from the Ludington Pumped Storage Reservoir during 1979.

	Station 7		Station 9		Total Reservoir Density	
Date	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	0	0	---	0	0
5/28/79	0	0	17	18	8	9
6/12/79	0	0	---	0	0	0
6/28/79	0	0	0	26	0	13
7/10/79	0	57	0	6	0	31
7/31/79	0	0	0	3	0	1
8/15/79	0	0	0	17	0	8
8/27/79	0	13	0	5	0	9
9/25/79	0	0	0	24	0	12

Table 27. Total number of *Pontoporeia hoyi* estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	0	0	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	0	0	5/23 - 6/5
6/12/79	0	0	6/6 - 6/20
6/28/79	0	0	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
8/1/79	0	0	7/22 - 8/8
8/15/79	624,090	7,587,741	8/9 - 8/21
8/27/79	0	0	8/22 - 9/11
9/26/79	10,400	217,401	9/12 - 10/12
		7,805,142	4/25 - 10/12

Figure 9. Density (No./$1000m^3$) of oligochaetes (Naididae) at different stations and contours near the Ludington Pumped Storage Power Plant in 1979.

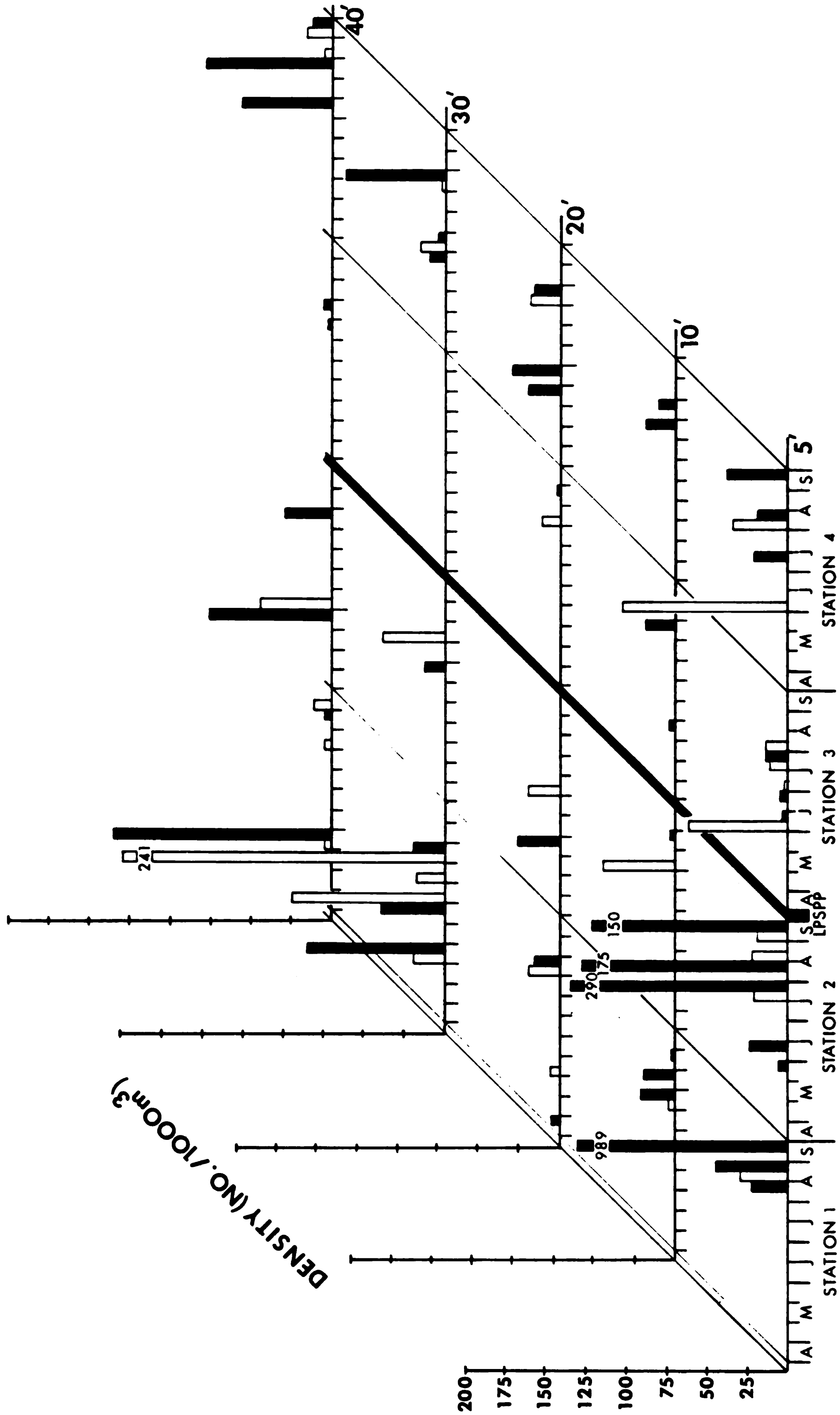

DENSITY (NO./1000m³)
200
175
150
125
100
75
50
25
STATION 1
STATION 2
STATION 3
STATION 4
5'
10'
20'
30'
40'
989
290
175
150
241
LPSPP

Table 28. Numbers of naidid oligochaetes estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth					Total
	5	10	20	30	40	
4/16/79	0	0	20,879	0	1,019,550	1,040,429
5/1/79	0	0	0	0	0	0
5/15/79	0	0	0	0	0	0
5/29/79	1,909	25,866	156,267	1,288,199	5,877,208	7,349,449
6/12/79	34,715	0	106,057	152,699	0	293,471
6/28/79	518	0	0	710,709	0	711,227
7/10/79	4,750	0	0	137,730	2,021,834	2,164,314
7/31/79	143,836	66,245	0	0	136,114	346,195
8/15/79	46,680	83,900	126,918	2,608,990	3,065,348	5,931,836
8/27/79	8,242	39,004	0	0	77,137	124,383
9/25/79	240,205	0	0	0	473,218	713,423
Total	480,855	215,015	410,121	4,898,327	12,670,409	18,674,727

summer farfield tows (Figure 9). Highest daylight density ($241/1000m^3$) was recorded on 15 August at station 1, 30 foot (9.1m) contour. Oligochaetes were collected at all stations on this date. Most naidids captured in day tows were taken at station 1. Peak night densities of naidid oligochaetes occurred at the 5 foot (1.5m) contour during summer sampling with the mode ($290/1000m^3$) occurring on 31 July. Lowest pelagic densities during night sampling occurred lakeward of the 10 foot (3.0m) contour at stations 3 and 4. Estimated abundance within the hypothetical rectangle was highest at the 40 foot (12.2m) contour (Table 28).

Naidid oligochaetes were collected in day tows made at the 40 foot (12.2m) contour at stations 1 and 4 in fall (Figure 9). Peak day collection density was noted at the 5 foot (1.5m) contour at station 2. Peak density ($989/1000m^3$) for the sampling year occurred in night collections made at the 5 foot (1.5m) contour. Greatest numbers of naidids were estimated at the 40 foot (12.2m) contour as a consequence of volume increases with depth (Table 28).

Entrainment

Oligochaetes were collected on two occasions during spring entrainment sampling (Table 2).

All oligochaetes entrained during summer sampling were members of the family Naididae (*Nais sp.* and *Stylaria sp.*). Oligochaete entrainment values ranged from 0 - 1,461,605 during summer (Table 2).

No oligochaetes were captured in fall tow series during entrainment sampling.

Reservoir

The first collection of naidid oligochaetes during day tows occurred on 28 May at station 9 (Table 29). Peak day pelagic density occurred on this date. Collection of naidids was quite sporadic with densities ranging from 0 - 21 organisms per $1000m^3$. Initial appearance of naidid oligochaetes in night tow samples was delayed until 15 August (Table 29). Peak night pelagic density was recorded on this date at station 9. Definitive conclusions on naidid distribution patterns were obscured by their limited occurrence in samples. General trends indicated that the majority of organisms were concentrated at station 7.

Extrainment

Highest release during spring sampling occurred on 29 May for oligochaetes (Table 30). These were identified as mostly Nais sp. with some Stylaria sp. also present.

The entrainment value for naidid oligochaetes averaged roughly 6% of the corresponding summer extrainment estimate. Substantial numbers of oligochaetes were released from the reservoir in late August (Table 30).

Minor Taxa

Farfield

Ephemeroptera were collected infrequently in spring farfield night tows. Members of the families Siphlonuridae (Isonychia sp.) and Heptageniidae (Heptagenia sp.) were collected at all stations. Heaviest concentrations appeared to be shoreward of the 30 foot (9.1m) contour (Table 31) for Heptagenia sp., with most distributed at stations 1 and

Table 29. Mean densities of naidid oligochaetes (#/1000m^3) in samples from the Ludington Pumped Storage Reservoir during 1979.

Date	Station 7		Station 9		Total Reservoir Density	
	Day	Night	Day	Night	Day	Night
5/10/79	0	---	0	---	0	---
5/15/79	0	0	0	---	0	0
5/28/79	0	0	21	0	10	0
6/12/79	0	0	---	0	0	0
6/28/79	0	0	0	0	0	0
7/10/79	8	0	0	0	4	0
7/31/79	0	0	10	0	5	0
8/15/79	0	1,617	10	3,977	5	2,797
8/27/79	0	1,640	4	15	2	827
9/25/79	0	8	0	0	0	4

Table 30. Total number of naidid oligochaetes estimated to be released from the Ludington Pumped Storage Reservoir during 1979.

Date	Number Extrained	Estimated Number Moved for Interval	Interval
5/1/79	27,702	56,159	4/25 - 5/8
5/15/79	0	0	5/9 - 5/22
5/29/79	76,287	844,978	5/23 - 6/5
6/12/79	40,526	1,403,452	6/6 - 6/20
6/28/79	0	0	6/21 - 7/4
7/10/79	0	0	7/5 - 7/21
8/1/79	89,235	1,564,485	7/22 - 8/8
8/15/79	1,377,006	16,741,760	8/9 - 8/21
8/27/79	738,914	11,934,293	8/22 - 9/11
9/26/79	0	0	9/12 - 10/12
		32,545,127	4/25 - 10/12

Table 31. Numbers of Heptageniidae (Ephemeroptera) estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

	Contour Depth					
Date	5	10	20	30	40	Total
4/16/79	0	0	22,414	115,899	0	138,313
5/1/79	2,438	6,753	43,810	119,006	0	172,007
5/15/79	214,925	106,602	499,461	1,923,837	1,281,283	4,026,108
5/29/79	6,343	5,362	47,252	108,336	55,463	322,756
6/12/79	4,349	0	0	180,764	0	185,113
6/28/79	0	0	0	0	0	0
7/10/79	0	0	0	0	0	0
7/31/79	4,990	0	0	0	0	4,990
8/15/79	0	0	0	0	0	0
8/27/79	0	0	0	0	78,974	78,974
9/25/79	4,359	0	0	0	252,522	256,881
Total	237,404	118,717	612,937	2,447,842	1,768,242	5,185,142

2. Siphlonuridae were distributed at all stations on 1 May but were captured mainly at the 40 foot (12.2m) contour (stations 2 and 3) during the 15 and 29 May sample series (Table 32).

Members of the families Perlodidae (Isoperla sp.) and Chaoboridae (Chaoborus sp.) were also collected sporadically during spring farfield tows as well as members of the order Hirudinea.

Mayflies (Ephemeroptera) were collected occasionally during farfield tows made in summer. Members of the families Baetidae (Baetis sp.), Heptageniidae (Heptagenia sp.), and Siphlonuridae (Isonychia sp.) appeared in samples. Heptagenia sp. and Isonychia sp. were captured primarily at the 5 (1.5m) and 10 foot (3.0m) contours (Tables 31 and 32), while Baetis sp. were taken in deeper water.

Chaoboridae, Ceratopogonidae (Diptera), Tubificidae (Oligochaeta), Hydropsychidae (Trichoptera) and Hirudinea also were identified from tows made at night in the farfield area during summer.

Hydropsychid caddisflies (Trichoptera), heptageniid mayflies (Ephemeroptera) and tubificid oligochaetes were also collected in the fall sample series in low numbers.

Entrainment

Chaoboridae (Chaoborus sp.), Perlodidae (Isoperla sp.), Heptageniidae (Heptagenia sp., Stenonema sp.), Isopoda (Asellus sp.) and Ephemeridae were infrequently collected during the course of entrainment sampling in 1979 (Table 2). Their occurrence in reservoir and extrainment samples was similarly low.

Table 32. Numbers of Siphlonuridae (Ephemeroptera) estimated to be contained within contour intervals in a 2.4 x 9.7km hypothetical rectangle near the Ludington Pumped Storage Power Plant in 1979.

Date	Contour Depth					Total
	5	10	20	30	40	
4/16/79	0	0	0	0	0	0
5/1/79	5,887	81,754	105,191	1,060,974	1,256,945	2,510,751
5/15/79	0	0	0	0	244,348	244,348
5/29/79	0	5,645	0	0	79,503	85,148
6/12/79	19,904	0	0	0	330,689	350,593
6/28/79	4,258	0	0	0	0	4,258
7/10/79	0	0	0	0	0	0
7/31/79	0	0	0	0	0	0
8/15/79	2,737	0	0	0	0	2,737
8/27/79	1,410	0	0	56,712	0	58,122
9/25/79	0	0	0	0	0	0
Total	34,196	87,399	105,191	1,117,686	1,911,485	3,225,957

DISCUSSION

Mysis relicta

Mysis relicta was the most common taxa distributed in the farfield area and entrained into the pumped storage reservoir (Tables 2 and 5). *Mysis* were the third most abundant organism returned to Lake Michigan (Table 4). *Mysis relicta* is primarily a benthic organism abundant in deep waters (>25m), but has been recorded in the shallows in spring and fall (Carpenter et al. 1974, Holmquist 1959). Beeton (1960) documented the vertical migrations undertaken by mysids in the Great Lakes. Reynolds and Degraeve (1972) recorded migration across depth contours. These migrations are a year-round phenomenon in deep lakes in the temperate zone (Morgan and Beeton 1978, Brownell 1970). *Mysis* serve as a fish food source at various stages, times or seasons during their existence (Michigan State University, Ludington Research Laboratory, unpublished data).

Mysis were taken in spring farfield day tows only on 29 May (Figure 3). Their low incidence was either a consequence of gear avoidance during day tows or a negative phototactic response. Beeton (1960) recorded initiation of *Mysis* descent when surface light intensity increased from 10^{-3} to 10^{-2} ft-candle during night sampling, indicating a marked sensitivity to intense light. In laboratory experiments, at least two visual pigments were isolated, one with an absorption peak at

515mμ and another with a peak at or below 395mμ (Beeton 1959). He concluded that sensitivity at 515mμ was important in orientation, and sensitivity to violet light (395mμ) possibly initiated negative phototaxis. Degraeve and Reynolds (1975) found mysids to be more tolerant of intense light at low temperatures.

Peak *Mysis* densities at the 12.2m contour during spring night tows occurred on 16 April at stations 2 and 3 (Figure 3). High densities were also recorded on this date at the 6.1m and 9.1m contours. Table 6 lists the entrainment estimate on this date, indicating that organisms distributed lakeward of the 6.1m contour at these stations (2 and 3) were more susceptible to pumping currents created by the plant. Most water entrained from Lake Michigan on the pumping mode is drawn from depths lakeward of 6m. Table 5 lists the estimated number of mysids contained within the hypothetical rectangle. Approximately 1% of the mysids estimated to be distributed in this volume (188,499,840m^3) were entrained on 16 April. Maturity data indicated that entrained *Mysis* were adult (11 - 15mm) and subadult (6 - 10mm) instars. Gravid females were evident in tow collections. Current data collected in 1978 revealed highest velocities between the 6 and 14m contours near the power plant (Liston et al. 1979). Peak spring entrainment occurred on 29 May when approximately 18% of the *Mysis* within the hypothetical rectangle were entrained (Table 5). *Mysis* densities at the 6.1m and 9.1m contours at stations 2 and 3 were roughly equivalent to values recorded on 16 April. However, maturity data for mysids indicated that most individuals collected on 29 May were juveniles (<6mm). It appears that juvenile *Mysis* are less able to actively avoid entrainment. Juvenile *Mysis* move further and descend later than adults (Brownell 1970, Beeton 1960).

This behavioral characteristic may possibly increase both the degree and duration of exposure to pumping currents and subsequent entrainment. Lessened inshore abundance appeared to be the cause of the decline in adult (>11mm) mysids collected in farfield and entrainment tows as spring sampling progressed. Table 5 lists *Mysis* distribution at depths in Lake Michigan. Those individuals taken shoreward of the 6.1m contour through 15 May were late instars (<9mm). Peak spring farfield concentration occurred on 1 May. Feeding on the spring bloom of *Melosira* was recorded by Bowers and Grossnickle (1978). *Melosira* is abundant during this period in the study area (Liston and Tack 1973).

Reservoir maturity data indicated most mysids taken were adults concentrated at densities above spring farfield values (Table 7, Figure 3). The higher reservoir densities for this length category indicate prolonged residence after initial entrainment of *Mysis*. Extended residence seems likely since entrainment values were higher than extrainment values over corresponding intervals during spring (Table 4). Definitive conclusions are obscured by data gaps in reservoir and extrainment samples in early spring.

The incidence of *Mysis* in day tows during summer sampling increased but still remained significantly lower than night sample densities (Figure 3). The day-night catch disparity was either a consequence of vertical distribution or gear avoidance. Most mysids captured in day tows were taken at the 12.2m contour as a consequence of negative phototactic response. Juveniles dominated day collections. Tattersall and Tattersall (1951) concluded that immature *Mysis relicta* were less sensitive to light. Holmquist (1959) encountered *Mysis* concentrated several meters off-bottom in 8 - 20m of water on a cloudy, rainy afternoon. Variations in Mysis distribution during day tows appeared to be a consequence of stage of maturity of the individuals collected, secondarily influenced by varying meteorological conditions.

Mysis farfield night densities increased during summer sampling as mysids moved inshore on feeding forays (Figure 3). Major increases at inshore contours (<9m) were a function of escalated numbers of juveniles captured in collections. Release of young was recorded in May by Beeton (1960) in Lakes Michigan and Huron. Adult mysids were predominantly distributed at farfield stations at depths greater than 6m during summer sampling. Vertical migrations of adults was arrested at approximately 10m in offshore waters (Beeton 1960). This was attributed to active concentration near the metalimnion. Nocturnal Mysis migrations into a metalimnetic chlorophyll *a* maximum were observed by Bowers and Grossnickle (1978). Grossnickle (1979) found these migrations to be a response to food availability. McWilliams (1970) recorded remains of Cladocera sp., diaptomid copepods, Melosira sp., Tabellaria sp. and Stephanodiscus sp. in mysid digestive tracts. Smaller frustules of the same diatoms were found in juveniles. Lasenby and Langford (1973) found mysids to be carnivorous at night and omnivorous by day, feeding on Daphnia sp., Kellicottia sp., algae and detritus. Juveniles <6mm fed exclusively on algae and detritus. Melosira sp. was recorded in high concentrations in April (35 - 40/ml) and late June (60 - 80/ml) in Lake Michigan (Liston and Tack 1973). Tabellaria fenestrata and Stephanodiscus also were noted at peak concentrations during the period late April - early May. Both Melosira sp. and Stephanodiscus sp. are euplanktonic, while Tabellaria fenestrata may be tycoplanktonic. These diatoms would be distributed in the water column. Water temperatures during this period are normally 5 - 9C in the inshore zone.

Mysis density increases on 31 July at the 6.1m and 9.1m contours at stations 1 and 2, and the 3.0m contour at station 2 were the consequence of an upwelling. Bottom temperature was found to have a greater influence than depth on shoreward distribution of mysids (Reynolds and Degraeve 1972). Shoreward increases were also noted during upwellings, and Beeton (1960) noted increased densities near surface associated with upwellings. Hulbert (1957) found horizontal migrations to be affected by currents or active seeking of more favorable substrate.

Mysis maturity data indicated that both adults and subadults increased in inshore tows made on 31 July. Brooks and Torke (1977) described an algal layer situated near the metalimnion in summer. As previously stated, Bowers and Grossnickle (1978) recorded Mysis migration into this algae layer. Large quantities of Cladophora sp. were noted in collections made on 31 July at depths above the matalimnion. Larkin (1948) found Mysis abundant among Cladophora sp. in shallow bays of Great Slave Lake.

Mysis densities on 31 July were greatest at the 6.1 and 9.1m contours at stations 2 and 3 (Figure 3). Concomitant entrainment increases were again noted with farfield density increases at the 6.1 and 9.1m contours at stations 2 and 3 (Table 2, Figure 3). As previously stated, most water moved through the plant is drawn from the 6m contour lakeward (Liston et al. 1979). The accompanying entrainment increase (1396/1000m^3; peak value for the collection term) was caused by either active migration to shallower depths at the impact stations (2 and 3) or passive transport in upwelling currents. High Mysis densities were also noted at the 6.1 and 9.1m contours at stations 2 and 3 on 10 July, resulting in high numbers entrained (Figure 3, Table 5). Bowers and Grossnickle (1978) recorded peak metalimnetic chlorophyll *a* concentrations ($9 mg/m^3$) to occur at inshore stations. Reynolds and Degraeve (1972) presented evidence for mysid migration across depth contours at their shallow stations (9 - 55m). Mysis possibly are concentrated on the edge of the nearshore zone and move inshore when food is abundant, making them susceptible to entrainment.

Mysis, particularly adult instars, avoided the nearshore zone after the formation of a well defined metalimnion in early August as indicated by declining farfield and entrainment densities (Tables 2 and 5). Beeton (1960) felt high epilimnetic temperatures repressed mysid migration. McNaught and Hasler (1966) found approximately 75% of their population did not migrate across the metalimnion. Brownell (1970) found immatures (<6mm) to migrate approximately 10m past the thermocline at a change of 2c/m. Degraeve and Reynolds (1975) indicated that Mysis relicta can tolerate temperatures up to 13C, but mortality increased rapidly at temperatures above 13C. Lethal temperatures varied with exposure duration. Beeton (1960) recorded ascent rates ranging from 0.4m/min. to 0.8m/min. Using these ascent rates and the average range between hypolimnetic and surface water temperature for Lake Michigan near Ludington of 1.18C to 1.57C during stratification, Mysis would be exposed to temperature rate increases ranging from .47c/min. to 1.97c/min. during migrations. The upper limit is approximately twice the rate of increase used by Degraeve and Reynolds (1975) which yielded a TL_{50} (median tolerance limit) of 20.4C, with marked mortality increase above 13C. Water temperature in the inshore waters of Lake Michigan normally ranges from 13 - 18C during stratification periods (Liston and Tack 1973).

Gravid females again appeared in farfield night collections in late July through early August. Females in the 16 - 20mm size class were collected during this period and in spring (16 April - 29 May). This agrees well with frequency peaks of instar V females recorded by Morgan and Beeton (1978) in Lake Michigan. They noted that these females composed a significant portion of the breeding population. The brood produced in late summer would be their second released (Morgan and Beeton 1978). Their absence nearshore during early summer was probably related to avoidance of elevated temperatures during the early part of embryo development. Berrill (1969) found heartbeat to be initiated in nauplii approximately three months old by temperature elevations from 3 to 15C. He also found periodic temperature elevation to stimulate the integration of activity rhythms (yolk movement, abdominal contraction, appendage fluttering). Tattersall and Tattersall (1951) documented that reproduction will not occur at temperatures above 7C. Gravid females possibly avoid the warm epilimnion in the early summer during the initial stages of nauplii development. Their movement into the epilimnion at night during the final stages of nauplii development initiating integration of organ systems. Brownell's (1970) findings support this hypothesis.

Increased farfield and entrainment representation by juveniles (<6mm) was a consequence of their proportional increase after release from the females' marsupia. Harder (1968) noted that young mysids showed no reaction to thermal stratification. Frequency peaks of <6mm individuals were noted in early April, and in late July through early August in sample tows in all areas. Morgan and Beeton (1978) found major peaks in the proportions of first instar individuals in tows made in March, July and November. McWilliams (1970) found four periods of release of juveniles in southern Lake Michigan. Instar peaks and corresponding size frequency data collected corresponded well with observed size frequency peaks in my collections in 1979.

Mysis distribution patterns in the reservoir during summer sampling underscored their documented avoidance of intense light and currents. (Degraeve and Reynolds 1975, Gregg and Bergerson 1980). Mysis densities in day tows were below farfield day densities at comparable depths with the exception of station 9 on 29 May (Figure 3, Table 7). Samples taken at station 9 on 29 May contained clay indicating that the net had bumped bottom. Those tows were not reflective of pelagic abundance.

Mysids collected at station 9 evidenced higher pelagic concentrations during day tows (Table 7). Mysis are possibly still disoriented from exposure to the pressure regime encountered during turbine passage. This, coupled with the tendency for "freshly" entrained water to be directed into the northern end of the reservoir resulting in the creation of severe currents possibly interfering with downward migration, may serve to keep the organisms suspended. Upward migration followed pressure increases in work done by Rice (1961). Light intensity variations didn't change the pressure response.

Night densities in the reservoir were either comparable or higher than farfield night densities at equivalent depths throughout the collection term. These data indicate extended residence after initial entrainment. Station 7 densities were higher than station 9 Mysis densities during night tows (Table 7). Current velocities are lower in the south end of the reservoir (Lawson 1977). Current directions and velocities have not been recorded in the reservoir because of assumed variability produced by combinations of units operating. However, the homeothermous condition of the reservoir (Liston et al. 1976) and daily cycling of water with Lake Michigan create severe currents. Mysis exhibit avoidance of current (Gregg and Bergerson 1980, Janssen 1978). Robertson et al. (1968) have directly observed actively swimming Mysis to maintain position in currents of 5 - 10cm/sec indicating possible avoidance of extrainment currents by Mysis. Survival in reservoir current regimes may also be possible but feeding would probably be limited or nonexistent in the reservoir. Bowers and Grossnickle (1978) were unable to initiate feeding in mysid cultures when current was introduced. Gregg and Bergerson (1980) found Mysis mortality on exposure to current to increase significantly over the 8-day experimental period. They also suggested that the adverse effect of turbulence increased with temperature elevation. Most (80 - 90%) of the mysids captured in summer reservoir tows were juveniles (<11mm).

Carpenter et al. (1974) documented Mysis increases in the shallows in fall. The incidence of mature (>11mm) mysids in farfield night tows increased in fall collections. Most were taken lakeward of the 6.1m contour at all stations (Figure 3). Entrainment estimates remained high for fall as a consequence of the high volumes of water withdrawn from Lake Michigan (Table 6). Fall reservoir densities were comparable to early summer estimates (Table 7).

Extrainment of mysids was low over the ten sample series in 1979 (Table 8). Overall, approximately 5.2% of entrained Mysis were estimated to be released by the plant (Table 4). Entrainment-extrainment comparisons analyzed seasonally, revealed highest percentage return of entrained mysids occurred in spring (14.3%). Percentage return values decreased from summer (5.1%) through fall (.4%). Organisms pumped into the reservoir may remain there for some time during periods of the year. Another important consideration was the frequency of entrainment-extrainment sampling in 1979. Low sampling frequency increased the possibility that large entrainment-extrainment peaks may have been missed, thus confusing the relationship between entrainment and extrainment. Greater numbers of *Mysis* were captured when samples were taken during periods of generation in darkness. Many organisms may leave the reservoir during the short periods when the plant generates after dark.

Estimation of *Mysis* release was calculated using a weighting factor to compensate for the hypothesized increase in densities during periods when the plant generated in darkness. A ratio of density after sunset to total density was determined on three dates when night samples were taken.

$$R = \frac{A}{T} \qquad \begin{array}{l} A = \text{density after sunset} \\ T = \text{"total" density} \\ R = \text{density ratio} \end{array} \qquad (6)$$

The ratios were averaged over the dates available. Through algebraic manipulation it can be shown then that:

$$A = \frac{R \times B}{1 - R} \qquad B = \text{density before sunset} \qquad (7)$$

This relation was used to calculate A on dates when only before sunset densities (B) were determined. Conversely, B could be estimated for dates when only A was available. The density estimates thus obtained were multiplied by the appropriate total volume for the sample period to produce estimated numbers extrained. In some cases the revised estimates were lower than the initial estimates, due mainly to changes in partitioning of the water volume moved.

A total of 75,484,303 Mysis were estimated to be released to Lake Michigan resulting in an estimate of 5.8% of the entrained mysids to be returned to the lake. Therefore, it would appear likely that a current related mortality factor is in operation in the reservoir. If Mysis are entrained while concentrated inshore during upwellings and then avoid extrainment currents as data indicate, prolonged residence time in the reservoir would expose them to elevated water temperatures from volumes moved during subsequent pumping periods. Loss of Mysis following initial entrainment may also be a function of intolerance to high water temperature (Degraeve and Reynolds 1975).

Survivorship of Mysis relicta cycled through the pumped storage power plant was extremely variable (Tables 33 and 34). Few mysids were captured both at the jetties and the control station during mortality sampling in 1979 and 1980. Sampling was geared primarily toward determination of ambient and plant induced ichthyoplankton mortalities. Nets towed in an oblique fashion would possibly have been more effective in capturing mysids. However, captured organisms would be subjected to additional abrasion along the net surface attendant with towing in this manner, increasing sampling induced mortality.

Samples taken on pumping and generating modes in 1979 indicated substantial survivorship independent of water temperature. Brownell (1970) noted that immature Mysis were not markedly affected by water temperature elevation. It is important to note that, with the exception of the 9 May samples all Mysis captured in tows were immatures (<11mm). Survivorship was 100% for the 9 May trial based on 3 individuals captured. Few Mysis were captured at the plant site during

Table 33. Survivorship of *Mysis* cycled through the Ludington Pumped Storage Reservoir in 1979.

Date	Water Temperature	Generate-Pump Alive		Generate-Pump Dead	Control Alive		Control Dead
5/9/79	7.8	3		0	0		0
			100%	Survivorship		--	
5/24/79	9.0	0		0	0		3
			--	Survivorship		0%	
6/5/79	12.0	12		2	0		0
			86%	Survivorship		--	
6/27/79	11.2	30		0	7		0
			100%	Survivorship		100%	
7/5/79	8.0	2		0	--		--
			100%	Survivorship		--	
8/6/79	15.2	35		3	2		1
			92%	Survivorship		67%	
8/28/79	17.0	50		0	0		0
			100%	Survivorship		--	
Totals		132		5	9		4
Total Survivorship			96%			69%	

Table 34. Survivorship of *Mysis* cycled through the Ludington Pumped Storage Reservoir in 1980.

Date	Water Temperature	Generate-Pump Alive		Generate-Pump Dead	Control Alive		Control Dead
4/30/80	7.8	0		0	20		0
			--	Survivorship		100%	
5/12/80	9.0	0		0	1		0
			--	Survivorship		100%	
5/27/80	12.0	1		3	0		0
			25%	Survivorship		--	
6/11/80	11.2	2		1	1		0
			67%	Survivorship		100%	
6/26/80	8.0	0		0	0		0
			--	Survivorship		--	
7/29/80	15.2	0		0	0		0
			--	Survivorship		--	
8/11/80	17.0	0		0	0		0
			--	Survivorship		--	
Totals		3		4	22		0
Total Survivorship			43%			100%	

mortality sampling in 1980. This was a consequence of sampling during daylight generating periods when mysid release rate was lowest.

As stated previously, plant impacts were based on the quantity of viable organisms returned to Lake Michigan in 1980. The low total survivorship at the plant evidenced in 1980 reflected the reservoir current-water temperature mortality factor. High survivorship in 1979 samples was a consequence of pooling samples taken on the generating and pumping modes since pumping mode samples contributed most to the total number of organisms captured. Sampling in 1978 also revealed high survivorship upon initial entrainment of mysids into the pumped storage reservoir (Liston et al. 1979).

Mortality assessment as a consequence of plant activity for 1979 revealed substantial estimated loss of Mysis. Calculated loss to Lake Michigan was 1,240,756,775 individuals for 1979. This results in an estimate of approximately 97% of Mysis unaccounted for after initial entrainment into the Ludington Pumped Storage Power Plant Reservoir. Effects of losses of this magnitude to the entire Lake Michigan system are inestimable. Mysis provide a substantial portion of the forage base, eaten by smelt, Osmerus mordax (Hale 1960), adult and juvenile bloaters, Coregonus hoyi (Yanusz 1979, Wells and Beeton 1963), juvenile lake trout, Salvelinus namaycush (Dryer et al. 1969), burbot, Lota lota (Bailey 1972) and fourhorn sculpins, Myoxocephalus quadricornis (Wells 1980). Actual losses of Mysis at the Ludington Plant may be lower simply as a consequence of underestimation of organism release from the plant. Extensive sampling to determine Mysis extrainment during periods of plant generation after darkness was not possible due to manpower limitations in 1979. Large numbers of mysids are suspected to leave the plant, particularly during periods of generation late in the week when reservoir volume is reduced. Since one of the variables in the model used to estimate losses is the number of organisms returned (extrained) to Lake Michigan, underestimation of organism release results in an over estimate of plant induced loss. Thus, the 1979 loss estimate is probably high but can be used as an upper-bound. Definitive conclusions with respect to *Mysis relicta* loss rate require the implementation of extensive field sampling to provide sufficient extrainment data to confidently address mortality determination.

Chironomidae

Chironomid larvae were the third most abundant organism distributed limnetically near the pumped storage plant (Table 9), and were second and first in dominance in entrainment and extrainment collections, respectively (Table 4).

The family Chironomidae is subdivided into seven subfamilies, Orthocladiinae, Chironominae, Diamesinae, Tanypodinae, Podonominae, Telmatogotoninae, and Aphroteniinae (Merritt and Cummins 1978). Orthocladiinae occur in both lentic and lotic habitats and are primarily distributed in colder regions. Tanypodinae and Chironominae are principally distributed in lentic habitats with higher numbers occurring in warm regions. The Diamesinae are, as a group, rheophilic, occupying well aerated habitats (Pennak 1978, Oliver 1971).

Chironomid dominance in spring farfield day tows at the 3.0 and 6.1m contours appeared to be caused by either active seeking of preferred substrates or passive transport in alongshore currents. Spring day densities were substantially below those recorded in night tows.

Chironomid limnetic activity peaked about 0200h based on entrainment sampling. Larvae developing in unfavorable substrates also actively migrate into the water column (Hilsenoff 1967). Turbulence created by storm activity may also cause pelagic migration in Chironomidae (Mundie 1957). The 1978 current data indicated peak velocities at 6 and 14m. Highest densities occurred at contours subjected to extrained water from the plant (Figure 4). Planktonic existence of first instar chironomids is a common dispersal mechanism (Davies 1974, Oliver 1971).

Peak farfield night densities in spring occurred in May at the 1.5 and 3.0m contours at stations 4 and 2, respectively. Tanypodinae were first noted in samples and were probably associated with increased oligochaete densities occurring on 29 May. Greatest overall densities were recorded at station 2. Farfield density increases at the 6.1 and 9.1m contours at stations 2 and 3 were followed by entrainment increases in May (Table 9, Figure 4, Table 11). Extrainment peaks coincided with entrainment peaks in spring. Highest day densities were recorded in the north end of the reservoir, thus maximizing exposure to extrainment currents. The dominance of _Tanypus sp._, _Procladius sp._, _Chironomus sp._, and _Glyptotendipes sp._ at shallow contours (1.5 and 3.0m) was probably related to food, temperature and substrate preference. Teter (1960) found _Chironomus sp._, _Crytochironomus sp._ and _Glyptotendipes_ to be restricted to shallow depths. Barton and Hynes (1978a) recorded _Chironomus fluviatilis_-grp. in gravel beds nearshore in spring in Lake Erie. McLachlan (1976) found _Glyptotendipes paripes_ to prefer coarse substrates. _Chironomus lugubris_ was found associated only with substrate types rich in micro-organisms (McLachlan and Dickenson 1977). Hilsenoff (1966) found _Chironomus plumosus_ to feed mostly on diatoms in

Lake Winnebago. Tanypus sp. and Procladius sp. are free living predators and are associated with food availability which would be high due to allochthonous inputs creating a rich faunal assemblage. Eukieferriella sp. and Monodiamesa sp. abundance at 10.0 and 12.2m was probably related to food and substrate preferences (Davies 1975, Dendy 1973), Thut 1969). Diamesinae were associated with rock or cobble substrates. A predominance of third and fourth instars was revealed in spring collections of Eukieferriella sp. The larvae overwinter as second and third instars and emerge in early summer the following year (Liston et al. 1978).

Chironomid pupae were collected during night at station 1 on 15 and 29 May at the 1.5 and 3.0m contours. Tanypodinae larvae and chironominae pupae were also present in reservoir collections. Peak emergence was recorded in late May (personal observation) and identified pupae were Chironominae, Diamesinae and Orthocladiinae. Hilsenoff (1966) linked Chironomus plumosus emergence to diatom density peaks in Lake Winnebago. This feeding stimulus was necessary for C. plumosus to pupate and emerge.

Highest day pelagic chironomid densities in summer occurred at station 2 shoreward of the 10.0m contour, probably as a consequence of wind generated current disruption of the sediments. Again day densities were substantially below those recorded at night. Hilsenoff (1966) found water currents to be an important determiner of C. plumosus distribution. Davies (1978) found chironomid larvae leave the substrate repeatedly in response to increases in water current speed at the sediment-water interface. Oliver (1971) suggests that chironomid movement in lakes may be density dependent, initiated by crowding, reduced resources, and/or unfavorable environment. These stimuli also may initiate migration into the water column near the power plant.

Entrainment peaks in summer occurred in early June and late August and were associated with density increases lakeward of the 6.1m contour at stations 2 and 3. Most entrained water is drawn lakeward of the 6.0m contour (Liston et al. 1979). Current data revealed highest velocities at 6 and 14m during plant operation modes. Plant generated currents may serve to increase migration from the substrate into the water column, thus increasing the susceptibility of larvae to entrainment currents. Chironomid extrainment trends and composition generally mimicked entrainment during summer.

The peak pelagic densities of chironomids during night tows in late July and August were partially a consequence of large numbers of third and fourth instar _Chironomus sp._ and _Cryptochironomus sp._ active in the water column. Late instar chironomid larvae commonly display premature pupal behavior (Davies 1974, Dugdale 1955). Peak pelagic activity culminated in emergence on 27 August. Similar pulses were noted in reservoir collections. Pupal densities were highest on this date at the 10 and 12.2m contours. Chironominae dominated pupal collections, but Tanypodinae and limited Diamesinae were also noted.

Peak larval density occurred at the 1.5m contour at station 1 but overall densities were highest at stations 1 and 2. This may indicate either higher benthic density south of the plant or greater migratory activity displayed by larvae in this area. Possible differences in substrate particle size may also influence larval distribution (Cummins and Lauff 1969, McLachlan 1969, Marks and Henderson 1970).

Duffy and Liston (1978) analyzing four years of benthic sampling in Lake Michigan found greater diversity evident in the benthic community south of the plant, particularly at station 1. Chironomids and oligochaetes dominate the benthic community at stations 2 and 3, with chironomid benthic abundance greatest between 6 and 12m. The relative homogeneity of the substrate at station 1 compared to those encountered at the impact stations (stations 2 and 3; Table 1 IN Duffy and Liston 1978) may account for the difference. Current data, collected in 1978 indicates plant generated currents are reduced at stations 2 and 3. However, the number of units operating, coupled with wind direction and ambient current conditions, can periodically subject benthos at these stations to current regimes above ambient levels during plant operation. Vertical migration exhibited by chironomids may be an avoidance response to this or other environmental disturbances (Davies 1978, Hilsenoff 1967, Bay et al. 1966, Waters 1964, Mundie 1957).

Most chironomids captured in fall day tows were taken at stations 1 and 4. Densities decreased lakeward with peak night density occurring at 2.0m on 26 September. Instar determination and pupal identification indicated that limited emergence of Orthocladiinae was occurring at this time.

Mortality associated with turbine passage for chironomid larvae was determined in 1979. Survivorship for chironomids was in excess of 95% so mortality assessment was not attempted. Entrained chironomids were determined to colonize the reservoir (Lawson 1977). Reservoir tows in 1979 indicated a build-up of chironomid larvae in the southern half of the reservoir (Table 12). Most of these individuals were *Chironomus sp.* Lawson (1977) reported the rare occurrence of orthoclads in benthos samples in the southern end. Chironominae were found to dominate the southern third of the reservoir, possibly as a response to current and food availability (Lawson 1977). The rheophilic species Monodiamesa sp. colonized the northern two-thirds of the reservoir. Major currents occur in this area and possibly, substrate and current regimes present in the reservoir may closely approximate those found in rivers. Day densities of pelagic chironomids were generally higher in the north end while night density peaks occurred in the southern portion of the reservoir (Table 12). This phenomenon was assumed to be associated with plant induced currents on the generating (day) and pumping (night) modes.

Distribution and degree of exposure to plant generated currents appears to be a consequence of microenvironmental preference for chironomids. Dispersal of first instar larvae by active migration into the water column appears to be behavioral (Oliver 1971). Migration by older instar individuals is initiated in response to storm generated turbulence (Davies 1974, Mundie 1966); unfavorable substrate (Hilsenoff 1966); crowding (Paterson and Fernando 1971); and decreased dissolved oxygen concentration (Bay et al. 1966).

The distribution of Chironomidae is assumed to be a result of the microdistribution patterns of current, substrate type and food. Wetzel (1975) states that most organic matter (75 - 99%) in lakes is decomposed in the water column before reaching bottom. In the inshore zone allochthonous production provides a rich substrate for both bacterial and detritivore activity. However, this material is not distributed uniformly on the substrate, creating a mosaic distribution pattern in the chironomid fauna. Variation in spatial distribution of chironomids may also be affected by some behavioral component of dispersion (Paterson and Fernando 1971). It is likely that the particulate organic matter pool in the nearshore area (particularly at stations 2 and 3) is enhanced by plant activity and associated fish kills causing organic enrichment (Liston et al. 1981).

Amphipoda

Pontoporeia hoyi has been reported as the dominant benthic invertebrate in the profundal zone of Lake Michigan (Marzolf 1965b, Teter 1960). *Pontoporeia* was the second most abundant organism estimated to be distributed in the farfield area within the hypothetical rectangle (Table 24), the fourth most abundant macroinvertebrate entrained and the sixth most abundant released (Table 4). Although *Pontoporeia* is not abundant in the nearshore area (<15m) of Lake Michigan (Duffy and Liston 1978), their large size magnifies their importance as a forage item. *Pontoporeia* has been observed in strata as shallow as 1.5m (Barton and Hynes 1978b, Wells 1968).

Figure 8 indicates few *Pontoporeia* nearshore in spring. Most *Pontoporeia* nearshore were subadult instars captured only during night tows. Barton and Hynes (1976b) recorded *Pontoporeia* as common on sand substrates at depths of roughly one meter. Nearly all of these individuals were immature instars. Adult instars dominated farfield night collections on 16 April lakeward of the 6.1m contour. Marzolf (1965b) observed less than 8% of the total population to take part in diel migrations. Adult and subadult instars were the predominant migrants.

The continual decline in *Pontoporeia* entrainment from the inception of farfield sampling through 15 May appeared to be a consequence of decreased density at the 6.1 and 9.1m contours at stations 2 and 3 (Figure 8). *Pontoporeia* entrainment increased again on 29 May as organism abundance increased at stations 2 and 3, increasing organism exposure to plant entrainment currents (Figure 8).

Pontoporeia abundance in the farfield area increased abruptly in late June as first instar individuals dominated collection at all depths. This coincides with the period of release observed previously in Lake Michigan (Liston et al. 1978, Duffy and Liston 1978, Mozely 1974). Fluctuation in amphipod populations was attributed to juvenile recruitment. High numbers of juveniles in samples in both 1978 and 1979 nearshore in tows support this conclusion.

The majority of Pontoporeia sampled at the shallow contours in early summer and after stratification in August were juveniles. Apparently juvenile instars are more tolerant of elevated water temperatures. Determination of 24 and 96 TL_m (median tolerance limits) yielded values of 12C and 10.9C at an acclimation temperature of 6C (Rees 1972). These values indicated probable higher lethal temperatures. Pontoporeia may also migrate into the nearshore zone for a limited time, retreating to a colder deep water refugium.

The marked increase in Pontoporeia entrainment on 31 July was a consequence of a massive increase in organism abundance at all contours in the farfield area (Table 24). Density increases at the 6.1 and 9.1m contours at stations 2 and 3 caused concomitant entrainment increases since these areas provide the majority of the source-water for entrainment. Approximately 14% of the total volume of water estimated to be contained within the hypothetical rectangle was pumped into the reservoir on this date. The peak summer entrainment value on 15 August was also related to Pontoporeia density at the 6.1, 9.1 and 12.2m contours at stations 2 and 3. Values remained at or above those recorded for 1 August while the total number of Pontoporeia within the rectangle declined by approximately 50% due to density declines at stations 1 and 4 (Table 25, Figure 8, Table 24). Avoidance of rising temperature may have initiated retreat to deeper water. No distinct reason is apparent for their paucity in farfield collections during this portion of the year.

Release of Pontoporeia from the reservoir may have been underestimated, as they are negatively phototactic (Marzolf 1965b). Reservoir tow density data indicated low concentration of Pontoporeia in the water column with peak densities occurring in station 9 night tows. These organisms are possibly freshly entrained as most water is directed into the northern third of the reservoir (personal observation). Lawson (1977) and Olson (1974) recorded Pontoporeia among the reservoir benthos over the year. Their findings would suggest that they are more abundant than extrainment data indicate (Table 27).

Pontoporeia abundance declined abruptly in fall (Table 24). Olson (1974) and Koehler (1975) noted increased abundance of Pontoporeia in the reservoir in October in benthos samples and drift net sets, respectively. Lawson (1977) recorded reduced numbers in fall. Mozely (1974) noted variations in fall Pontoporeia collections and attributed them to time of release of young. Station 1 and 2 displayed higher pelagic densities of Pontoporeia than 3 and 4 in fall. This phenomenon was also noted during summer collections and is probably related to substrate differences. Station 1 and 2 are dominated by sand substrate providing ideal colonization habitat for Pontoporeia. Barton and Hynes (1976) noted Pontoporeia's preference for sand, recording population densities of up to 30/m^2 in nearshore areas. These densities are far below values recorded for deeper areas (Mozely and Alley 1973) but are probably related to non-uniformity of the habitat and/or bacterial content and distribution in the sediment (Marzolf 1965a, Paterson and Fernando 1971).

Gammarus fasciatus and Gammarus pseudolimnaeus combined were the fourth most abundant macroinvertebrate group estimated to be contained within the hypothetical rectangle (Tables 16 and 17). They ranked fifth in abundance in entrainment and extrainment, respectively (Table 4).

Gammarus spp. have been found to primarily inhabit the breakwall and jetties. Colonization has been attributed to current, substrate and food (Duffy and Liston 1978). These species represented 46% of entrainment and 68% of extrainment estimates for amphipods. Entrained Gammarus spp. were drawn from the jetty area as evidenced by low farfield densities (Figures 6 and 7). Adult G. pseudolimnaeus tolerated maximum current speed of 54.86cm/sec, a value slightly below average current speeds recorded between the jetties (Rees 1972). Plant generated currents probably influence Gammarus spp. farfield distribution. Highest Gammarus pseudolimnaeus densities occurred at the 1.5m contour at station 1, generally. Barton and Hynes (1976) recorded them as abundant on boulder substrates. Rees (1972) documented their preference for gravel to cobble substrates. Gammarus fasciatus were recorded infrequently in collections in the farfield area in spring. May sampling in the littoral zone in Lake Erie produced similar results (Barton and Hynes 1976). Olson (1974) recorded G. fasciatus on rock basket samplers from the jetties.

Most pelagically active G. pseudolimnaeus occurred at the deep contours (6.1 and 9.1m) at station 2 during day tows in summer. Night tows indicated peak activity at the 1.5 and 3.0m contours. Organisms sampled during daylight may be dispersed by plant generated currents or are simply active at these depths, migration to the shallows occurring at night. Barton and Hynes (1978a) felt that *Gammarus spp.* move directly in and out of the wave zone during calm weather. Shallow contour collections of *G. pseudolimnaeus* and *G. fasciatus* revealed these individuals to be juvenile instars. Their absence in the water column during the day may also simply be a behavorial response to avoid predation. Entrainment samples during summer also were dominated by juvenile *G. fasciatus* and *G. pseudolimnaeus*. *Gammarus spp.* entrainment increases were associated with release of young in summer.

The low incidence of *G. fasciatus* in farfield collections was probably a consequence of their close affinity for *Cladophora sp.* covered substrates (Barton and Hynes 1978b, Bocsor and Judd 1972). Barton and Hynes (1978b) also found *G. fasciatus* in the gravel trough immediately below the swash step in summer. *G. fasciatus* remained in the shallows through fall, retreating to a deep water refugium with the onset of severe weather (Barton and Hynes 1976).

The paucity of *Gammarus spp.* in reservoir samples indicated low numbers of these organisms distributed pelagically in the reservoir, since Olson (1974) and Lawson (1977) recorded them as common members of the benthos during their studies. In fact, percent release of *Gammarus pseudolimnaeus* exceeded 100% of the entrainment estimate on several dates during summer, indicating biomass produced in the reservoir. Total release of *Gammarus spp.* was higher than the value recorded for *Pontoporeia* but subordinate to *Gammarus spp.* entrainment (Table 4).

All amphipods entrained into the reservoir on dates in 1979 and 1980 were combined for survivorship determination. Pontoporeia comprised roughly 54% of entrained amphipods with the remaining 46% being Gammarus spp. Results are admittedly scant, but entrainment survivorship appears high (Tables 35 and 36). Exposure of Gammarus spp. to simulated turbine passage pressure regimes at the Cornwall Pumped Storage Power Plant produced no significant mortality (Beck et al. 1975). Enright (1961) found a sensitivity threshold during rapid pressure increase between .007 - .015 atm. The vertical migrations of Pontoporeia hoyi and attendant hydrostatic pressure variation have been documented (Wells 1968, Marzolf 1965b).

Survivorship determined for amphipods was 86% at the plant and 100% at the control stations, yielding generating mortality (M_g) and control mortality (M_c) values of .14 and 0, respectively. Mortality due to mechanical effects at the Zion Generating Station was estimated at 10% a value slightly below that calculated at the Ludington Plant (Nalco 1976). The value determined for entrainment (N_{Te}) was 64,024,719 with extrainment (N_{Tx}) estimated at 24,035,724 during the sample year at the Ludington Pumped Storage Power Plant. Calculated loss employing equation 5 (see Mortality Methods) yielded an estimate of 43,353,996 for the sample period. Again, as with Mysis this is probably an upper-bound estimate due to the low values for N_{Tx}.

Oligochaeta

The naidid oligochaetes Stylaria sp. and Nais sp. were not common in the farfield area until late spring. Stylaria dominated collections throughout the year. Highest densities occurred nearshore during

Table 35. Survivorship of amphipods cycled through the Ludington Pumped Storage Reservoir in 1979.

Date	Water Temperature	Generate-Pump Alive	Generate-Pump Dead	Control Alive	Control Dead
5/9/79	7.8	4	0	0	0
		100% Survivorship		--	
5/24/79	9.0	1	0	0	0
		100% Survivorship		--	
6/5/79	11.2	8	4	1	0
		67% Survivorship		100%	
7/5/79	8.0	1	1	0	0
		50% Survivorship		--	
8/6/79	15.2	15	1	1	0
		94% Survivorship		100%	
8/28/79	17.0	7	1	0	0
		88% Survivorship		--	
Totals		36	7	2	0
Total Survivorship		84%		100%	

Table 36. Survivorship of amphipods cycled through the Ludington Pumped Storage Reservoir in 1980.

Date	Water Temperature	Generate-Pump Alive	Generate-Pump Dead	Control Alive	Control Dead
4/30/80	7.8	0	0	15	0
	Survivorship	--		100%	
5/12/80	9.0	2	0	0	0
	Survivorship	100%		--	
5/27/80	12.0	0	0	0	0
	Survivorship	--		--	
6/11/80	11.2	2	0	0	0
	Survivorship	--		--	
6/26/80	8.0	3	1	1	0
	Survivorship	75%		100%	
7/29/80	15.2	0	0	0	0
	Survivorship	--		--	
8/11/80	17.0	0	0	0	0
	Survivorship	--		--	
Totals		7	1	16	0
Total Survivorship		88%		100%	

farfield day and night sampling throughout the sample term (Figure 9). Increase lakeward for naidids was a consequence of increased volume with depth. Stimpson et al. (1975) found naidids distributed in greatest numbers at 3 and 6m. Abundance decreased lakeward with none noted at the 18m contour. Hiltunen (1967) collected Naididae from Lake Michigan between the 5.5 - 18.5m contours. He noted that some naidids are active swimmers, stating that others could be transported in alongshore currents. Wiley and Mozely (1978) also recorded Naididae active in the water column. Low densities at stations 3 and 4 were possibly related to naidids preference of sand substrates (Stimpson et al. 1975). Naidid densities remained high through early fall at the 1.5m contour (Figure 9).

Estimates of Naididae entrainment were roughly equivalent to extrainment values (Table 4). Reservoir pelagic occurrence (Table 29) generally coincided with release peaks (Table 30). Olson (1974) did not record Stylaria sp. or Nais in reservoir benthos collections. Lawson (1977) grouped the naidids under "rare species" in his collections. They may remain active in the water column until release generation periods.

The increased numbers in late summer and fall collections corresponds with peak maturity and reproduction for Naididae (Hiltunen 1967). He collected mature Stylaria sp. in September samples. Naididae feed primarily on algae and detritus (Pennak 1978).

Minor Taxa

Infrequently collected taxa were grouped under this heading. Their low abundance did not warrant mortality determinations. Collected taxa include Ephemeroptera, Plecoptera, Trichoptera, Isopoda and Diptera.

Members of the Ephemeroptera collected during sampling included the families Siphlonuridae, Isonychia sp.; Heptageniidae, Heptagenia sp., Stenonema sp.; Ephemeridae, Ephemera sp. and Baetidae, Baetis sp. Isonychia sp. and Baetis sp. are active swimmers (Shapas 1976). Some of the Baetidae employ migration into the water column as a dispersal mechanism (Corkum 1978). Siphlonurids were relatively common in spring at the deeper contours at stations 2 and 3. Barton and Hynes (1978a) recorded Baetis sp. as common on cobble and boulder substrates. Heptagenia sp. and Stenonema sp. also were noted on cobble size substrates. SCUBA observations at stations 1 and 2 revealed heptageniids to be distributed in crevices on rocks and boulders. Stenonema sp. was identified only in spring farfield and entrainment samples. Olson (1974) found Stenonema sp. throughout spring and summer on rock basket samplers at the jetties. He recorded one individual in collections in the reservoir in June. One Ephemera sp. was collected during entrainment sampling.

Plecoptera collected consisted of the Perlodidae genus Isoperla sp. Isoperla sp. was collected in spring farfield and entrainment samples. One Isoperla sp. was captured on boulders at the 6.1m contour at station 2 while diving. This individual was captured with a partially engulfed Diamesinae larva. Fahy (1972) found Isoperla sp. to be carnivorous with roughly 5% of its gut contents consisting of algae and detritus at productive habitats.

Hydropsyche spp. were captured occasionally in all areas during sampling in 1979. They were taken infrequently in farfield tows in summer and fall. Benthic densities at station 2 were estimated at

$20 - 30/m^2$ during dives in August. Trichoptera were observed to construct cases on the undersides of and crevices between rocks. Barton and Hynes (1978a) noted that net structure and alignment were highly variant hypothesizing that the erratic current pattern in the nearshore zone may restrict less flexible species.

Isopoda, identified as Asellus sp., were collected in all areas. Asellus sp. were common inhabitants of the jetties and breakwall and the rock scour pad within the reservoir (Olson 1974, Lawson 1977). They are probably accidental inhabitants of the water column.

Dipterans of the families Chaoboridae and Ceratopogonidae were infrequently collected during sampling. Chaoborus sp. was identified in farfield night tows in spring and summer. Two Ceratopogonids were captured in summer farfield night tows. Kajak et al. (1978) noted migration to deeper contours as maturation advanced.

Hirudinea were seldom collected in farfield and reservoir tows. Condition of captured specimens did not allow identification. Barton and Hynes (1978b) collected leaches occasionally in .5m of water.

SUMMARY

During 1979 it was attempted to estimate day/night abundance, distribution, entrainment and release rates, and survivorship of macroinvertebrate drift organisms near the Ludington Pumped Storage Power Plant. Macroinvertebrates were sampled biweekly at four stations and five contours (1.5, 3.0, 6.1, 9.1, 12.2m) in Lake Michigan, one site between the jetties and two stations in the upper reservoir from 17 April to 30 October 1979. One meter plankton nets (351μ) towed in an oblique fashion were employed to determine farfield abundance, reservoir densities and entrainment/extrainment rates, while mortality sampling employed use of a two meter plankton net in a vertical haul. Impacts of power plant operation were compared to estimated organism abundance in a hypothetical rectangle (2.4 x 9.7km) in Lake Michigan surrounding the plant, for assessment.

A total of 1045 collections were made on 19 dates in 1979 (739 in farfield day/night collections; 89 for entrainment; 74 reservoir; 68 extrainment; and 75 mortality samples). Farfield collections were dominated by _Mysis relicta_, four chironomid subfamilies, two genera of amphipods (_Pontoporeia_ and _Gammarus_) and naidid oligochaetes. Entrainment/extrainment and reservoir collections were composed of the same taxa though their order of abundance was not identical.

Mysis relicta was the most abundant organism collected in Lake Michigan on all dates, though abundance continually declined after

31 July. Densities of Mysis ranged from 0 - $7871/1000m^3$ exhibiting a definite lakeward increase. Lower numbers of Mysis were collected at the control sites (stations 1 and 4), and appeared to be caused by plant operation.

Chironomids were collected on all sample dates. Chironominae were captured on all dates, though peak concentrations were noted in farfield samples from June through August. Orthocladiinae exhibited a bimodal peak in late May and July through August. Orthocladiinae occurrence was low in early spring and fall collections. Diamesinae larvae were noted from June through August, and nearly absent in fall. The predaceous Tanypodinae were the least abundant of the chironomids, virtually absent in samples until late May - early June and again in late August. Total concentration of Chironomidae ranged from 0 - $5990/1000m^3$. Larvae were more abundant at stations 1 and 2 with peak abundance recorded at station 2.

Amphipods were collected on all sample dates, though differences between Pontoporeia and Gammarus were substantial. Pontoporeia were collected on all dates with greatest abundance occurring in late June through August. Densities of Pontoporeia ranged from 0 - $406/1000m^3$. A positive relationship between density and increasing depth was observed at all stations. Gammarus pseudolimnaeus were at all stations and depths but were concentrated in the shallows. First appearance in abundance was in early June with densities ranging from 0 - $1192/1000m^3$ recorded. These organisms appeared to be associated with cobble and gravel substrates. Gammarus fasciatus were the least abundant amphipod in pelagic collections. They displayed densities ranging from 0 - $30/1000m^3$ in collections. Gammarus fasciatus were associated with

Cladophora sp. covered substrates. Spatially, Gammarus spp. appeared to be more abundant at stations south of the power plant.

The naidid oligochaetes Stylaria sp. and Nais sp. were recorded in tow collections in the farfield area beginning in early June, with abundance ranging markedly. Pelagic occurrence for these organisms was a combination of active entry of the water column and passive dispersal in strong water movements.

Mysis relicta were collected in reservoir tows from the inception of sampling. Densities ranged from 0 - 908/1000m^3 during sampling. Peak day densities occurred in the north end (station 9) of the reservoir while night density modes were noted in the south end (station 7). Highest pelagic densities were recorded in the south end of the reservoir. This phenomenon was attributed to current avoidance associated with plant operational mode.

Densities of chironomid larvae fluctuated from 0 - 3047/1000m^3, after initial collection in the reservoir in May. Station 7 exhibited highest night densities while peak day densities occurred at station 9. Highest densities occurred in station 7 during night tows. Chironomid pupae were captured sporadically, with initial appearance occurring on 28 May. Two density pulses were indicated from reservoir collections, one in early June, and another in late July to early August. Pupal densities ranged from 0 - 836/1000m^3 during sampling.

Low numbers of both Pontoporeia and Gammarus spp. were captured during day and night sampling in 1979. Pontoporeia hoyi and Gammarus pseudolimnaeus were collected initially on 28 May, while Gammarus fasciatus was first captured on 15 May. Gammarus spp. pelagic activity was low in comparison with concentrations recorded in previous benthic investigations. Limited incidence of Pontoporeia in the reservoir was indicated by low tow densities and previous benthic sampling.

Collection of naidid oligochaetes was quite sporadic. Densities in tows ranged from 0 - 3977/1000m^3 in day/night samples. Distribution patterns in the reservoir indicated the majority of organisms to be concentrated at station 7.

All the major groups of macroinvertebrates collected in farfield samples were observed in entrainment/extrainment samples. Mysis relicta were again the most abundant organism entrained and second in extrainment samples. Peak Mysis entrainment occurred in late June through July and a total of roughly 1.3 billion were entrained over the sample term. Sixty-seven million Mysis were extrained. Chironomidae were the second most abundant organism entrained and the most abundant in extrainment samples. Midge larvae were composed of the same subfamilies collected in farfield samples. A total of 188 million chironomids were entrained and 195 million were released. Both species of amphipods were taken in entrainment collections while G. pseudolimnaeus was the most abundant gammarid. More Gammarus spp. were released from the reservoir than Pontoporeia. A total of nearly 7 million Pontoporeia were released while Gammarus spp. extrainment was 16 million. Entrainment for Pontoporeia and Gammarus spp. was roughly 35 and 29 million, respectively.

Loss estimates of Mysis indicated that approximately 97% of the initially entrained organisms were unaccounted for (1,240,756,775 individuals). Survivorship of Mysis was generally high. Loss estimates were affected principally by low extrainment values and should be used as an upper-bound.

Survivorship of amphipods (*Pontoporeia* and *Gammarus* combined) was 86%. Estimated loss was set at 43,253,996 for amphipods over the sample period. This value is also affected by the low extrainment estimate.

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