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Title: BATHYMETRIC ZONATION OF NEARSHORE MYSIDS WITH EMPHASIS ON THE BEACH-DWELLING MYSID *Archaeomysis grebnitzkii*

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Mysids were sampled seasonally from the intertidal zone of the beach to a depth of 61 m offshore along the mid-Oregon coast. The seven mysid species collected occurred in characteristic bathymetric zones, with members of different genera occupying overlapping zones while members of the same genus occupied largely different zones.

The distribution of one mysid species, *Archaeomysis grebnitzkii* was examined in greater detail. Adult and juvenile *A. grebnitzkii* were found to occupy different zones. Juveniles occurred in the inner surf zone and beach in high densities while adult animals were normally found from the seaward edge of the surf zone to 30 m in much lower densities. The mean brood size of *A. grebnitzkii* was found to be 47.2, with larger

brood sizes occurring in early spring and summer corresponding to larger body sizes of the breeding females.

Bathymetric Zonation of Nearshore Mysids with Emphasis on the Beach-dwelling Mysid *Archaeomysis grebnitzkii*

by

Janet George Llewellyn

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THE BATHYMETRIC ZONATION OF NEARSHORE MYSIDS WITH EMPHASIS ON THE BEACH-DWELLING MYSID *Archaeomysis grebnitzkii*

INTRODUCTION

Mysids are shrimplike invertebrates of the order Mysidacea (phylum Arthropoda, class Crustacea) that occur in marine, estuarine and freshwater regions of the world. While some species are strictly pelagic, many species live in association with the sediment, either swimming above it or resting on the surface (hypopelagic). A few species are known to burrow into the sediment. Mysids normally occur in low concentrations in oceanic samples, but can be very abundant in neritic waters and estuaries. Table 1 gives a bathymetric classification for mysids that was developed by Wigley and Burns (1971) and was expanded by Mauchline (1980).

The high concentrations of mysids in coastal regions make them a potentially important food source for coastal fish. The mysid *Neomysis kadiakensis* is reported to be an important prey item for sand sole (*Psettichthys melanostictus*), speckled sanddab (*Citharichthys stigmaeus*), pacific tomcod (*Microgadus proximus*), whitebait smelt (*Allosmerus elongatus*), and night smelt (*Spirinchus starksi*) taken at 9 m and 22 m stations off the Oregon coast (Wakefield, personal communication). It was also abundant in stomachs of starry flounder (*Platichthys stellatus*) and sand sole (*Psettichthys melanostictus*)

TABLE 1. BATHYMETRIC CLASSIFICATION OF SPECIES OF MYSIDS (Mauchline, 1980).

Title of species	Normal habitat	Total range of depth (m)
1. Freshwater	0-50 m depth	0-200
2. Brackish water	0-10 m depth	0-20
3. Littoral	Intertidal or subtidal	0-10
4. Shallow shelf	Less than 50 m depth	2-100
5. Eurybenthic shelf	Broad range of depth	2-400
6. Deep shelf and upper slope	Outer shelf and on slope	100-400
7. Slope	On the slope	200-700
8. Epipelagic	Oceanic surface layer	0-300
9. Mesopelagic	Oceanic, 200-700 m depth	
10. Bathypelagic	Oceanic, c. 500 m to very deep (6000 m)	

in East Sound, Orcas Island, Washington (Miller, 1967), as well as all size groups of flathead sole (*Hippoglossoides ellasodon*) off the coast of Washington state (Miller, 1970). Another mysid species, *Acanthomysis nephropthalma*, formed a significant component in stomachs of rock sole (*Lepidopsetta bilineata*) and petrale sole (*Eopsetta jordani*) captured at a 73 m station off the Oregon coast (Wakefield, personal communication). A third species, *Archaeomysis grebnitzkii* Czerniavski, while relatively unimportant in the diet of coastal fish (Wakefield, personal communication), was found to be a major prey item for fish in the brackish and marine portions of the Columbia River estuary (Haertel and Osterberg, 1967).

The present study was designed to investigate the mysids of the littoral and shallow shelf bathymetric zones off the mid-Oregon coast, with particular emphasis on the littoral species *Archaeomysis grebnitzkii*. *A. grebnitzkii* has been described by several authors (Tattersall, 1951; Banner, 1948; Ii, 1964). Holmquist (1975) established that *Archaeomysis maculata* (Holmes) is a synonym of *A. grebnitzkii* Czerniavski. Although *A. grebnitzkii* has been the subject of physiological studies (Enright, 1962; Jawed, 1973), little work has been done on its distribution or life history. This species has previously been thought to be restricted to the inner surf zone (Tattersall, 1951; Ii, 1964;

Clutter, 1967), where it burrows into the sand and exhibits an endogenous tidal rhythm in emergence and swimming (Enright, 1963). Kasoaka (1974) studied the development of the male genital system of A. grebnitzkii collected from the beaches on San Juan Island, Washington. He states that they breed year around as animals in all stages of development could be collected from the beach at all times of the year. The present study provides information on the number of juveniles per brood and utilization of different parts of the habitat by different life stages of A. grebnitzkii.

Quantitative sampling of mysids can be difficult as they are not sampled efficiently with either conventional benthic or pelagic samplers. Often a variety of sampling methods is required. Epibenthic sleds towed over the surface of the sediment are commonly used to sample hypopelagic species. Clutter (1967) states that 90% of the pelagic mysids he studied over the open coast of southern California occurred within 0.3 m of the sand bottom. While epibenthic sleds are effective in collecting these hypopelagic species, they may miss strictly benthic species that are buried in the sediment. Grab samplers have been used to collect burrowing mysids, but if the densities are not high, the number of mysids collected is low. The present study examined mysids from Smith-McIntyre grab samples in addition to samples taken with a beam trawl designed to disturb the sediment ahead of it. In this way both hypopelagic and benthic mysids should be effectively collected.

II. METHODS AND MATERIALS

Study Area

The study area was located in the nearshore region of the mid-Oregon coast from 1.3 km south of the mouth of Three Mile Creek to just north of the mouth of the Siltcoos River (Figure 1). The coastline in this region consists of long stretches of unprotected sandy beach. Samples were collected within the bathymetric range extending from the intertidal sandy beach out to a depth of 61 m below MLLW. This zone is characterized by wave action and turbulence on the beach and within the surf zone, giving way to a more stable environment seaward of the surf zone. The region from 0 to 3 m below MLLW was not sampled due to inaccessibility for sampling from either the shore or the ocean.

Quantitative Study

The study was composed of two parts, a quantitative study undertaken to provide quantitative information on the distribution of *Archaeomysis grebnitzkii*, and seasonal sampling designed to provide information on the relative distribution of mysid species in the littoral and shallow shelf regions. As a quantitative

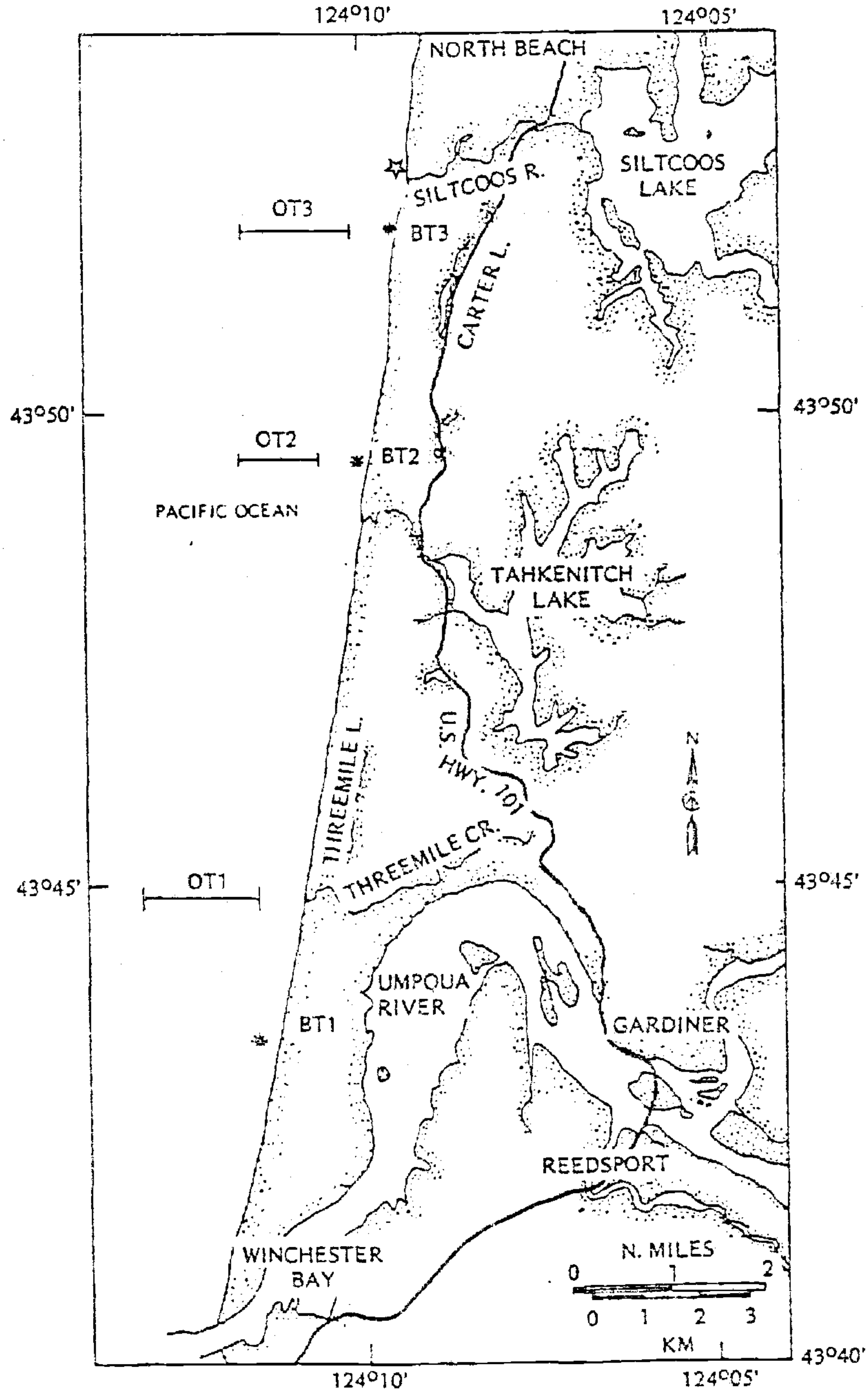

Figure 1. Location of sampling sites. Star indicates beach site sampled during seasonal study.

study, a series of infaunal samples was examined. These samples were collected as part of a previous study reported by Oregon State University, School of Oceanography (1982). The samples were collected along three beach and three ocean transects on the mid-Oregon coast. (Figure 1). The beach transects, BT1, BT2 and BT3, were sampled on 18 and 20 June, 1980. These transects were divided into four intervals on the basis of tidal height, 0 m to +0.3 m, +0.3 m to +0.7 m, +0.7 m to +0.9 m, and +0.9 to +1.2 m, where 0 m = MLLW. Five randomly placed samples were collected within each interval using a 15.4 cm diameter hand corer to a depth of 10 cm. In addition, a 3.5 cm diameter x 5 cm deep sediment core was collected at the mid-point of each interval for textural analysis. The samples were taken at low tide. The 0 m to +0.3 m interval of transect BT1 was omitted as it was under water at the time of sampling.

Subtidal ocean transects, OT1, OT2, and OT3 (Figure 1) were sampled on 17 and 19 June, 1980 using a 0.1 m^2 Smith-McIntyre grab sampler. Each of the ocean transects was divided into tidal depth intervals of 4.3 m to 7.0 m, 7.3 m to 10.1 m, 10.4 m to 19.5 m and 19.5 m to 37.5 m below MLLW. Five samples were collected within each interval at randomly selected points. However, only two depth intervals, 7.3 m to 10.1 m, and 19.5 m to 37.5 m were sampled in transect OT2. A 3.5 cm diameter x 5 cm deep subsample was removed from each grab sample for textural analysis.

The *Archaeomysis grebnitzkii* in each sample were counted and measured for standard length, from the base of the eye to the tip of the telson, excluding spines. Each animal was classified by developmental stage based on a scheme presented by Amaratunga and Corey (1975):

unsexable juvenile: no secondary sexual characteristics observable

immature male; gonads visible, 3rd pleopod either not elongate or partially elongate

immature female; enlarged pleuron on the first abdominal segment, developing or small marsupium

adult male; 3rd pleopod elongate to the end of abdomen

adult female; enlarged pleuron on first abdominal segment, large marsupium

adult gravid female; marsupium containing eggs or embryos

In the case of gravid females with intact brood pouches, the number of eggs or embryos were counted and classified as eggs, embryos without eyes or embryos with eyes.

Seasonal Study

Sampling was conducted quarterly from February to October, 1981, along transect OT3 located two miles south of the mouth of the Siltcoos River. Limited beach access prevented regular sampling in the area of BT3, and therefore beach samples in this portion of the study were taken quarterly at a site just north of the mouth of the Siltcoos River (Figure 1). On each date a sample was collected from the wave wash zone of the beach and a series of subtidal samples were collected offshore.

To collect mysids subtidally, in relatively large numbers, a beam trawl was constructed with a mouth area 0.3 m high x 1.0 m wide. It was equipped with a 0.5 mm Nitex mesh net 1.4 m in length. A second net of ¼" knotless nylon was fitted around the inner net for protection. A "tickler" chain was fixed across the mouth of the trawl during surveys 3 and 4 to stir up the bottom sediment in front of the net to improve capture of benthic mysids. Trawl samples were taken from the shallowest depth allowed by surf conditions out to a depth of 61.0 m below MLLW. Each tow was approximately five minutes in duration (Table 2).

At depths >15 m, the sediment was fine and filtered easily through the fine mesh of the inner net. At depths <15 m, however, shell material or sand dollars tended to clog the net and cause the cod end and net to fill with sand and shell debris. In these instances, the contents of the cod end, as well as large portions of the sand and debris from the net were collected. On some sampling dates, the weight and abrasive nature of these samples caused damage to the fine mesh net and prevented

TABLE 2. DATE AND DEPTH OF BEAM TRAWL AND SWEEP NET SAMPLES TAKEN DURING SURVEYS 1-4.

Subtidal Beam Trawl Samples

Survey	Date	Depth (m below MLLW)										
		3.0	6.1	9.1	12.2	15.2	18.3	24.4	30.5	39.1	45.7	61.0
1	2/25,26/81			X	X	X	X	X	X		X	X
2	6/12/81	X	X		X			X			X	
3	8/26/81		X	X	X	X	X	X	X		X	X
4	10/16/81		X	X	X	X	X	X	X	X	X	X

Beach Sweep Net Samples

Survey	Date	Approximate depth (m above MLLW)
1	2/23/81	0.6
2	6/13/81	1.4
3	8/26/81	1.4
4	10/17/81	2.3

the collection of a complete sample set. The depths at which samples were collected on each date are given in Table 2.

Beach samples were collected from the wave wash zone with a 0.5 mm mesh hand sweep net with a mouth area of 0.026 m^2 by placing the net in the water and allowing receding waves to flow through it. Dates and approximate tidal heights at which each sample was collected are presented in Table 2. All samples were preserved with 5% buffered formalin.

Samples containing large amounts of sand and shell material were elutriated prior to sorting. This was accomplished by placing small amounts of the sample in a jar and repeatedly filling it with water and decanting. Random subsamples of each beam trawl and sweep net sample were sorted until a minimum of 200 mysids were counted. These animals were then identified to species. Additional subsamples were sorted for Archaeomysis grebnetzkii until at least 200 animals of this species were obtained, if possible. Each A. grebnitzkii was measured and classifed as described for the quantitative survey.

III. RESULTS

Mysid Species Collected

A total of seven mysid species representing three genera of the family Mysidae were collected. These included: Acanthomysis davisii Banner, Acanthomysis macropsis (Tattersall), Acanthomysis nephropthalma (Banner), Acanthomysis sculpta (Tattersall), Neomysis kadiakensis (Ortmann), Neomysis rayii (Murdoch), and Archaeomysis grebnitzkii Czerniavski. A. macropsis and N. kadiakensis are hypopelagic in the open sand habitat, but also occur in kelp beds (Clutter, 1967). A. grebnitzkii and A. sculpta are essentially benthic in the open sand habitat (Clutter, 1967). A. sculpta is a more typical resident of kelp canopies, and in the open sand habitat is often associated with detrital kelp and eel grass washed in from nearby rocky areas (Clutter, 1967). In the nearshore region of Santa Catalina Island, California, A. sculpta was found to live in close association with the surface of the sediment by day, and migrate toward the surface waters at night (Hobson and Chess, 1976).

Bathymetric Ranges

The trawl and beach net samples taken seasonally were not quantitative, and therefore do not provide absolute densities for the mysids collected. However, they do provide information on relative species composition and delineate the depth ranges occupied for each species. Figure 2 shows the proportion of the total mysid catch that each species represented at each depth in surveys 1-4. Acanthomysis sculpta was collected only during surveys 2 and 3, and in both cases in the shallowest subtidal trawls taken. It was never collected deeper than 9.1 m, nor in the beach samples. Presumably this species would have been collected in surveys 1 and 4 if sea conditions had allowed sampling closer to the surf zone.

Neomysis rayii was also found to be a littoral species (found predominantly from 0-10 m below MLLW), although its bathymetric range was broader than that of A. sculpta. It was collected in surveys 1, 2 and 3. In surveys 2 and 3, it was concentrated from 3-5 m while in survey 1, a few individuals were collected out to 25 m.

Acanthomysis davisii was collected in all four surveys. It occurred from the shallowest subtidal trawls taken out to a depth of approximately 12 m in surveys 2 and 3, and was present in small numbers to 46 m and 30 m in surveys 1 and 4, respectively.

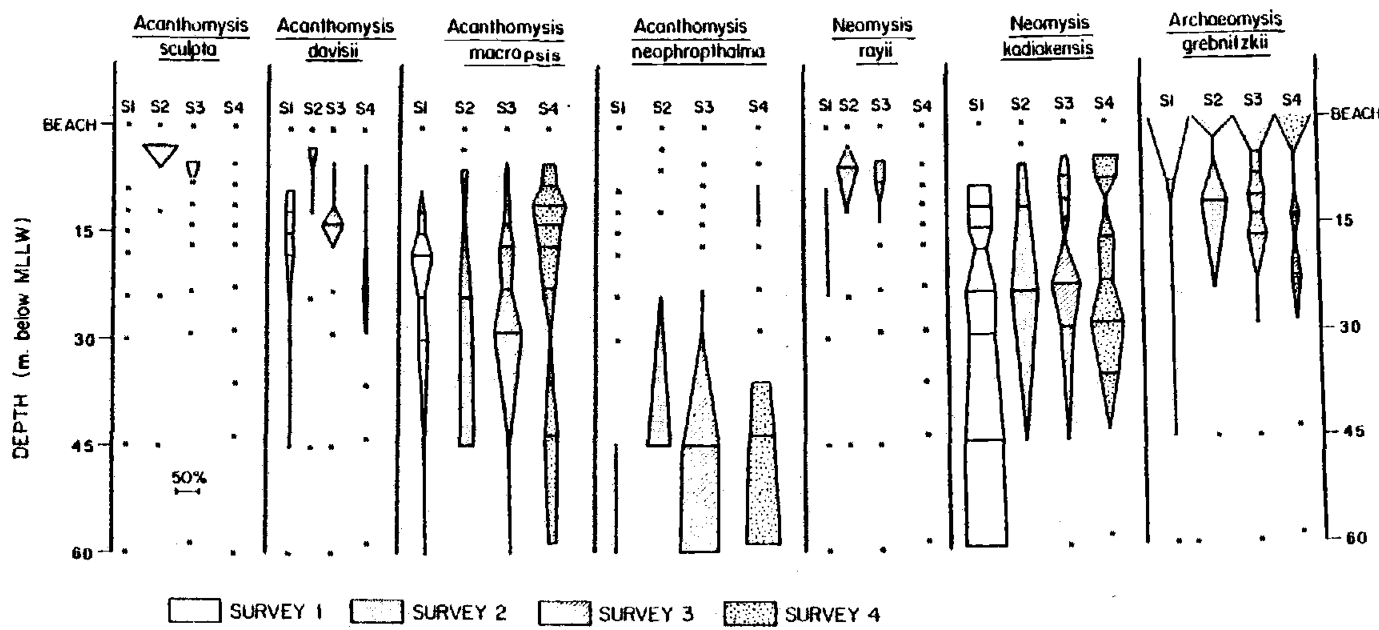

Figure 2. Proportion of total mysid catch represented by each mysid species at each depth during surveys 1-4.

Acanthomysis macropis and Neomysis kadiakensis were both abundant in samples from about 6 m to 46 m in all four surveys. In survey 1, N. kadiakensis continued to be the most abundant species in the 61 m sample.

Acanthomysis nephropthalma was abundant in the deeper samples, generally appearing at about 30 m and becoming the most abundant species in the 46 and 61 m samples. The seaward extent of its range was not established by this study.

Archaeomysis grebnitzkii formed 100% of the mysid sample taken from the beach, and its depth range extended offshore to 24 m in survey 2, 30 m in surveys 3 and 4, and to 46 m during survey 1.

The depth zones occupied by each species were fairly consistent in surveys 2, 3 and 4. A seaward extension of bathymetric range occurred for some species during the February collection (survey 1) including A. davisii, N. rayii, N. kadiakensis, and A. grebnitzkii. A. nephropthalma, which formed a large proportion of the 46 m and 61 m samples in surveys 2, 3 and 4 formed only a small proportion of these samples in survey 1.

Bathymetric zonation appeared between members of the same genus. N. rayii was concentrated in the inner surf zone, usually less than 12 m, while N. kadiakensis appeared at the seaward edge of the surf zone and was present in high numbers to 61 m. Zonation was also evident within the genus Acanthomysis, with the shoreward to seaward order of their appearance in the samples being _A. sculpta_, _A. davisii_, _A. macropsis_ and _A. nephropthalma_. While _A. sculpta_ is benthic in this habitat at least some of the time (Hobson and Chess, 1976), its depth zone did not greatly overlap that of the pelagic species (_A. davisii_) of the same genus.

Substantial overlap of zones occurred between species of _Acanthomysis_ and _Neomysis_, particularly between _A. davisii_ and _N. rayii_ and between _A. macropsis_ and _N. kadiakensis_. In one instance, however, species of these two genera appeared to be forming exclusive zones. The proportion of _A. nephropthalma_ increased at 45 m and 61 m in surveys 2, 3 and 4 as the proportion of _N. kadiakensis_ decreased. In survey 1, when the proportion of _N. kadiakensis_ remained high at 61 m, only a few _A. nephropthalma_ were collected.

A. grebnitzkii was the sole member of this genus collected. Its bathymetric range does not fit neatly into the bathymetric classification scheme presented in Table 1 as it was present from the wave wash zone of the beach out to 30 m below MLLW. Its depth range overlapped the benthic _A. sculpta_ as well as several pelagic species.

Distribution of _Archaeomysis grebnitzkii_

The seasonal samples indicate that _A. grebnitzkii_ is present from the wave wash zone of the beach to approximately 30 m below MLLW. The quantitative infaunal samples, as well as the size composition of the mysids captured in both sets of samples, give a clearer picture of how this mysid is distributed within this zone.

Archaeomysis grebnitzkii were collected in the infaunal samples from 1.0 m above MLLW in transect BT1 to 35.1 m below MLLW in transect OT3. Maximum densities occurred in the beach cores taken at the water's edge in all three transects (Figure 3). Densities reached 11,868/m^2 in transect BT1, 5,659/m^2 in transect BT2, and 42,199/m^2 in transect BT3.

In transect BT1, the maximum density was found at +0.34 m relative to MLLW, and fell rapidly to zero at +0.67 m. The animals occurred sporadically and in comparatively low numbers from +0.67 m to +1.19 m. In transect BT2, maximum density occured at 0 m, decreased to +0.34 m, and none were found in the beach cores taken from +0.34 m to +1.25 m. The same trend was observed in transect BT3: maximum density occurred at 0 m, decreased in the samples until +0.46 m, and no animals were collected in the cores from +0.46 m to +1.19 m.

Sediment data available from the beach study indicate a fairly homogeneous sediment structure occurring in the 0 m to +1.2 m area of the beach. Median grain size varied between 1.6 and 1.8ϕ, and was very similar among intervals and across transects.

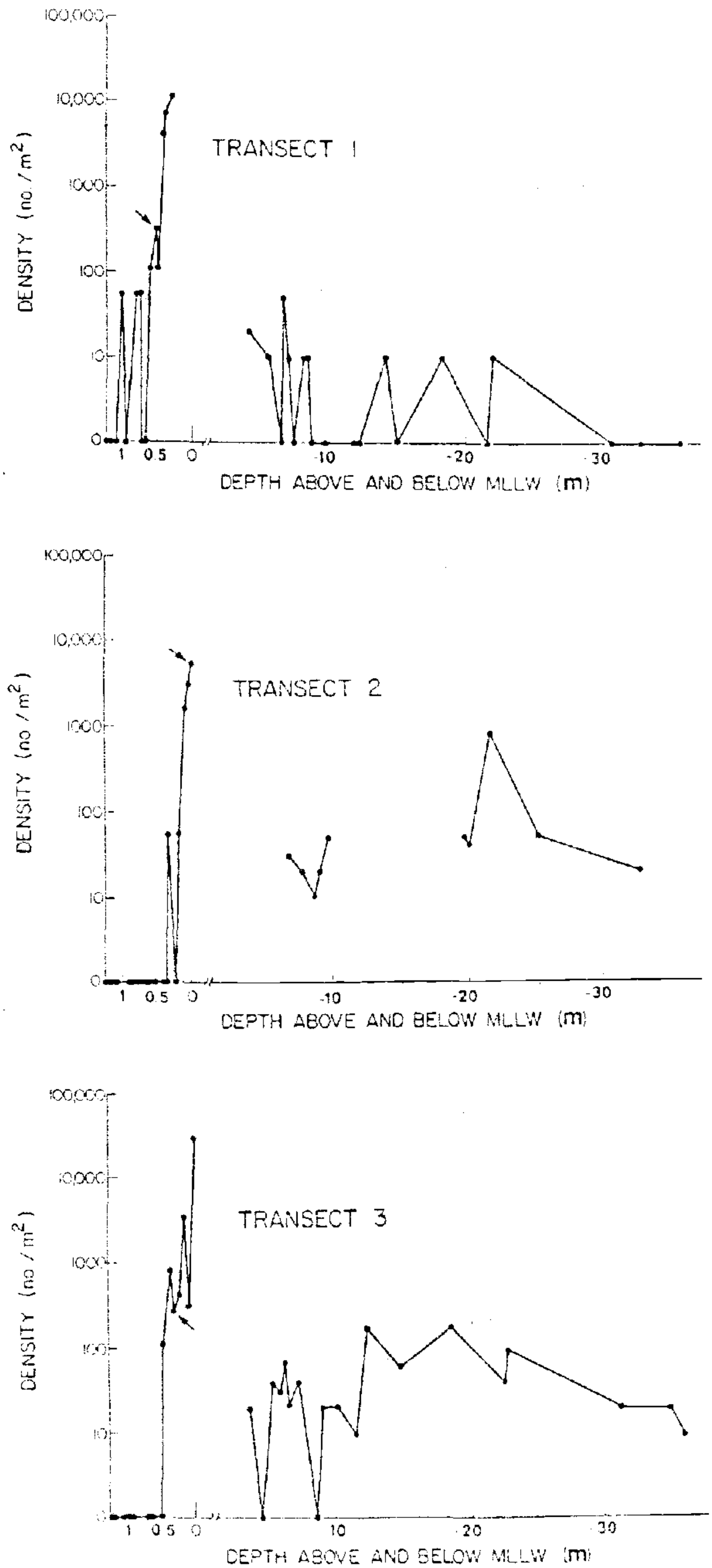

Figure 3. Density of Archaeomysis grebnitzkii collected along transects 1, 2 and 3. Arrows indicate the edge of the wave wash zone.

A. grebnitzkii in the subtidal samples were collected out to a depth of 21.3 m in transect OT1, 32.0 m in transect OT2, and 35.1 m in transect OT3 (Figure 3). Densities were much lower than those found in the wave wash zone of the beach. Densities ranged from zero to a high of 180/m^2 found in transect OT2. The distribution of the animals was patchy and no clear trend with depth is observable in the subtidal samples.

The offshore sediment samples show distinct patterns of change with depth. Median particle size (Figure 4) decreased, and percent silt and clay (Figure 5) increased with depth, illustrating the accumulation of finer sediment away from the surf zone. Median particle size was highly variable from 4.3 m to 10.1 m with values ranging from 1.3-2.6ϕ. Values were more stable below 10.1 m ranging from 2.6-2.8ϕ. The lowest phi values were observed in transect OT1. Percent silt and clay values were also low but variable nearshore, and became higher and more stable with depth. Values ranged from 0.15 to about 1.7%. The sharpest transition in sediment size occurred at approximately 16 m, indicating the seaward edge of the surf zone.

A two-way analysis of variance with transect and depth interval was conducted on the density of *A. grebnitzkii* for transects OT1 and OT3. The five samples taken within each depth interval were treated as replicates. Transect OT2 was omitted from the analysis as

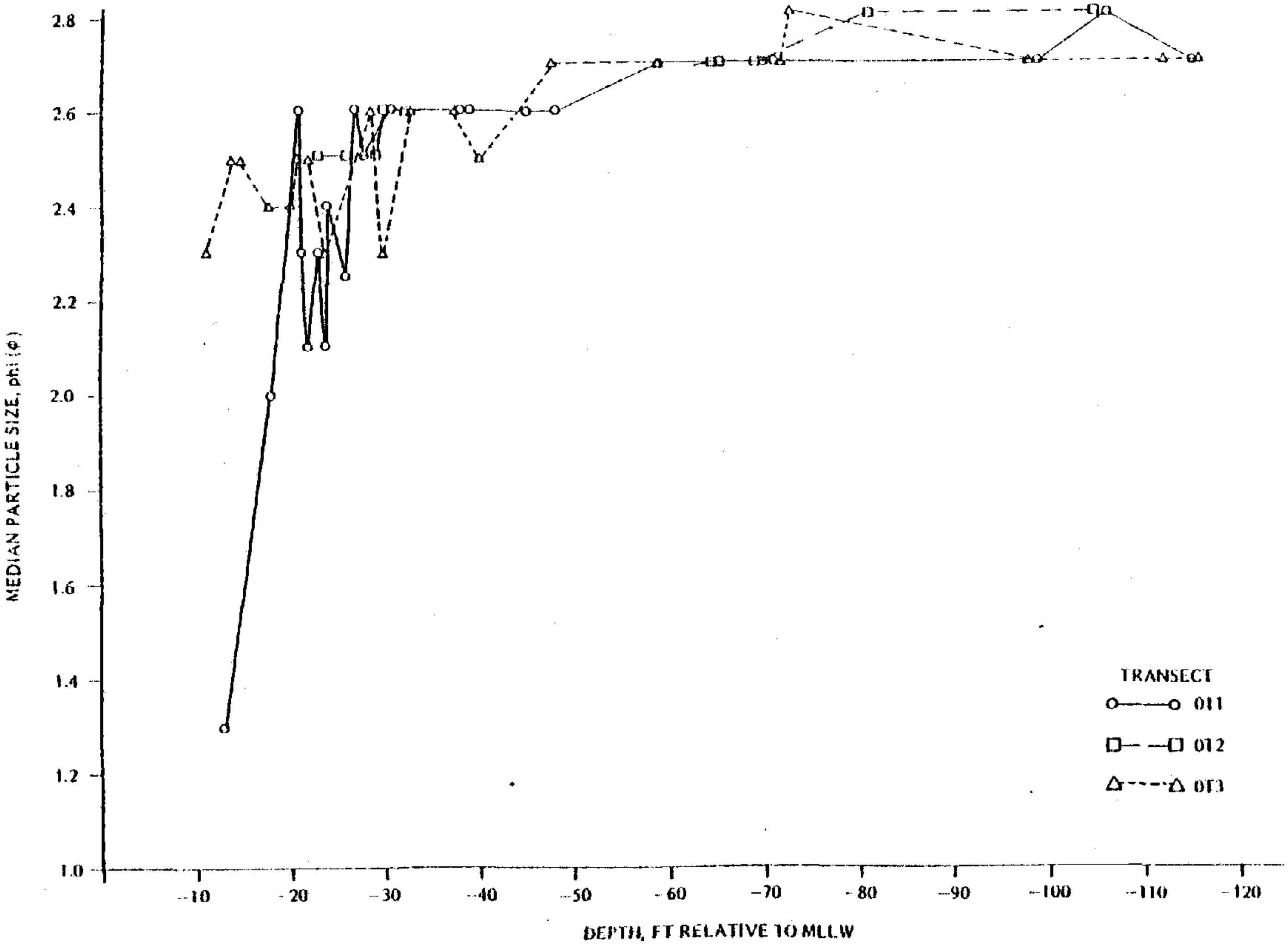

Figure 4. Median particle size at transects OT1, OT2 and OT3.

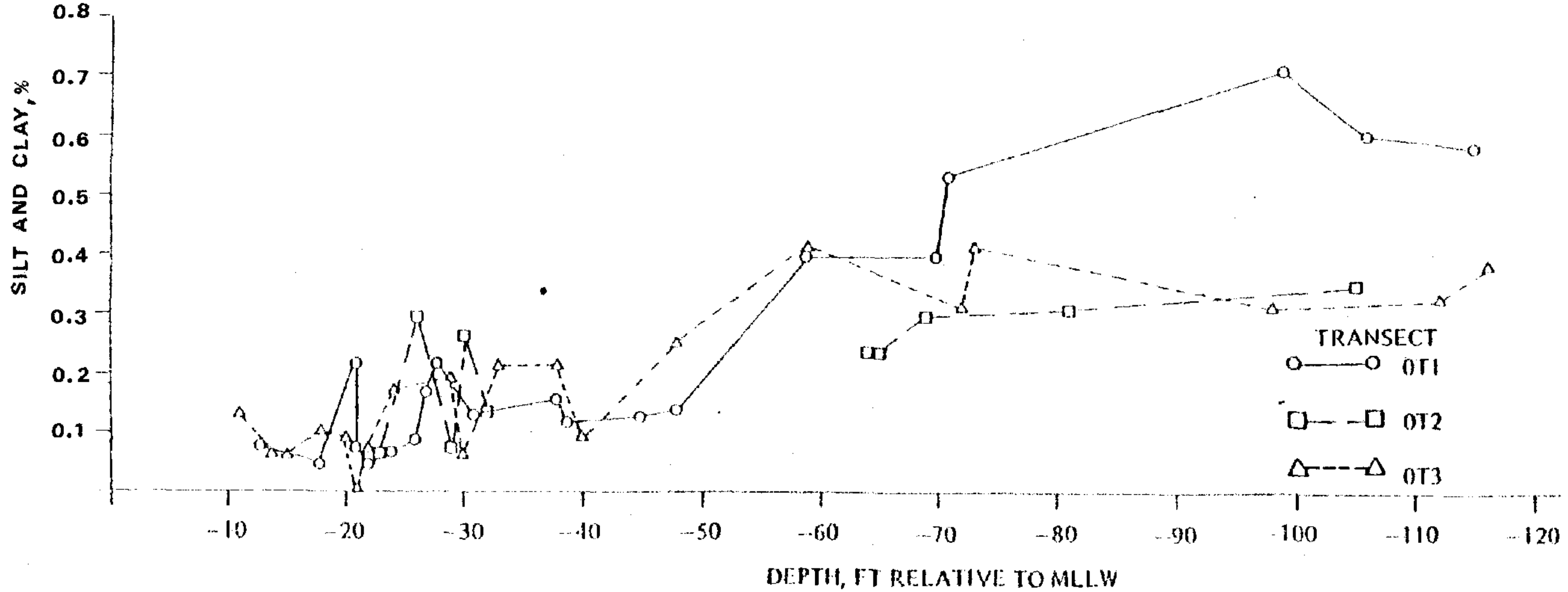

Figure 5. Percent silt and clay at transects OT1, OT2 and OT3.

it contained only two of the four depth intervals. The depth interval effect and the depth interval x transect interaction effect were found to be non-significant (Table 3), indicating that depth, and indirectly sediment, are not factors affecting density on the coarse level defined by the depth intervals. The transect effect was highly significant (Table 3), indicating that transect OT3 had significantly higher mean densities than transect OT1 (Table 4).

The length frequency of A. grebnitzkii from the beach cores combined and the offshore Smith-McIntyre samples combined are presented in Figure 6. A distinct difference can be seen in the size of the animals inhabiting these two areas. The animals in the beach cores, responsible for the high densities found in the wave wash zone, were predominantly unsexable juveniles, 1.5 to 3.5 mm in length, and male and female immatures 3.0 to 6.5 mm in length. A very small number of larger immatures and adults were collected in the beach cores. The reverse is true of the offshore samples (Figure 6). Only a few juveniles were collected in the grab samples. The majority of the samples were made up of large immatures and adults ranging from 4.0 to 17.0 mm in length.

A similar pattern of size distribution was observed in the seasonal samples (Figures 7-10). In survey 1, the beach and 9.1 m samples were composed primarily of small individuals, unsexable juveniles and immature males

TABLE 3. RESULTS OF TWO WAY ANOVA ON DENSITY OF *Archaeomysis grebnitzkii*.

Source	MSE	d.f.	F	p
Transect	108.90	1	12.22	0.005
Depth Interval	12.17	3	1.37	NS
Transect x Interval	22.17	3	2.49	NS
Error	8.91	32		

C.V. = 12.70

TABLE 4. MEAN DENSITIES (no./m^2) OF *Archaeomysis grebnitzkii* BY TRANSECT AND DEPTH INTERVAL.

	OT1		OT2		OT3	
Interval	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
1 (4.3 m-7.0 m)	18.00	19.24	--	--	18.00	17.89
2 (7.3 m-10.1 m)	4.00	5.48	26.00	15.17	30.00	26.46
3 (10.4 m-19.5 m)	4.00	5.48	--	--	76.00	68.04
4 (19.5 m-37.5 m)	2.00	4.47	68.00	63.80	36.00	32.09

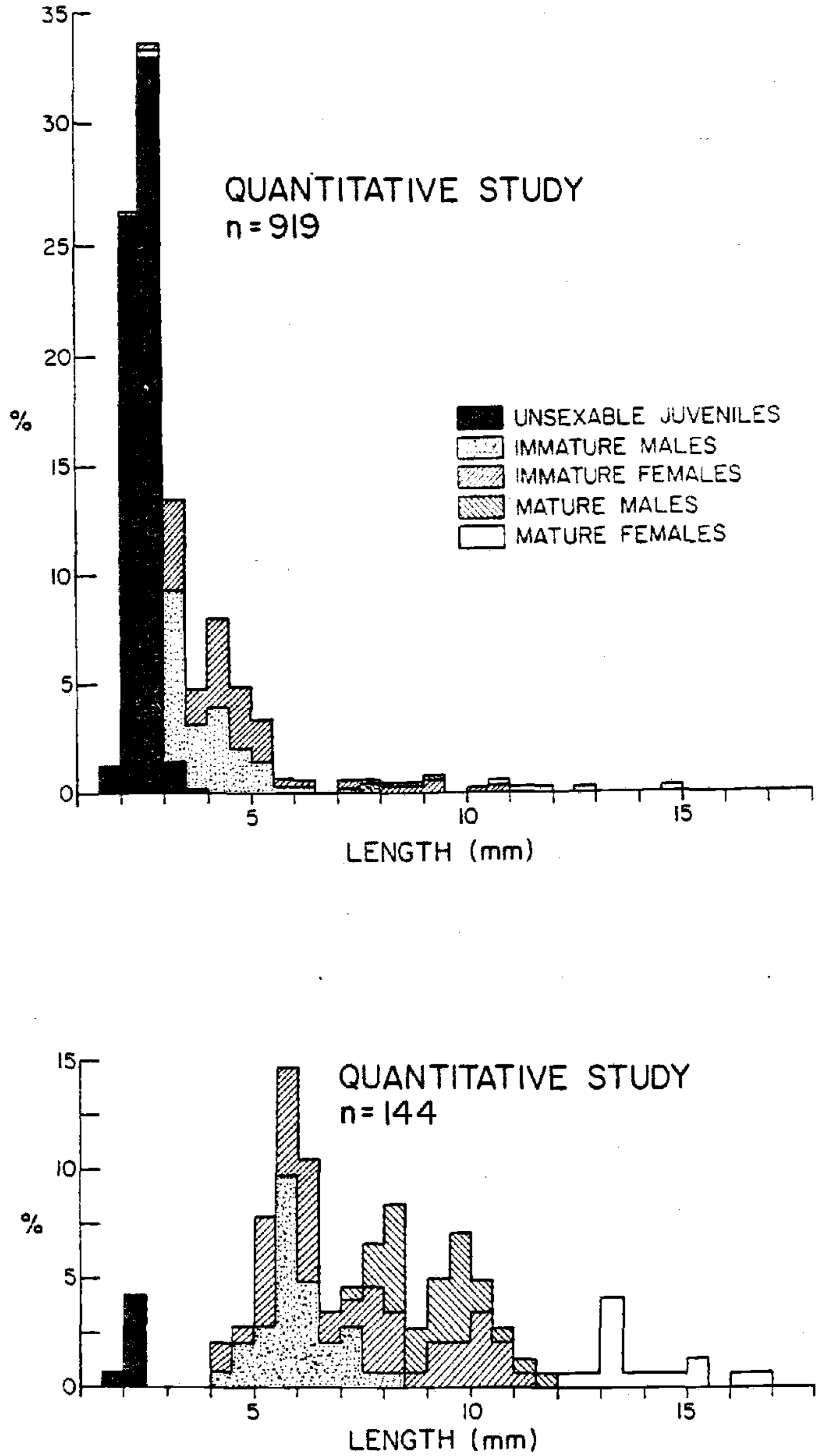

Figure 6. Length frequency of all <u>Archaeomysis grebnitzkii</u> collected from BT1, BT2 and BT3 (top) and OT1, OT2 and OT3 (bottom).

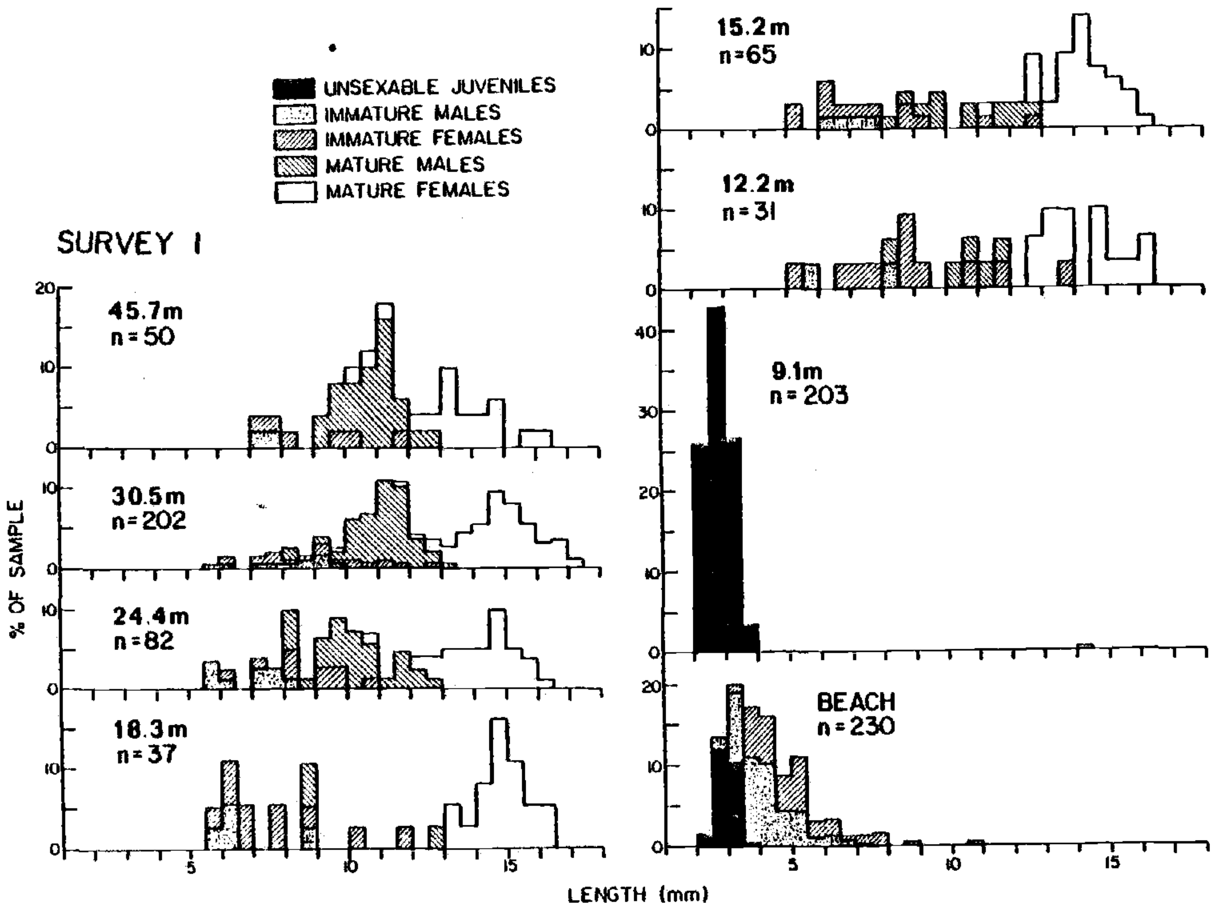

Figure 7. Length frequency of Archaeomysis grebnitzkii collected at each depth during survey 1.

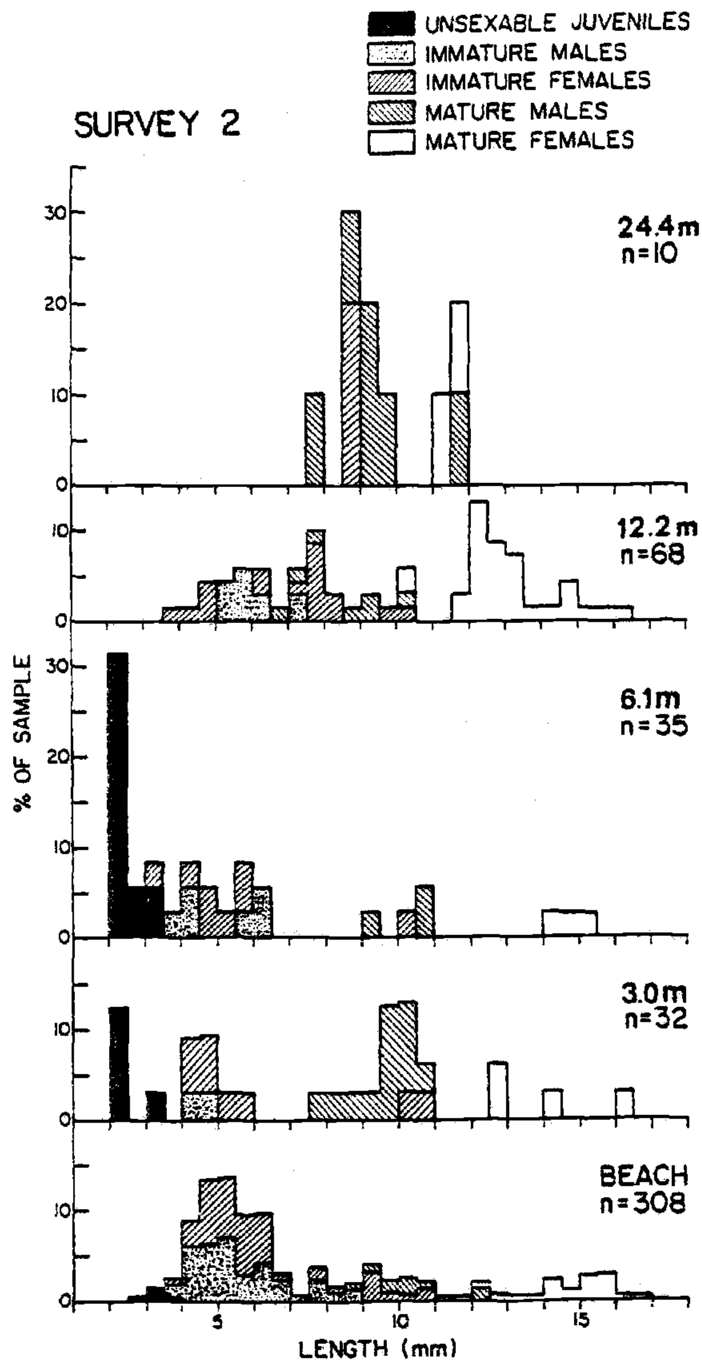

Figure 8. Length frequency of *Archaeomysis grebnitzkii* collected at each depth during survey 2.

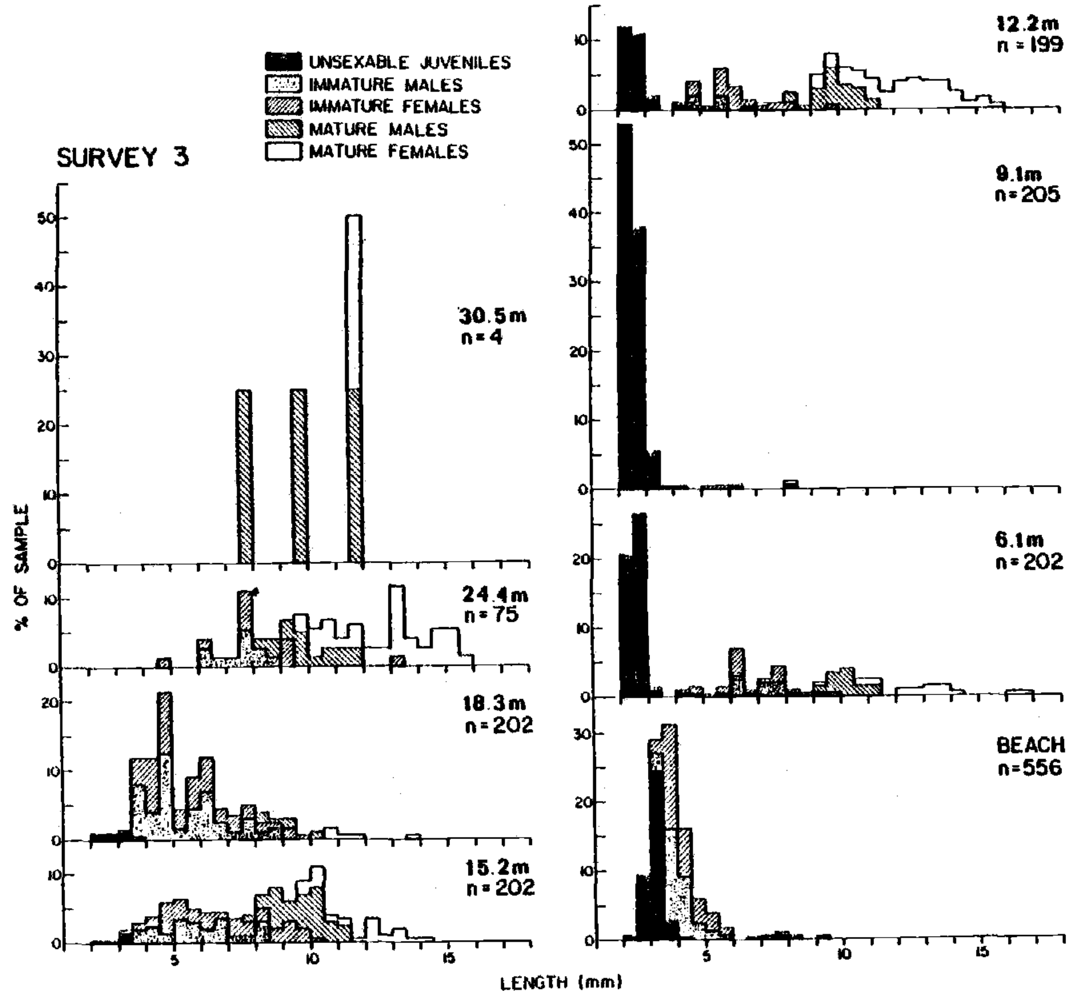

Figure 9. Length frequency of *Archaeomysis grebnitzkii* collected at each depth during survey 3.

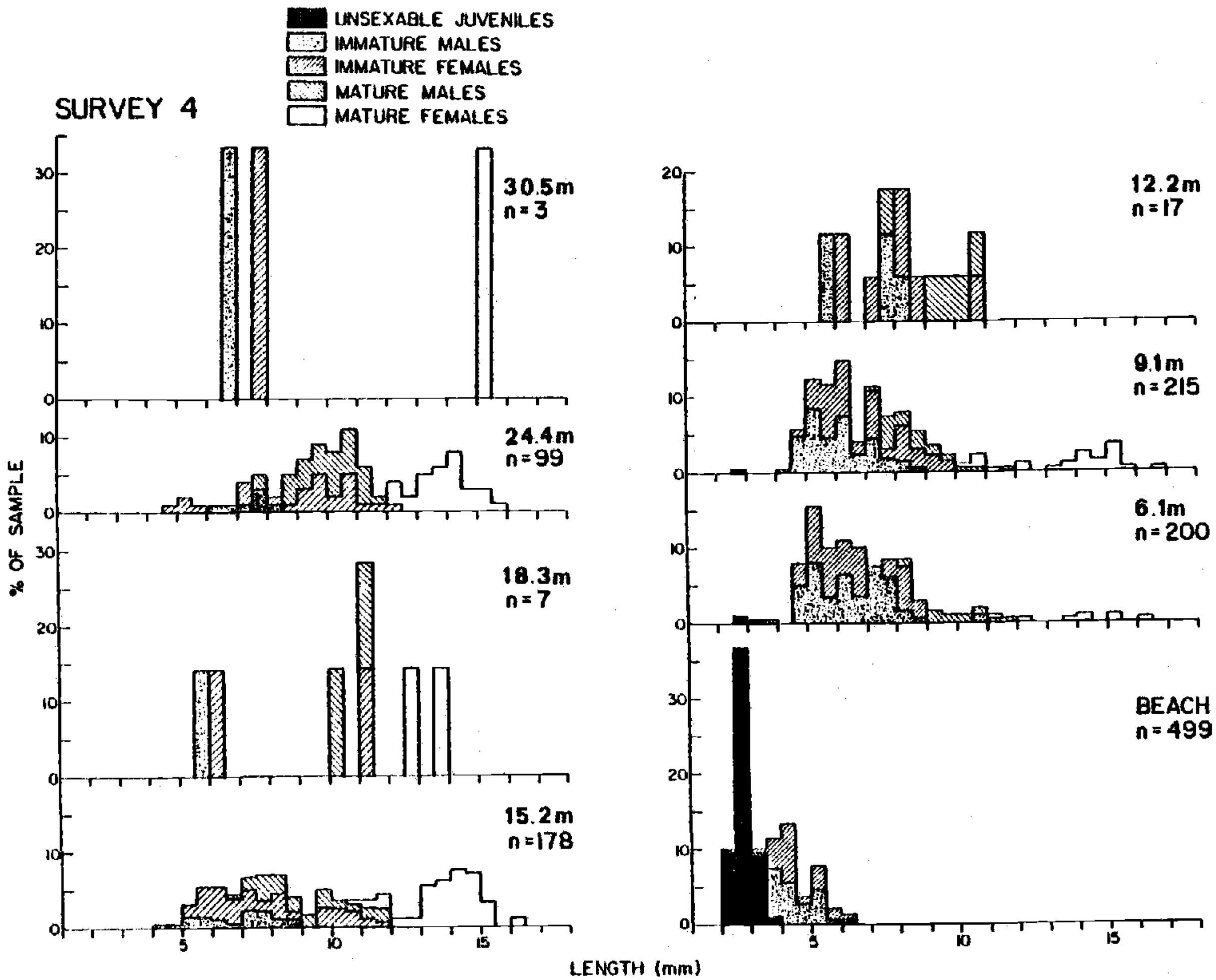

Figure 10. Length frequency of Archaeomysis grebnitzkii collected at each depth during survey 4.

and females, ranging from approximately 2-6 mm. The 12.2 m through 45.7 m samples had a distinctly different composition including larger immature and adult male and female individuals ranging from 5-17 mm. No unsexable juveniles were seen in the 12.2-45.7 m samples.

The distribution of age classes with depth was somewhat different in survey 2. Juveniles, immature and adult animals were collected from the beach, 3.0 m and 6.1 m samples. Immatures and adults, but no juveniles were collected in the 12.2 m and 24.4 m samples.

In survey 3 the unsexable juveniles were concentrated in the beach, 3.0 m, 6.1 m and 9.1 m samples, but were present at 12.2 m, 15.2 m and 18.3 m samples as well. No adults were collected on the beach or at 9.1 m, but adults as well as larger immature animals were collected at 6.1 m and in the 12.2 m to 30.5 m samples.

Survey 4 showed the same basic pattern with only juveniles and small immature individuals collected from the beach, their proportion of the sample decreasing in the 6.1 m and 9.1 m samples where larger immature and adult animals became dominant.

Brood Size and Breeding Length of *Archaeomysis grebnitzkii*

A total of 204 gravid *A. grebnitzkii* females with intact brood pouches were examined over the four surveys. Brood sizes ranged from 20 to 91 larvae, with a mean of 47.2 (Table 5). The largest mean brood size of 58.9 was observed in survey 1 while mean brood sizes for surveys 2-4 ranged from 37.5 to 42.3. The length of gravid females collected ranged from 11.5 mm to 16.9 mm with a mean of 14.5 mm (Table 6). The size of the gravid females also varied somewhat from survey to survey. The largest mean length of gravid females, 14.6 mm, occurred in survey 1, the smallest, 13.93 mm, during survey 3.

A one-way analysis of variance with survey was conducted for both brood size and length of gravid females. The effect of survey on brood size was highly significant (Table 7). A set of orthogonal contrasts showed that females collected in surveys 1 and 2 combined had significantly larger brood sizes than females from surveys 3 and 4 combined. Survey 1 brood sizes were significantly higher than survey 2 brood sizes while differences in brood sizes between surveys 3 and 4 proved nonsignificant. Brood size, therefore, was found to be higher in the early spring and summer than later in the year with the largest broods occurring in survey 1, the February collection.

Time of survey also had a significant effect on the length of gravid females (Table 8). Orthogonal contrasts showed that gravid females in surveys 1 and 2 combined were significantly larger than gravid females collected during surveys 3 and 4 combined. Survey 4

TABLE 5. MEAN BROOD SIZE OF GRAVID *Archaeomysis grebnitzkii* COLLECTED DURING SURVEYS 1-4.

Survey	$\overline{X}$	S	max.	min.	n
1	58.94	14.39	91	22	80
2	39.72	11.23	71	20	47
3	42.32	10.48	72	25	34
4	37.51	8.46	61	23	43
Surveys combined	47.23	15.26	91	20	204

TABLE 6. MEAN LENGTH (mm) OF GRAVID *Archaeomysis grebnitzkii* COLLECTED DURING SURVEYS 1-4.

Survey	$\overline{X}$	S	max.	min.	n
1	14.76	0.93	16.70	12.36	80
2	14.44	1.34	16.87	11.52	47
3	13.93	1.13	16.53	12.02	34
4	14.54	0.90	16.20	12.86	43
Surveys combined	14.50	1.09	16.87	11.52	204

TABLE 7. SUMMARY OF STATISTICAL ANALYSIS OF BROOD SIZE OF *Archaeomysis grebnitzkii*.

		ANOVA		
Effect	MSE	d.f.	F	p
Survey	6164.45	3	42.83	<0.01
Error	143.92	200		

C.V. = 25.40

Orthogonal Contrasts

Contrast Coefficient Matrix

	Survey			
	1	2	3	4
Contrast 1	1	1	-1	-1
Contrast 2	1	-1	0	0
Contrast 3	0	0	1	-1

	T value	T Prob.	Sig./NS
Contrast 1	5.337	<0.01	Sig.
Contrast 2	8.715	<0.01	Sig.
Contrast 3	1.748	0.082	NS

TABLE 8. SUMMARY OF STATISTICAL ANALYSIS OF LENGTH OF GRAVID FEMALES.

Source	MSE	ANOVA d.f.	F	p
Survey	5.66	3	5.00	0.0023
Error	1.13	200		

C.V. = 7.34

Contrast Coefficient Matrix

	Survey 1	2	3	4
Contrast 1	1	1	-1	-1
Contrast 2	1	-1	0	0
Contrast 3	0	0	1	-1

	T Value	T Prob.	Sig/NS
Contrast 1	2.342	0.020	Sig.
Contrast 2	1.663	0.098	NS
Contrast 3	-2.521	0.012	Sig.

gravid females proved to be significantly larger than survey 3 gravid females, while the differences between survey 1 and survey 2 gravid females were non-significant. Late summer and autumn breeding females, therefore, were smaller in body size than those breeding in the early part of the year, with the smallest gravid females occurring in survey 3, in August.

To determine the relationship between length of the gravid female and brood size, regression lines were fitted with brood size as the dependent variable and length as the independent variable for all data combined and each survey separately (Table 9). The regression line fitted for all data combined demonstrated a positive relationship between brood size and length of the gravid female. A significant positive relationship also existed in the survey 1 and 3 data, while the lines fitted for surveys 2 and 4 had slopes that did not differ significantly from zero, indicating that brood size did not vary according to length in these surveys. The regression lines for surveys 1 and 3 were tested for equality according to the procedure presented by Neter and Wasserman (1974). The slopes of these two lines did not differ significantly. However, their intercepts were statistically different, with the intercept for survey 1 being higher than that of survey 3.

TABLE 9. REGRESSION OF BROOD SIZE ON LENGTH FOR SURVEYS 1-4 AND ALL DATA COMBINED. x = LENGTH OF GRAVID FEMALE, y = NUMBER PER BROOD.

Survey		Correlation coefficient
1	$y = -15.144 + 5.018\,x$	0.32
2	$y = 12.216 + 1.905\,x$	0.23
3	$y = -27.245 + 4.996\,x$	0.54
4	$y = 37.752 - 0.0165\,x$	0.00
all data combined	$y = -15.719 + 4.341\,x$	0.31

Distribution of Gravid Females

Gravid females were collected in all four surveys. The depths inhabited by adult females were examined to determine if gravid females inhabited depths different than those of the adult population as a whole. Contingency tables were used to test the independence of the depth of occurrence from the ovigerous condition (gravid vs. nongravid) of the adult females for each survey (Tables 10-13). In some cases, samples were grouped together to achieve sample sizes large enough for the analysis.

In survey 1, a significant association existed between the frequency of gravid females and depth. Lower than expected frequencies occurred at 12.2 m, 30.5 m, and 45.7 m, while higher than expected frequencies were seen in the mid-depth samples of 15.2 m, 18.3 m and 24.4 m (Table 10). In surveys 2 and 3, the association between ovigerous condition and depth was non-significant. The Chi-square test for survey 4 showed a significant association, with frequencies of gravid females being higher than expected at depths <15 m, lower than expected at 15 m, and about predicted values at depths >15 m. In general, no clear trend of ovigerous condition of adult females with depth is seen over the four surveys outside of the pattern of separation previously observed between small and large individuals.

All stages of larval development, eggs, embryos

TABLE 10. CONTINGENCY TABLE AND SUMMARY OF CHI-SQUARE TEST OF INDEPENDENCE BETWEEN OVIGEROUS CONDITION OF ADULT FEMALE AND DEPTH FOR SURVEY 1.

	Frequency		
Depth (m)	non-gravid	gravid	Total
12.2	11	3	14
15.2	14	21	35
18.3	2	18	20
24.4	6	26	32
30.5	62	29	91
45.7	15	7	22
Total	110	104	214

$\chi^2 = 46.02$

$p = 0.005$

TABLE 11. CONTINGENCY TABLE AND SUMMARY OF CHI-SQUARE TEST OF INDEPENDENCE BETWEEN OVIGEROUS CONDITION OF ADULT FEMALE AND DEPTH FOR SURVEY 2.

	Frequency		
Depth (m)	non-gravid	gravid	Total
<6.1	13	36	49
>6.1	11	26	37
Total	24	62	86

$\chi^2 = 0.11$

not sig.

TABLE 12. CONTINGENCY TABLE AND SUMMARY OF CHI-SQUARE TEST OF INDEPENDENCE BETWEEN OVIGEROUS CONDITION OF ADULT FEMALE AND DEPTH FOR SURVEY 3.

Depth (m)	Frequency non-gravid	gravid	Total
<12.2	12	6	18
12.2	48	22	70
15.2	21	10	31
>15.2	32	13	45
Total	113	51	164

$\chi^2 = 0.17$

not sig.

TABLE 13. CONTINGENCY TABLE AND SUMMARY OF CHI-SQUARE TEST OF INDEPENDENCE BETWEEN OVIGEROUS CONDITION OF ADULT FEMALE AND DEPTH FOR SURVEY 4.

Depth (m)	Frequency non-gravid	gravid	Total
<15.2	28	19	47
15.2	50	16	66
>15.2	7	25	32
Total	85	60	145

$\chi^2 = 25.82$

$p = 0.005$

without eyes, and embryos with eyes, were seen in the gravid females collected in each survey. The stage of the larvae within the brood pouch of the gravid females also did not appear to be related to depth, although sample sizes were too small to test this effect.

IV. DISCUSSION

Bathymetric Ranges

The depth ranges occupied by the mysid species in this study were consistent with those reported in the literature for *Acanthomysis sculpta*, *A. macropsis*, *A. davisii*, *A. nephropthalma*, and *Neomysis kadiakensis* by Banner (1948), Tattersall (1951) and Clutter (1967). *N. rayii* was collected predominantly in the littoral region although this species is reported as being coastal (found seaward of the littoral region) in the literature (Tattersall, 1952; Ii, 1964). *Archaeomysis grebnitzkii*, previously thought to be restricted to the inner surf zone (Tattersall, 1951; Ii, 1964; Clutter, 1967), was commonly collected out to 30 m below MLLW. This species may have been overlooked in previous offshore sampling due to its benthic nature.

Mysid Zonation

Particular species of mysids have been shown to occur in characteristic bathymetric zones (Clutter, 1967; Wittman, 1977). In the present study a tendency was observed within a genus for an individual species to be replaced by a second species along the depth gradient of the transect, while species of different genera often coexisted over much of their bathymetric range. This type of data lends itself to interpretation by classical niche theory, wherein closely related species, in this case those within a genus, would be highly competitive and therefore not occupy the same area (Hardin, 1960). Conversely, those species that do coexist would be avoiding competition by partitioning the habitat and utilizing different resources within a depth zone (MacArthur, 1968). These statements assume that the resources available are limiting, and that the populations are in equilibrium (Hutchinson, 1961). If this were true, co-occurring species should be ecologically differentiated, either in their food habits, or perhaps in their utilization of space within a depth zone. Mysids, in general, are omnivores, capable of exploiting a wide range of food resources including phytoplankton, small crustaceans, and detritus (Mauchline, 1980). Although they are generally considered to be of the same ecological feeding type, the morphology of their feeding appendages is very diverse, suggesting some specialization in their choice of food. Mauchline (1980) reviews the available literature on the structure of mysid feeding appendages, but no comprehensive study of their morphology relative to function has been made.

Substrate preference may also play a role in the distribution of mysid species. Wittman (1977), in a study of Strujan Bay and islands off Rovinj (Istria, Yugoslavia) found that mysid species show a preference for certain bathymetric zones, and within a zone different species occupy different substrates and distinct microhabitats (i.e. sand, rocks, mud, algae). Therefore, he states that species whose depth zones overlap usually associate with different substrates, while species preferring the same substrate usually occur in different bathymetric zones. This type of habitat partitioning is less likely to be important in the nearshore environment studied, however, as the substrate is fairly homogeneous within a depth zone.

In some cases, co-occurring species may be avoiding competition by a vertical separation within a depth zone. *Archaeomysis grebnitzkii*, as a benthic species that burrows into the sediment, would not be competing for physical space with hypopelagic species that remain above the sediment, and the bathymetric range it inhabits is relatively broad.

Energy levels of the different zones, and the associated sediment size and food distribution may be influencing the zone inhabited by each species. Those species living within the surf zone must be physically adapted to high turbulence, while those preferring a calmer environment remain outside the surf zone.

Distribution of *Archaeomysis grebnitzkii*

In all three beach transects in the quantitative study, the densities of *Archaeomysis grebnitzkii* in the beach cores were highest within the wave wash zone regardless of tidal height. Shoreward of the wave wash zone, the densities fell drastically and the distribution of the animals became patchy (Figure 3). The density pattern of *A. grebnitzkii* observed in the beach cores is common for littoral mysid species. The animals become concentrated at the water's edge at low tide, and are dispersed throughout the intertidal area during high tide (Mauchline, 1980). The difference in the maximum densities observed between transects most likely reflects different stages of tide and surf conditions as well as the patchy nature of the distribution of the animal, rather than real differences between transects.

The subtidal densities of *A. grebnitzkii* were also highly variable and did not appear to be correlated with depth or sediment. As with the beach cores, it is difficult to interpret apparent density differences between transects due to the patchy nature of the population.

From the seasonal studies as well as the quantitative study, it is clear that juvenile and adult *A. grebnitzkii* inhabit different bathymetric zones. The juveniles are restricted to the inner surf zone, abundant from the intertidal habitat out to a depth of approximately 9 m. The adults and larger immature animals appear to be most common from the seaward edge of the surf zone to approximately 30 m below MLLW. This pattern is clearest in surveys 1 and 4, where sharp transitions between large and small animals were seen at 12 m and 6 m respectively. In survey 3 the zones overlapped, with juveniles occurring out to 18 m. Occasionally, the zone occupied by the adults extended shoreward onto the beach as observed in survey 2.

Adult and juvenile mysids of a species occupying different habitats has been observed by several other authors. Mauchline (1970) reports that in Loch Entive, Scotland, juvenile Shistomysis ornata occupied the innermost region of the loch at depths of approximately 35 m while mature adults were concentrated toward the seaward end of the loch at approximately 65 m. He suggested that the young inhabit the shallower, less saline area of the loch until they migrate into deeper areas to breed. Amaratunga and Corey (1975) found a similar pattern occurring in Mysis stenolepis in Passamaquoddy Bay, New Brunswick. The young are released in shallow water in spring. The following fall the young adults migrate to deeper water and breeding occurs. The females return to shallow waters to release their brood in the spring. Clutter (1967) found that the bathymetric distribution of juvenile and adult Metamysidopsis elongata on the open coast of southern California were different, while adult male and female distributions were generally similar. In this case, the zone occupied by the juveniles overlapped that of the adults, but was broader, extending into both deeper and shallower water.

Based on the present study, juvenile Archaeomysis grebnitzkii appear to remain within the surf zone until they move into deeper water as large immatures where breeding presumably takes place. It is not clear if the gravid females return to shallow waters to release their brood. In survey 2, adult mysids were collected in unusually high numbers on the beach and at shallow subtidal stations. However, these adults included males and early stage gravid females as well as late stage gravid females. The distribution of animals in this case is more likely related to local surf conditions than to the release of larvae. Boroditch and Havlena (1973) found that two littoral mysid species move temporarily offshore to avoid wave action. The zone occupied by larger A. grebnitzkii may also fluctuate with the intensity and location of the surf zone, extending toward the beach on calm days and moving offshore on rough days.

Release of mysidacean larvae, as well as breeding, generally takes place at night (Green, 1970; Berrill, 1971; Mauchline, 1980). The nighttime distribution of A. grebnitzkii, both vertically and horizontally, may be quite different than the daytime distribution sampled in this study. Many species perform a diel vertical migration, rising toward the surface layers at night and returning to deeper layers at daylight.

This has been observed for four species of the genus Gastrosaccus (subfamily Gastrosaccinae)(Macquart-Moulin, 1973, 1977). These species burrow into the sand during the day and emerge into the pelagic environment at night. It is likely that A. grebnitzkii, also a member of the subfamily Gastrosaccinae, exhibits similar behavior, remaining buried during the day, and becoming active at night. During this time the females may move into shallow water to release their brood.

Remaining in deeper areas outside the surf zone may be advantageous to the adult mysids for several reasons. The inner surf zone is a highly turbulent and abrasive habitat. Damage to the brood pouch and loss of embryos by gravid females is much less likely to occur outside this zone. Also, breeding may be accomplished more successfully in a more stable environment.

In addition to physical damage, mysids in the intertidal sandy beach area would be more susceptible to bird predation. Moran and Fishelson (1971) report two species of plovers (Charadriidae) feeding heavily on the beach dwelling mysid Gastrosaccus sanctus. The birds were found to hunt along the sandy shore on the sites of the densest mysid population. Although Moran and Fishelson originally reported that predation was occurring at random, unrelated to the size of the prey, a reevaluation of their data by Schneider (1981) demonstrated that the birds were selecting the larger prey. Large adult mysids would appear to be prime targets for visually feeding shorebirds, and therefore remaining in deeper waters may also be a mechanism for avoiding bird predation.

V. SUMMARY

1. Five of the seven mysid species collected in this study fall into the following bathymetric classifications:

   Littoral: *Acanthomysis sculpta*
   Neomysis rayii

   Shallow shelf:
   Acanthomysis davisii
   Acanthomysis macropsis
   Neomysis kadiakensis

   The benthic species *Archaeomysis grebnitzkii* does not fit well into this classification scheme as it inhabits both the littoral and the shallow shelf region. The seventh species, *Acanthomysis nephropthalma*, was present in the deeper end of the range defined for shallow shelf species. The seaward limit of this species was not established.
2. Bathymetric zonation of mysid species was apparent. Members of the same genus occupied largely different zones, while members of different genera occupied overlapping zones. Benthic species overlapped pelagic species, but only those of different genera.
3. Slight shoreward and seaward movement of the zones occurred, but the relative order of the species

with respect to depth remained constant.

4. Adult and juvenile *Archaeomysis grebnitzkii* were found to occupy different zones. The juveniles are concentrated in the inner surf zone, while the adults are generally located from the seaward edge of the surf zone to around 30 m below MLLW.

5. Reproduction appears to be year round. Brood sizes were largest in early spring and summer, corresponding to larger body sizes of the breeding females. The mean year round brood size was determined to be 47.2. A positive relationship was found to occur between brood size and length of the gravid female.

BIBLIOGRAPHY

Amaratunga, T.; Corey, S. Life history of Mysis stenolepsis Smith (Crustacea, Mysidacea). Can. J. Zool. 53:942-952; 1975.

Banner, A. H. A taxonomic study of the Mysidacea and Euphausiacea (Crustacea) of the Northeastern Pacific. Part II. Mysidacea, from tribe Mysini through subfamily Mysidellinae. Trans. Roy. Can. Inst. 27:65-125; 1948.

Berrill, M. The embryonic development of the avoidance reflex of Neomysis americana and Praunus flexuosus (Crustacea:Mysidacea). Animal Behavior. 19:707-713; 1971.

Boroditch, N. D.; Havlena, F. K. The biology of mysids acclimatized in the reservoirs of the Volga River. Hydrobiologia. 42:527-539; 1971.

Clutter, R. I. Zonation of nearshore mysids. Ecology. 48:200-208; 1967.

Enright, J. T. Responses of an amphipod to pressure changes. Comp. Biochem. and Physiol. 7:131-145; 1962.

Enright, J. T. The tidal rhythm of activity of a sand beach amphipod. Z. vergl. Physiol. 46:276-313; 1963.

Green, J. W. Observations on the behavior and larval development of Acanthomysis sculpta (Tattersall) (Mysidacea). Canadian J. Zool. 48:289-292; 1970.

Haertel, L., Osterberg, C. Ecology of zooplankton, benthos and fishes in the Columbia River estuary. Ecology. 48:459-472; 1967.

Hardin, G. The competitive exclusion principle. Science. 131:1292-1297; 1960.

Hobson, E. S.; Chess, J. R. Trophic interactions among fishes and zooplankters nearshore at Santa Catalina Island, California. Fish. Bull. NOAA. 74:567-598; 1976.

Holmquist, C. A revision of the species _Archaeomysis grebnitzkii_ Czerniavsky and _A. maculata_ (Holmes) (Crustacea, Mysidacea). Zool. Jahrb. Abt. Syst. Okol. Geogr. Tiere. 102:51-71; 1975.

Hutchinson, G. E. The paradox of the plankton. Amer. Naturalist. 95:137-145; 1961.

Ii, N. Fauna Japonica, Mysidae (Crustacea). Biogeographical Society of Japan; 1964.

Jawed, M. Effects of environmental factors and body size on rates of oxygen consumption in _Archaeomysis grebnitzkii_ and _Neomysis awatschensis_ (Crustacea: Mysidae). Marine Biology. 21:173-197; 1973.

Kasaoka, L. D. The male genital system in two species of mysid crustacea. J. Morph. 143:259-284; 1974.

MacArthur, R. H. The theory of the niche. R. C. Lweontin, ed. Population Biology and Evolution. Syracuse, N.Y.; Syracuse University Press; 1968: 159-176.

Macquart-Moulin, C. L'activité natatoire rhythmique chez les peracarides bentho-planktoniques. Determinisme endogène des rhymes nycthemeraux. Tethys. 5:209-231; 1973.

Macquart-Moulin, C. Le controle de l'emergence et des nage nocturnes chez les peracarides des plages de Méditerranée. _Eurydice affinis_ Hansen (Isopoda). _Gastrosaccus mediterraneus_ Bosescu, _Gastrosaccus spinifer_ (Goes) (Mysidacea). J. Exp. Mar. Biol. and Ecol. 27:61-81; 1977.

Mauchline, J. The biology of _Schistomysis ornata_ (Crustacea, Mysidacea). J. Mar. Biol. Assoc. U.K. 50:169-175; 1970.

Mauchline, J. The biology of mysids and euphausiids. New York: Academic Press, Inc; 1980.

Miller, B. S. Stomach contents of adult starry flounder and sand sole in East Sound, Orcas Island, Washington. Journal of the Fisheries Research Board of Canada. 24:2515-2526; 1967.

Miller, B. S. Food of the flathead sole (_Hippoglossoides ellassodon_) in East Sound, Orcas Island, Washington. Journal of the Fisheries Research Board of Canada. 27:1661-1665; 1970.

Moran, S.; Fishelson, L. Predation of sand-dwelling mysid crustacean Gastrosaccus sanctus by plover birds (Charadriidae). Mar. Biol. 9:63-64; 1971.

Neter, J.; Wasserman, W. Applied Linear Statistical Models. Homewood, Ill: Richard D. Irwin, Inc; 1974.

Oregon State University, School of Oceanography. Environmental studies on the effects of the Gardiner mill ocean outfall on the Pacific Ocean. Final Report, CRC Project 1693. Environmental Sciences, International Paper Company, Corporate Research Center, Tuxedo Park, N.Y.; 1982.

Schneider, D. C. Size-selective predation on mysids by birds (Plovers). Mar. Ecol. Prog. Ser. 5:223-224; 1981.

Tattersall, W. M. A review of the Mysidacea of the United States National Museum. Bull. U.S. Nat. Mus. 201:1-292; 1951.

Wakefield, W. 1982. Personal communication. University of California, Scripps Institution of Oceanography, La Jolla, CA.

Wigley, R. L.; Burns, B. R. Distribution and biology of mysids (Crustacea, Mysidacea) from the Atlantic coast of the United States in the NMFS Wood's Hole collection. Fish. Bull. NOAA. 69:717-746; 1971.

Wittman, K. J. Modification on association and swarm-in North Adriatic Mysidacea in relation to habitat and interacting species. Keegan, B. F.; Ceidigh, P. O.; Boaden, P. J. S. eds. Biology of benthic organisms: European Marine Biology Symposium; 1976, October 5-11; University College, Galway, Ireland; 1977:605-612.