A SURVEY STUDY OF THE METAZOAN FAUNA OF THE PSAMMOLITTORAL ZONE OF MUD LAKE, BARRY COUNTY, MICHIGAN

Thesis for the Degree of M. S.

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ABSTRACT

A SURVEY STUDY OF THE METAZOAN FAUNA OF THE PSAMMOLITTORAL ZONE OF MUD LAKE, BARRY COUNTY, MICHIGAN

by Peter G. Weber

Core samples were collected from the psammolittoral zone of Mud Lake (T. 2 N., R. 9 W., S. 8, Barry County, Michigan) from October 1961 to the end of August 1962 with the purpose of investigating the abundance and distribution of psammolittoral organisms and their variance throughout a season. Particular attention was focused on the distribution of organisms--both vertical and horizontal--within the psammon. Wherever possible correlations between distributional patterns and physico chemical factors were made.

The following physico chemical measurements were taken: sand temperature, pH oxygen concentration, carbon dioxide concentration, beach slope, and position of the "black layer." Since the characteristics of these were found to vary approximately in the same manner as found in previous studies, an extensive discussion was not undertaken, but a listing of these characters for the Mud Lake psammon is included.

Peter G. Weber

The composition of the Mud Lake flora and fauna was approximately the same as that reported by Pennak (1940) and Neel (1948) in their studies. A notable difference between this and the two previously mentioned studies was in the relatively meager rotifer fauna found in Mud Lake. Cladocera, Malacostraca, and Acari were major taxons of the Mud Lake sand which previously had not been reported from the psammon. Other minor faunal differences were discussed as well. The seasonal and spatial (vertical and horizontal) distribution of the major taxons found in the sand was discussed and compared with that found by previous investigators.

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By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure | Page

LIST OF PLATES

I. INTRODUCTION

The purpose of this study was to gain some insight onto the kinds, numbers, and distribution of psammon organisms and their variance throughout a season. Admittedly studies of this sort have previously been undertaken and therefore part of the initial purpose of the study was to acquaint the author with the psammolittoral environment and its organisms.

The psammolittoral region is one which investigators have found to contain quite varied and extensive communities of both plants and animals. Pennak (1940) concluded in his study that "Perhaps no other environment is capable of supporting such a dense and diversified group of microorganisms as the sandy beach." This is also an environment which, compared to other regions of the lake, has received relatively little attention. Neel (1948) gave a brief review and an extensive bibliography of the work done to 1948 and Pennak (1940) also gave a good summary in his study. Except for Myer's work, all of the fresh water psammolittoral studies in this country have been undertaken in Wisconsin and Michigan. The most recent work, by Neel (1948), stressed the physico chemical aspects of the psammon in contrast to the emphasis upon psammo organisms in previous studies. The present study is concerned more with the biota of the psammon than with its non-biological features.

II. DESCRIPTION OF AREA STUDIED

No previous study, limnological or otherwise, has ever been undertaken on Mud Lake; consequently nothing is known of either its biological or physico chemical characteristics. The lake was selected for study primarily because of its relative isolation. It is also one of the few lakes in this particular area of Michigan with a natural sandy beach relatively undisturbed by human inhabitants.

The psammolittoral region has been divided by several workers into zones or sub-regions. Wiszniewski (in Neel, 1948) considered the psammolittoral to extend lakeward for an indefinite distance and landward to a few meters above the water-line; he divided this region into three general areas:

1) hydropsammon: the shoal portion of the psammon (i. e. the submerged sand).
2) hygropsammon: the consistently moist region 0-1 meters above the water-line.
3) eupsammon : the most landward portion of the psammon from 1-2 meters landward.

Though there are other ways of dividing the psammon, the zonation of Wiszniewski is used throughout this paper since it conveniently includes the entire psammolittoral zone; other classifications being restricted to only the beach portions.

Coarse sand, gravel, and an abundance of surface vegetation characterized the Mud Lake psammon. According to residents of the region the lake has been receding in the past few years; the shoreward portion of the psammon has thus been increasing in size and the shallows decreasing. The width of the psammon varied but on the average was eight meters. Collections were only taken from the lakeward five meters of this region.

Three transects were arbitrarily selected, one on the western shore (T1), one on the southern (T2), and one on the northern (T3) (see plates 1-3). Collections were made alternately from each of the three transects throughout one year.

All three transects were overlaid by surface organic debris expecially in the hydropsammon, as well as by a considerable growth of surface vegetation (mostly Scirpus sp. and Carex sp.). The beach of both T1 and T2 was composed of rather coarse sand grains and pebbles. The slopes of the three beaches also differed (see Table 1).

On T1, the fine surface sand continued two meters shoreward from the water-line and there was replaced by coarse gravel and sand which extended landward for another four and one half meters. Surface plants were found mostly in the gravel region. T2 was distinguished by sand and gravel throughout the entire beach region.

The psammolittoral zone was considered to extend shoreward six meters from the water's edge and into the water to where the layer of organic deposition replaced the sand. The water-line was used as a reference point and designated as 0, stations landward of the water-line were designated as plus (+), and those shoalward as minus (-).

III. PROCEDURE

The methods employed for collecting and extracting organisms were similar to those suggested in <u>Limnological Methods</u> (Welch, 1948). Aluminum tubes of two-inch internal diameter were inserted into the sand at 50cm. intervals along a transect on the beach. The tubes were inserted by hand pressure to as great a depth as possible, which, in most cases, was to about 15 cm. Immediately the tubes with their sand core samples were stored upright in a portable icebox and transported to the laboratory for processing. Samples were refrigerated until processed. Collections were made alternately from three different transects. In order to get an estimate of seasonal variation in the fauna, collections were made at monthly intervals except September and those months when snow and frozen ground impeded field work. Collections on a given transect were made within 50 cm. of each other so that subsequent samples were taken from the same region.

The process of extracting the organisms from the sand was that suggested by Welch (1948) and also used by Neel (1948) in his study. A plunger was inserted into the lower end of the aluminum tube, the sand core pushed out and divided into one cc. sections from which the organisms were extracted. The one cc. sand core was then placed into an evaporating dish and one cc. of a saturated solution of menthol added as a relaxing agent. The sample was allowed to soak in the menthol for five minutes after which 15 cc. of tap water was added. A fine capillary stream of air was bubbled into the evaporating dish bouncing the sand grains around and separating out the organisms from the sand; this procedure lasted two minutes. The water was then slowly decanted and centrifuged for one minute and the super-natant again poured back into the sample in the evaporating dish. The entire procedure was repeated in the same manner three times per one cc. sand sample. The material obtained from a one cc. section of sand was then preserved in 16 cc. screwcap vials in a solution of 40% glycerin in 4% formalin. Other preservatives such as 4% formalin and FAA were tried but the glycerin mixture was the best for taxonomic purposes.

Analyzation, counting and identification, of the contents of the one cc. sand sample was done by shaking the 16 cc. vial to homogenize the concentrate thoroughly, extracting one cc. with a dropper and placing this in a Sedwick-Rafter counting cell. The average from ten counts was used to determine the number of organisms per cc. of sand. In this manner an attempt was made to obtain an estimate of vertical and horizontal as well as seasonal distribution.

Due to the impracticability of such a large number of samples it was not possible to make a second series of ten counts which would have given greater accuracy to the population estimates.

Because certain of the organisms (copepods, oligochaetes, cladocerans, insects, and mites) were not present in sufficient numbers to appear in the ten counts made with the Whipple micrometer two different kinds of tabulations were made:

1) An estimate was taken with a Whipple micrometer of the organisms present in sufficient number to appear consistently in counts (these included Testacea, algae, rotifers, nematodes, and tardigrades). The average of ten counts from a one cc. Sedwick-Rafter counting cell was taken and the number of organisms per cc. of sand determined from this.

2) A second tally of the number of organisms per cc. was taken by counting the total number of a particular organism in the one cc. Sedwick-Rafter counting cell; the number of organisms per cc. of sand were determined from this.

Since the two counts were not equivalent there were no comparisons made between them but they were instead treated separately in the discussion.

IV. PHYSICAL CHARACTERS OF THE PSAMMON

Beach Slope

Measurements of slope were made at 50 cm. intervals along a transect with a Brunton compass. The importance of the degree of slope in limiting the horizontal distribution of psammo organisms was pointed out be Pennak (1940). In general, the greater the slope the smaller the width of the beach inhabited by psammo organisms. Greater slopes do not permit the movement of capillary water up the beach and in these beaches there is a reduced quantity of capillary water in the surface sand nearer the lake. Slope then, is a primary factor in determining the distribution of capillary water which, in turn, limits the distribution of psammolittoral organisms.

Figure 1 shows the differences in the slopes of the three transects.

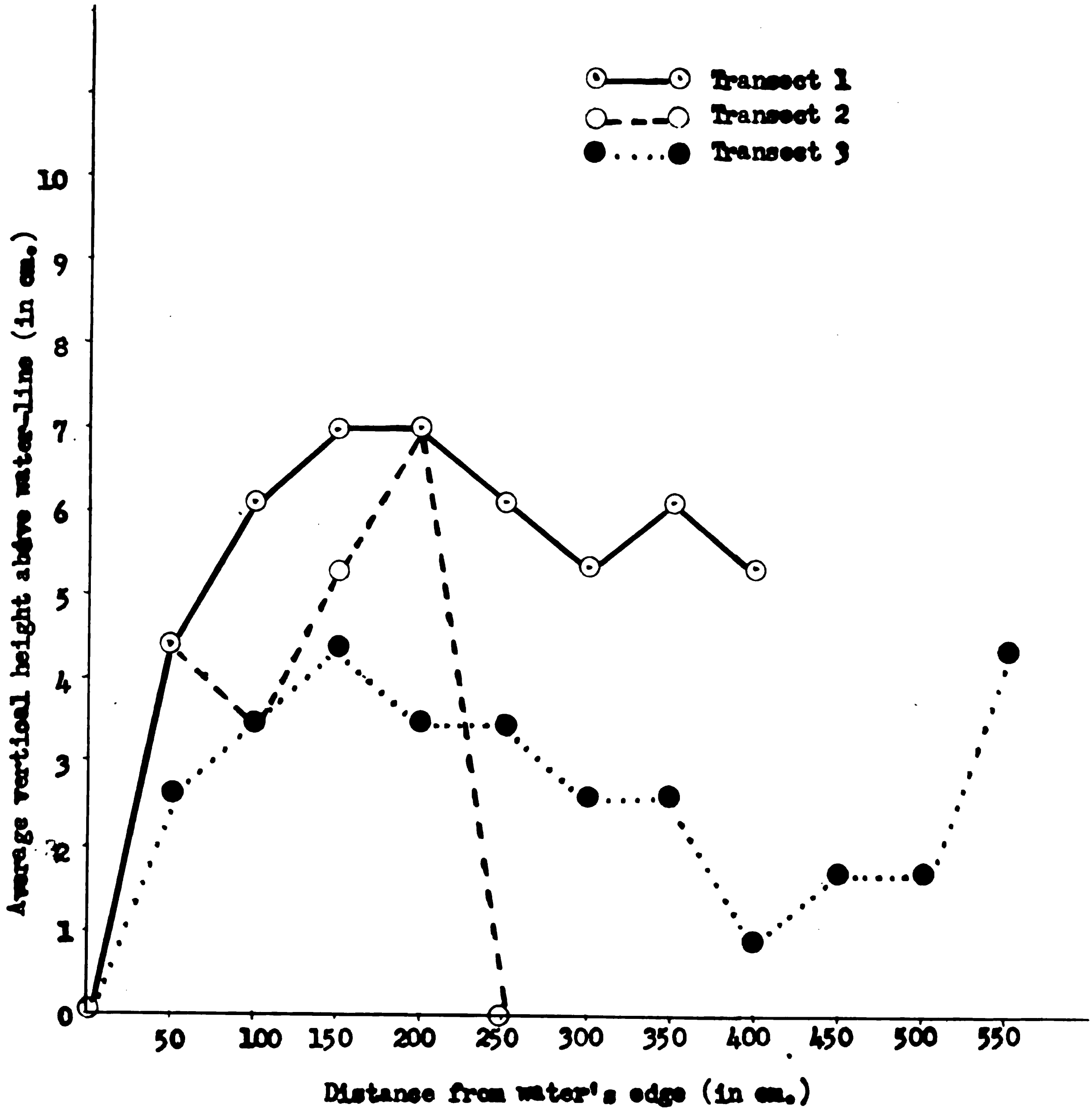
Organic Debris

At depths of between 3-5 cm. below the surface there was a stratum of organ material, the black layer (Table 2). This layer, 4-6 cm. in thickness, extended vertically to a maximum depth of 10-14 cm. below the surface. Occasionally a sample would not show a distinct black layer. Conversely, a few samples contained a considerable amount of organic material throughout most of their depth.

TABLE 1.--Slopes of the three transects at Mud Lake

Distance from Water's Edge (in meters)	Slope (in degrees)			Average Height Above Water-line (in cm.)		
	T1	T2	T3	T1	T2	T3
0 (water-line)	0	4	3			
0.5	5	5	3	4.4	4.4	2.6
1.0	7	4	4	6.1	3.5	3.5
1.5	8	6	5	7.0	5.3	4.4
2.0	8	8	4	7.0	7.0	3.5
2.5	7	0	4	6.1	0.0	3.5
3.0	6		3	5.3		2.6
3.5	7		3	6.1		2.6
4.0	6		1	5.3		0.9
4.5			2			1.7
5.0			2			1.7
5.5			5			4.4

Figure 1. Average height above water-line on the three transects. As determined from the slopes taken with a Brunton compass.


Transect 1
Transect 2
Transect 3
Average vertical height above water-line (in cm.)
0
1
2
3
4
5
6
7
8
9
10
50
100
150
200
250
300
350
400
450
500
550
Distance from water's edge (in cm.)

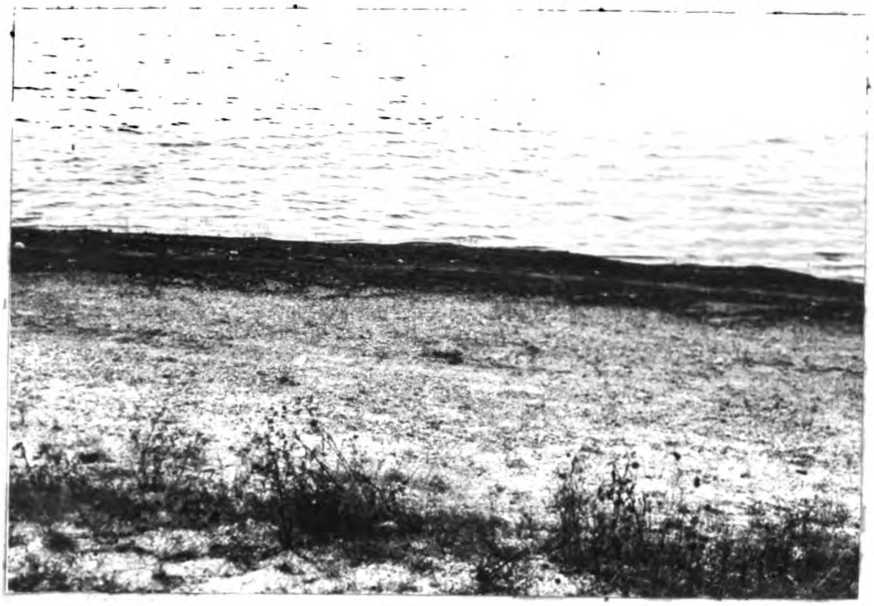


Plate 1. Transect 1 on the eastern shore of Mud Lake.

Plate 2. Transect 2 on the southern shore of Mud Lake; note the great amount of surface organic matter in hygropsammon.

Plate 3. Transect 3 on northern shore of Mud Lake; note profuse surface vegetation.

TABLE 2.--Location of the black layer given as depth (in cm.) from the surface of sand; bottom figure in the box is bottom limit of the black layer. Poorly developed layer. Blank cells indicate absence of the black layer.*

	Distance From Water's Edge (in meters)												
	(-)					(+)							
Date and transect	2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	$\bar{X}$
Nov. 18, 1961 1.		3 8	3 7	4 11	4 10	3.5 6	5 11	5 8	3 7				4 9
Oct. 22, 1961 2.			*	*	*	3 9	*	*	*	6 9			
Oct. 28, 1961 3.					5 10	9 14	5 9	8 12	4 10	4 8	3 7		5 10
Nov. 12, 1961 1.			4 11	4 8	4 12	4 13	3 9	4 5	8 14	*	*		4 10
Dec. 3, 1961 2.			*	*	4 12	3 8	*	4 6	*	3 9			3 9

*Asterisks indicate presence of black layer but no distinct upper or lower limits.

According to Neel (1948) and others, ". . . the black layer is due to the reduction of iron oxides by sulfides produced by anaerobic decomposition of organic material," and that ". . . color changes associated with penetration of oxygen into black sand indicate that the upper limit of the black layer marks the division between anaerobic and aerobic zones in the sand." Very few organisms occurred below 2-3 cm., and, apparently the black layer may be a major limiting factor in restricting the vertical occurrence of the psammobiota. Table 3 graphically demonstrates the distribution of some of the psammoorganisms in relation to the black layer on the three transects at a particular time. In every instance, except the oligochaetes which are highly motile, there were no organisms found below this layer. Certain other factors, aside from the black layer,such as the amount of oxygen and light, the latter of which particularily restricts the algal flora to a depth of 2-3 cm. , were factors limiting the vertical distribution. Since in transects where the black layer was poorly developed organisms did not occur to depths greater than in the transects with a well developed stratum, the exact importance of the black layer was impossible to evaluate in comparison to other factors (e. g. amount of light, water, etc.) in restricting the depth to which psammo organisms occur.

TABLE 3a.--Distribution of six groups of organisms in relation to the black layer (dark line) for November 12, 1961. (T2).

Date and Transect	Depth (cm)	(-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5	4
Nov. 12, 1961 1.														
Mites	1			48	48	0	0	0	0	16	0	16		
	2				16									
	3													
	4													
	5													
	6													
	7													
	8													
	9													
Copepoda	1			32	48	16	32				16			
	2				64		96							
	3				48		32	16	32					
	4									48				
	5													
	6													
	7													
	8													
	9													
Oligochaeta	1			96	160	32	64		16	0	0			
	2				16		32		16					
	3						48							
	4													
	5								48					
	6													
	7													
	8													
	9													

TABLE 3c.--(Continued)

Date and transect	Depth (cm)	(-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.4	4
Oct. 22, 1961 2														
Testaceous rhizopods	1			3200		0	1600		3200	3200	1600			
	2			1600						9600				
	3							1600		1600	3200			
	4								1600		9600			
	5							3200	1600					
	6								4800					
	7													
	8													
	9													
Nematoda	1				1600									
	2			1600						1600				
	3							1600			3200			
	4									1600				
	5													
	6													
	7													
	8													
	9													
Immature insects	1			48	16	0	0	0	0	0	0			
	2													
	3													
	4				16									
	5													
	6													
	7													
	8													
	9													

Temperature

Sand temperatures (T_s^o) were taken at 2.5, 8, and 12 cm. below the surface of the sand. As seen from the temperature graphs (Figs. 1-3), there was a considerable horizontal variation along the psammon, especially in the top 2.5 cm. and at the higher sand temperatures (e. g. Fig. 1, June, July, October 18 and 22). At lower T_s^o and greater depths (8, 12 cm.) the T_s^o differences between readings horizontally along the psammon were not as great as at lesser depths (i. e. 2.5 cm.) or at higher T_s^o. Rain also tended to cause the T_s^o to flatten out. Pennak (1940) found the surface temperatures between the (+) 0.5-2.5 meter stations to be fairly homogeneous with rarely a difference greater than 2.5° C between any two horizontal readings. This he attributed to the influence of the capillary water in this region. In the present study such homogeneity in surface T_s^o was found at the lower but not higher sand temperatures, though the differences between any two temperature readings even at the higher temperatures were slight.

Vertically the mean T_s^o for the entire psammon decreased with depth. In one instance the T_s^o remained the same from 2.5-12 cm. and in two cases it increased very slightly (Table 3).

Pennak (1940) enumerated the following factors which in combination in general determined sand temperatures:

TABLE 3b.--(Continued)

Date and transect		Distance From Water's Edge (in meters)												
Oct. 28, 1961 3	Depth (cm)	(-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5	4
Testaceous rhizopods	1					3200	1600	1600	4800		3200	8000		
	2						8000		1600	4800		48000		
	3				27200		3200	3200	4800	3200	1600			
	4				3200									
	5				6400									
	6													
	7													
	8						4800							
	9													
Nematoda	1									1600		4800		
	2						1600							
	3										1600			
	4													
	5													
	6													
	7													
	8													
	9													
Immature insects	1				0	16		32	0	0	0	0		
	2													
	3													
	4													
	5													
	6													
	7						16							
	8													
	9													

TABLE 4.--Air, water, and sand temperature (T^{o}_{s}) taken with a Weston thermometer.

Beach and Weather Conditions	Date and Transect	Air Temp. (C°)	Water Temp. (C°)	Sand			
				Depth (cm.)	Distance (-) 2	1	.5
Waves choppy onshore, weather clear	Oct. 18, 1961 1.	18	16.5	2.5 8.0 12.0	17 15 15	17 16 15	
Beach moist throughout overcast	Nov. 12, 1961 1.	10	8.5	2.5 8.0 12.0			
	Apr. 7, 1962 2.	7	6	2.5 8.0 12.0			
Waves mild onshore clear	June 25, 1962 1.	29	31	2.5 8.0 12.0			
No wave action clear	Oct. 22, 1961 2.	14	14	2.5 8.0 12.0			
Beach moist clear; some ice on lake	Dec. 3, 1961 2.	10	6.5	2.5 8.0 12.0			
Waves strong onshore clear	July 27, 1962 2.	--	--	2.5 8.0 12.0			
Waves onshore choppy, over-cast, wet	Oct. 28, 1961 3.	9	10	2.5 8.0 12.0			
Waves mild, parallel to shore, rain	May 1, 1962 3.	13	18	2.5 8.0 12.0			

Temperature (C°)

from Water's Edge (in meters)

						(+)				
1	.5	0	.5	1	1.5	2	2.5	3	3.5	$\bar{X}$
17.5	17	16	18	19	19	19.5				17.5
17	16	15	17	17	16	18				16.0
14.5	15	14	15	15	15	16				15.0
8.5	8.5	9	9	9	9	9	9.5			9.0
8	8	8.5	8.5	9	9	9	9			8.5
	8	8.5	8.5	8.5	8.5	8.5	8.5			8.5
		5.5	5	5	5	5.5				5.0
		5.5	5	5	5	5.5				5.0
		5.5	5	5	5	5.5				5.0
30	31	31	31	34	36	36				32.5
28	28	29.5	29.5	30	33	33				30.0
26	26	27	28	27	31	30				28.0
14.5	15	17.5	15	14	15	14	14.5			15.0
14	14.5	15	14.5	14	15	14	14.5			14.0
14	14	15	13.5	13	14	13	14			14.0
7	8	8	7	7	7.5	8	7	8		7.5
6	7	6	5.5	6	6	6	5.5	6		6.0
6	6.5	5	4	4	5	5	4.5	6		5.0
	26	26	22	23	23	25	25	29		25.0
	25	25	23	24	24	24	25	27		25.0
	24	24	22	23	22	22	23	24		23.0
		8.5	8.5	8.5	8.5					8.5
		9	8.5	8.5	8.5					8.5
		9	9.5	8.5	8.5					9.0
		17	14	14	14	14	14	14.5	15	14.5
		17	16	16	16	15.5	15	15.5	15	15.5
		16	16	16	16	15.5	15.5	15	15	15.0

". . . lake water temperature, air temperature, amount of capillary water in the sand and its evaporation, wind, rain, and sunshine." According to Neel (1948) isolation and lake temperature affect the shoal portions of the sand exclusively. Previous workers have studied the T_s^o extensively and it is not the purpose of this paper to indulge in a discussion of sand temperature characteristics.

Hydrogen Ion Concentration

Table 5 shows pH determinations taken with a Beckman pocket 180 meter. The data indicates that the acidity increased shorewards. This agrees with the findings of others (Pennak, 1940; Neel, 1948). Lake pH and capillary water pH were much alike though in every case the interstitial water of the most shoreward station sampled (+1M.) was more acid than the lake water.

Carbon Dioxide Content

As shown in Table 6 the amount of free CO_2 was higher in the landward station than in the lake. Likewise, the bound CO_2, as expressed by the methyl orange (M. O.) alkalinity, also increased. No phenolphthalein alkalinity was obtained

Oxygen Content

Determinations of the oxygen concentration were made by means of the Ridal-Steward modification of the Winkler method.

Temperature

Sand temperatures (T_s^o) were taken at 2.5, 8, and 12 cm. below the surface of the sand. As seen from the temperature graphs (Figs. 1-3), there was a considerable horizontal variation along the psammon, especially in the top 2.5 cm. and at the higher sand temperatures (e. g. Fig. 1, June, July, October 18 and 22). At lower T_s^o and greater depths (8, 12 cm.) the T_s^o differences between readings horizontally along the psammon were not as great as at lesser depths (i. e. 2.5 cm.) or at higher T_s^o. Rain also tended to cause the T_s^o to flatten out. Pennak (1940) found the surface temperatures between the (+) 0.5-2.5 meter stations to be fairly homogeneous with rarely a difference greater than 2.5° C between any two horizontal readings. This he attributed to the influence of the capillary water in this region. In the present study such homogeneity in surface T_s^o was found at the lower but not higher sand temperatures, though the differences between any two temperature readings even at the higher temperatures were slight.

Vertically the mean T_s^o for the entire psammon decreased with depth. In one instance the T_s^o remained the same from 2.5-12 cm. and in two cases it increased very slightly (Table 3).

Pennak (1940) enumerated the following factors which in combination in general determined sand temperatures:

Figure 2. Horizontal variation in sand temperature. Temperature taken at depth of 2.5 cm.

Temperature (C°)

from Water's Edge (in meters)

						(+)				
1	.5	0	.5	1	1.5	2	2.5	3	3.5	X̄
17.5	17	16	18	19	19	19.5				17.5
17	16	15	17	17	16	18				16.0
14.5	15	14	15	15	15	16				15.0
8.5	8.5	9	9	9	9	9	9.5			9.0
8	8	8.5	8.5	9	9	9	9			8.5
	8	8.5	8.5	8.5	8.5	8.5	8.5			8.5
		5.5	5	5	5	5.5				5.0
		5.5	5	5	5	5.5				5.0
		5.5	5	5	5	5.5				5.0
30	31	31	31	34	36	36				32.5
28	28	29.5	29.5	30	33	33				30.0
26	26	27	28	27	31	30				28.0
14.5	15	17.5	15	14	15	14	14.5			15.0
14	14.5	15	14.5	14	15	14	14.5			14.0
14	14	15	13.5	13	14	13	14			14.0
7	8	8	7	7	7.5	8	7	8		7.5
6	7	6	5.5	6	6	6	5.5	6		6.0
6	6.5	5	4	4	5	5	4.5	6		5.0
	26	26	22	23	23	25	25	29		25.0
	25	25	23	24	24	24	25	27		25.0
	24	24	22	23	22	22	23	24		23.0
		8.5	8.5	8.5	8.5					8.5
		9	8.5	8.5	8.5					8.5
		9	9.5	8.5	8.5					9.0
		17	14	14	14	14	14	14.5	15	14.5
		17	16	16	16	15.5	15	15.5	15	15.5
		16	16	16	16	15.5	15.5	15	15	15.0

TABLE 5.--pH of lake and capillary water taken with a Beckman 180 pocket pH meter.

Date and Transect	Lake pH Taken at (-) .5M	Capillary Water pH Taken at a depth of 4 cm. (average of 3 recording)					
		Distance from Water's Edge (in meters)					
		(-)			(+)		
		.5	0	.5	1	1.5	2
Aug. 17, 1961, T3	7.0	7.0	7.0	6.9	6.9		
Nov. 1, 1961, T1	7.2	7.1	7.1	7.1	6.9		
Nov. 18, 1961, T1	7.1	7.1	7.1	7.1	7.0		
Dec. 3, 1961, T2	7.1	7.1	7.1	7.0	7.0		

Figure 2. Horizontal variation in sand temperature. Temperature taken at depth of 2.5 cm.

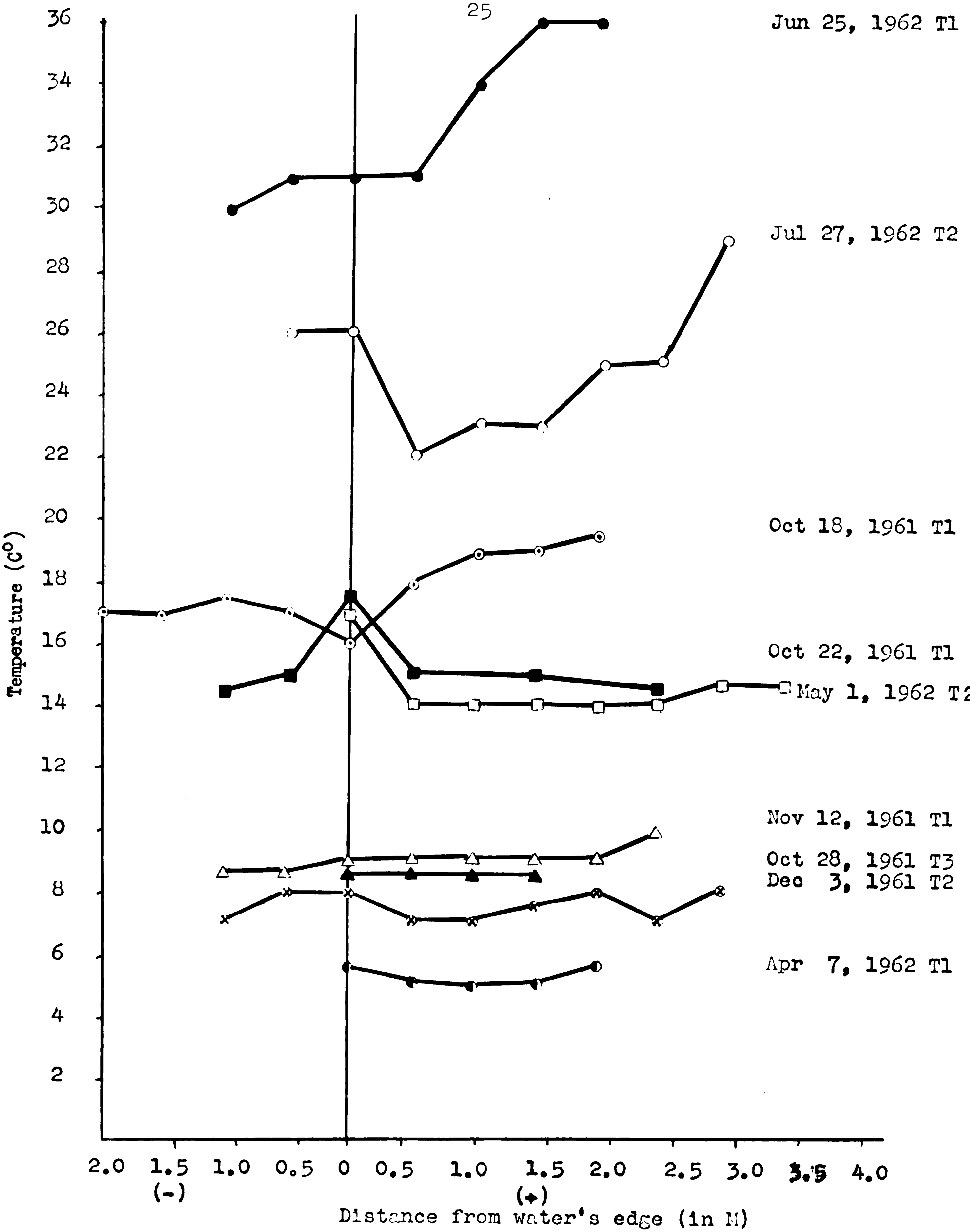

Jun 25, 1962 T1
Jul 27, 1962 T2
Oct 18, 1961 T1
Oct 22, 1961 T1
May 1, 1962 T2
Nov 12, 1961 T1
Oct 28, 1961 T3
Dec 3, 1961 T2
Apr 7, 1962 T1
Temperature (C°)
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
2.0 1.5 1.0 0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
(-)
(+)
Distance from water's edge (in M)

Figure 3. Horizontal variation in sand temperature. Temperature taken at depth of 8 cm.

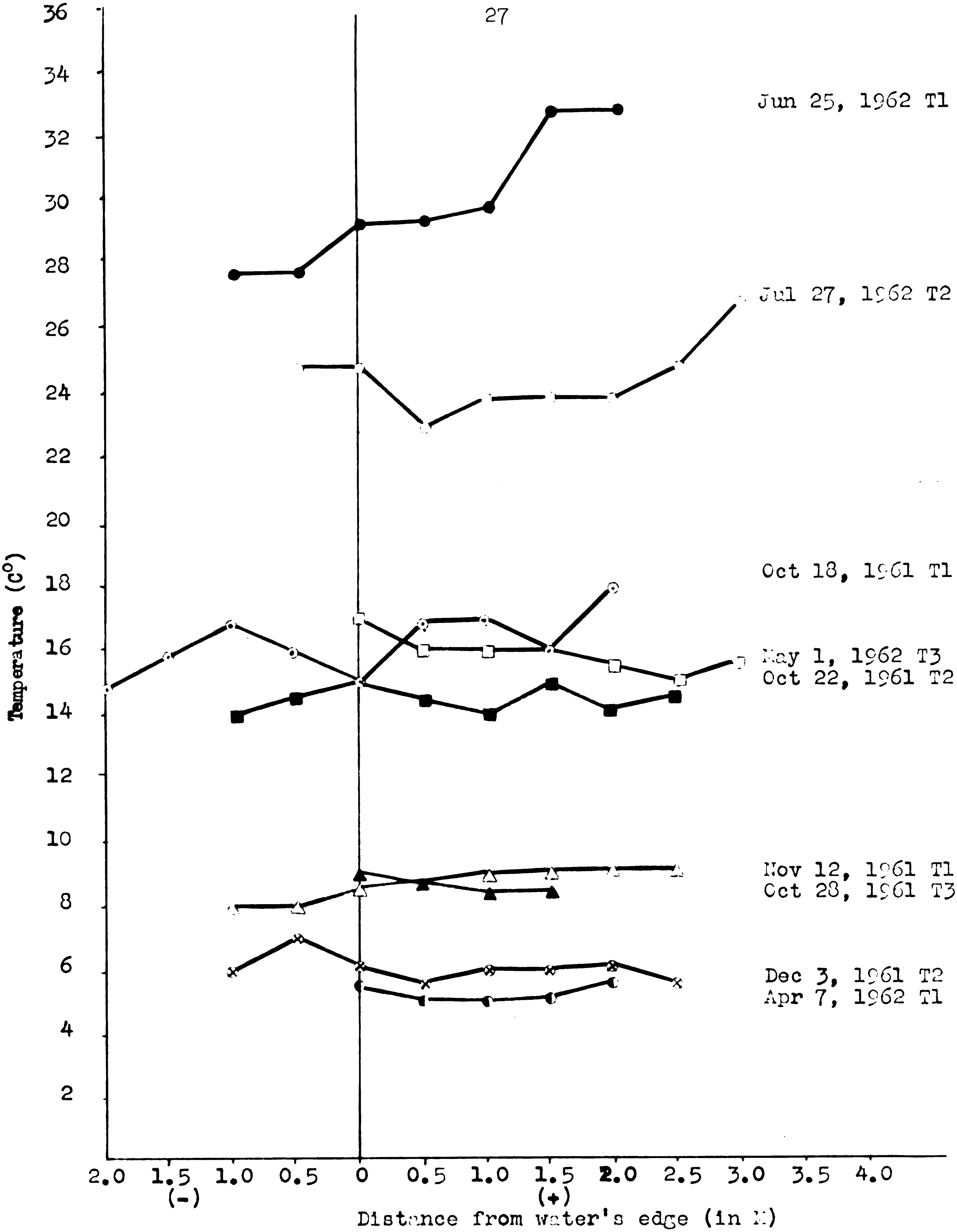

36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Temperature (C°)
Jun 25, 1962 T1
Jul 27, 1962 T2
Oct 18, 1961 T1
May 1, 1962 T3
Oct 22, 1961 T2
Nov 12, 1961 T1
Oct 28, 1961 T3
Dec 3, 1961 T2
Apr 7, 1962 T1
2.0 1.5 1.0 0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
(-)
(+)
Distance from water's edge (in M)

Figure 4. Horizontal variation in sand temperature. Temperature taken at depth of 22 cm.

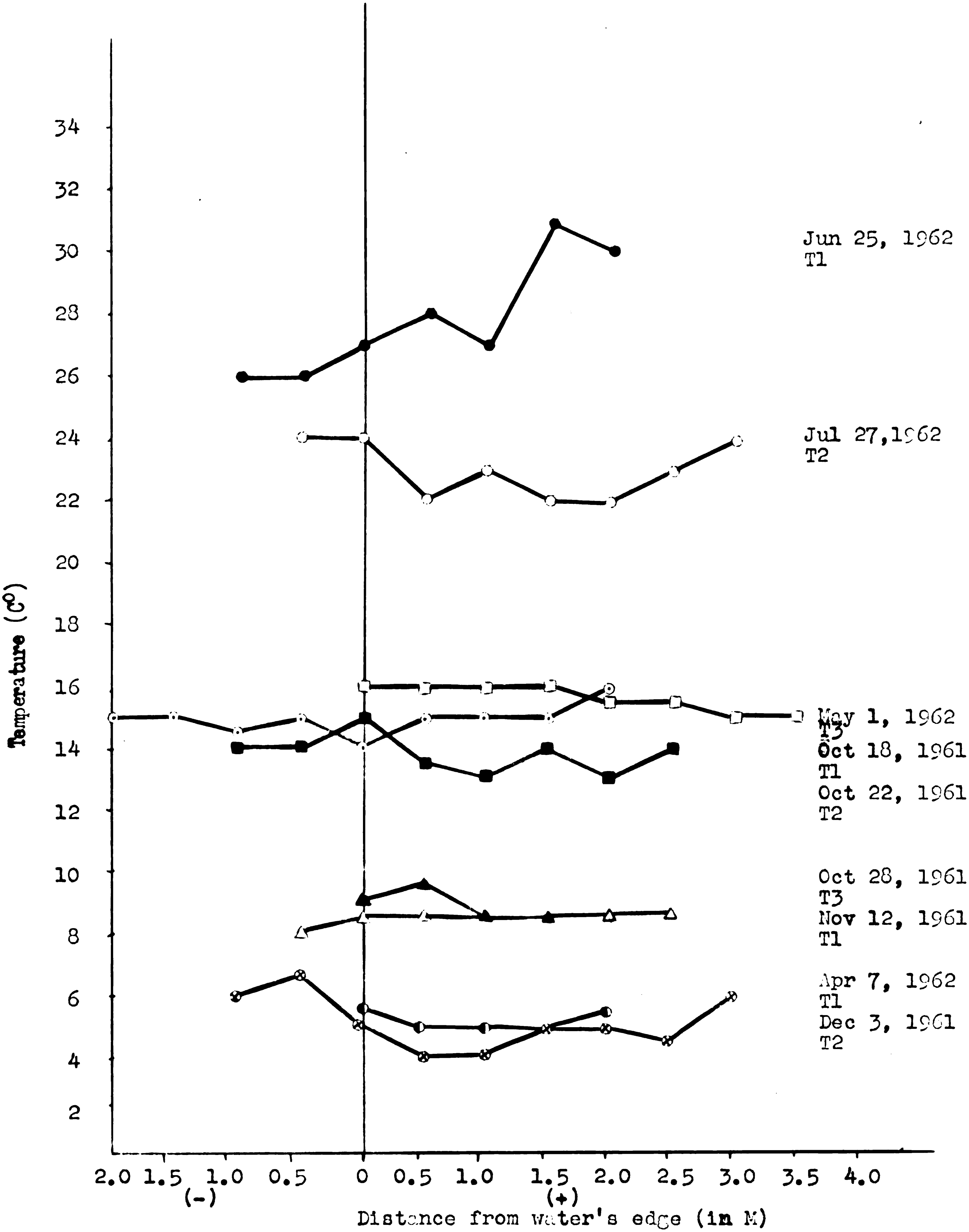

Temperature (C°)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
Jun 25, 1962
T1
Jul 27,1962
T2
May 1, 1962
T3
Oct 18, 1961
T1
Oct 22, 1961
T2
Oct 28, 1961
T3
Nov 12, 1961
T1
Apr 7, 1962
T1
Dec 3, 1961
T2
2.0 1.5 1.0 0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
(-)
(+)
Distance from water's edge (in M)

TABLE 6.--Chemical features of the Mud Lake capillary water; O_2, CO_2, and Alkalinity(the average from two readings).

Date and Transect	Station	Oxygen (ppm.)	Free CO_2 (ppm)	M. O. Alkalin (ppm.)	Ph-th Alkalin (ppm.)	Temp. (C^o)
8-17-61	(-) .5m	9.9	5.7	105	0.0	
T3	0m	4.2	7.7	130	0.0	31
	(+) .5m	1.4	32.2	168	0.0	
8-21-63	(-) .5m	7.6	4.0	125	0.0	
T2	0m	3.0	9.6	125	0.0	26
	(+) .5m	0.0	50.2	150	0.0	

The oxygen concentration decreased ~~landward~~ (Table 6), the concentration in the shoal stations being considerably higher than that of the beach stations. All previous investigators have reported such a shoreward gradient of oxygen.

<u>Other Physico Chemical Characters of the Psammon</u>

Light, grade distribution of sand, pore space, wave action, and interstitial organic matter are other known factors affecting the distribution and population size of psammon organisms. Due to the limited scope of this investigation the measurement of the above mentioned factors was not undertaken. Previous papers of Bruce (1928), Pennak (1940), and Neel (1948) investigating the psammon, and in particular the non-biological characteristics, discuss these points in some detail.

The major problem in determining the chemistry of interstitial water is first, the amount of this water is very small, and secondly, water is quite difficult to sample at given vertical levels in the sand with any degree of accuracy. A modified Irwin sampler as used by Neel (1948) was employed to extract the water. Capillary water was always taken from a depth of four cm. Beyond (+) 1.5 meters, however, water could not be drawn in sufficient quantities to make the necessary determinations, and even at (+) 1 meter it was difficult to extract water without a considerable amount of air being taken up at the same time.

V. BIOLOGICAL ASPECTS OF THE PSAMMON

General Features

The horizontal distribution of organisms* along the psammon exibited approximately the same pattern on each of the three transects (Figs. 7-9): high numbers of both algae and microfauna in the (+) .5 to 2.5m region of the beach whereas the hydro-psammon, (0 to (-) 1.5m) contained a relatively meager fauna and flora; the shoreward region beyond the meters contained few organisms.

Population peaks in the horizontal distribution of algae did not necessarily imply correlating peaks in the microfaunal (Testacea, Nematoda, Rotifera, and Tardigrada) populations (Figs. 7-9). One might expect somewhat of a correlation here since the majority of psammo-organisms are herbivores or bacterial feeders.

A more detailed description of the spatial as well as the seasonal distribution of the various psammon groups will be undertaken in the discussion of the individual taxons.

---

*Organisms in this instance refers to only the following: algae, Testacea, nematodes, tardigrades, and rotifers, all of which were estimated in a slightly different manner from the larger psammomicroorganisms (e. g. Copepoda and Oligochaeta).

Algae were identified to genus with the exception of diatoms. Two kinds of counts were taken of the diatoms: one estimate of the total number of fustules and a second of just those fustules with chloroplasts. The diatom count was extremely high when one considered the total number of fustules per cc. However, the count became smaller than the blue-green or green algal estimates when only fustules with chloroplasts were included. Other investigators, Pennak (1940) and Neel (1948), have found diatoms to be the most abundant psammon algal group. Their estimates--if based upon the total number of fustules--would be too high and thus misleading. Large numbers of filamentous Cyanophyta (mostly Lyngbya sp. and Oxcillatoria sp.) appeared at certain times in some of the transects; Merismepedium sp. was the only other blue-green alga of common occurrence. The green algal flora was represented by a greater number of genera but not by as many individuals as the diatom or Cyanophyta groups. The most abundant of the Chlorophyta were Cylindrocystis sp., Netrium sp., and Cosmarium sp; very few filamentous Chlorophyta occurred in the Mud Lake psammon. The Euglenophyta, though not often found in the counts of preserved material, were suspected, on the basis of preliminary observations of "live sand" samples, to be abundant in the psammon.

Seasonally, excepting December and April when populations were low, the algae as a group exibited no consistent population fluctuations or patterns (Fig. 4). The Cyanophyta were most abundant in October and May and at low numbers during June, July, April, and December. The Chlorophyta, conversely, were at a peak during May, June, July, November, and portions of October but at relatively low numbers during December and April. Paradoxically large algal populations appeared in May during which the psammo-microorganisms were at the lowest numbers.

Figure 5. Seasonal distribution of algae, testaceous protozoa, rotifers, and nematodes.

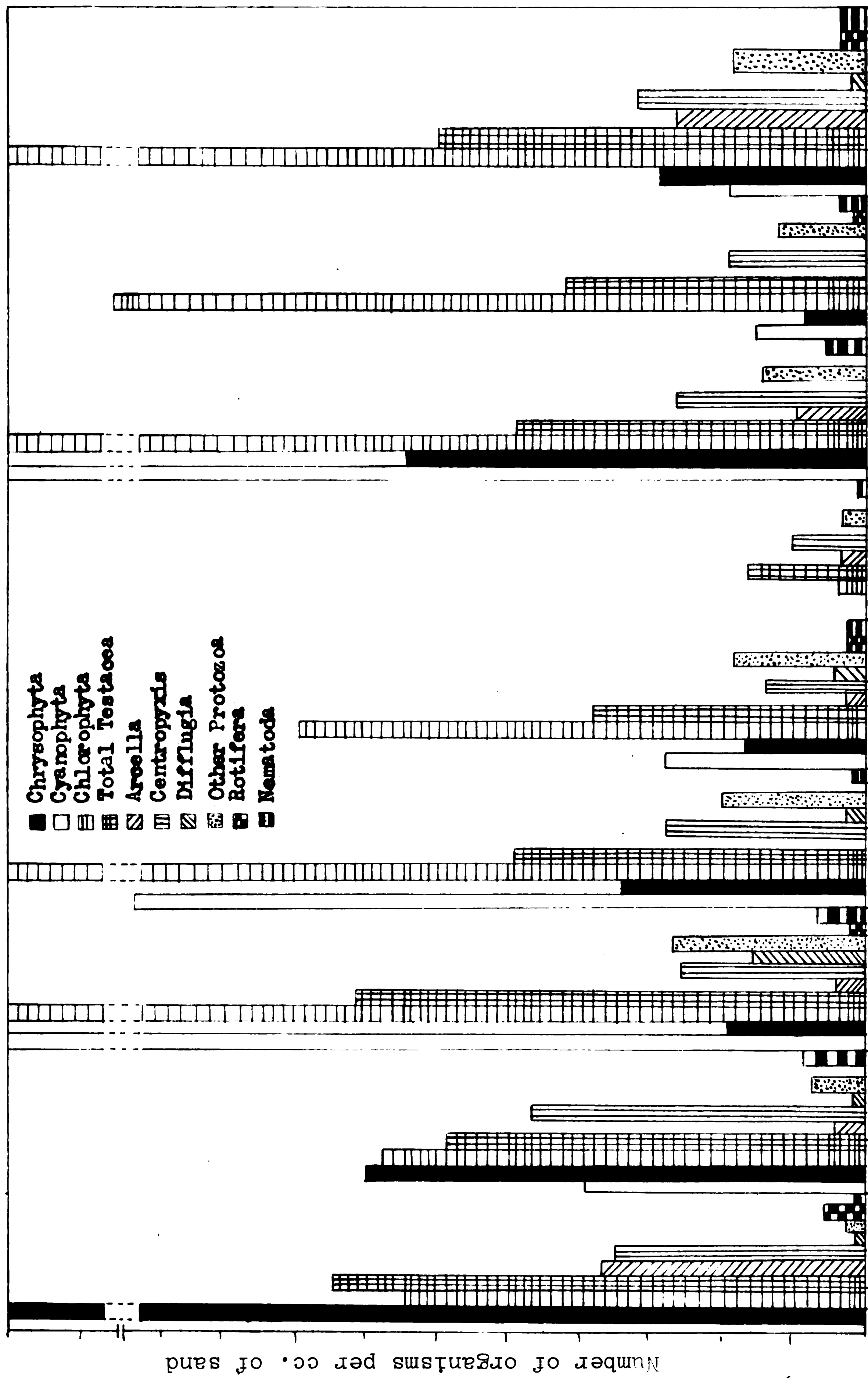
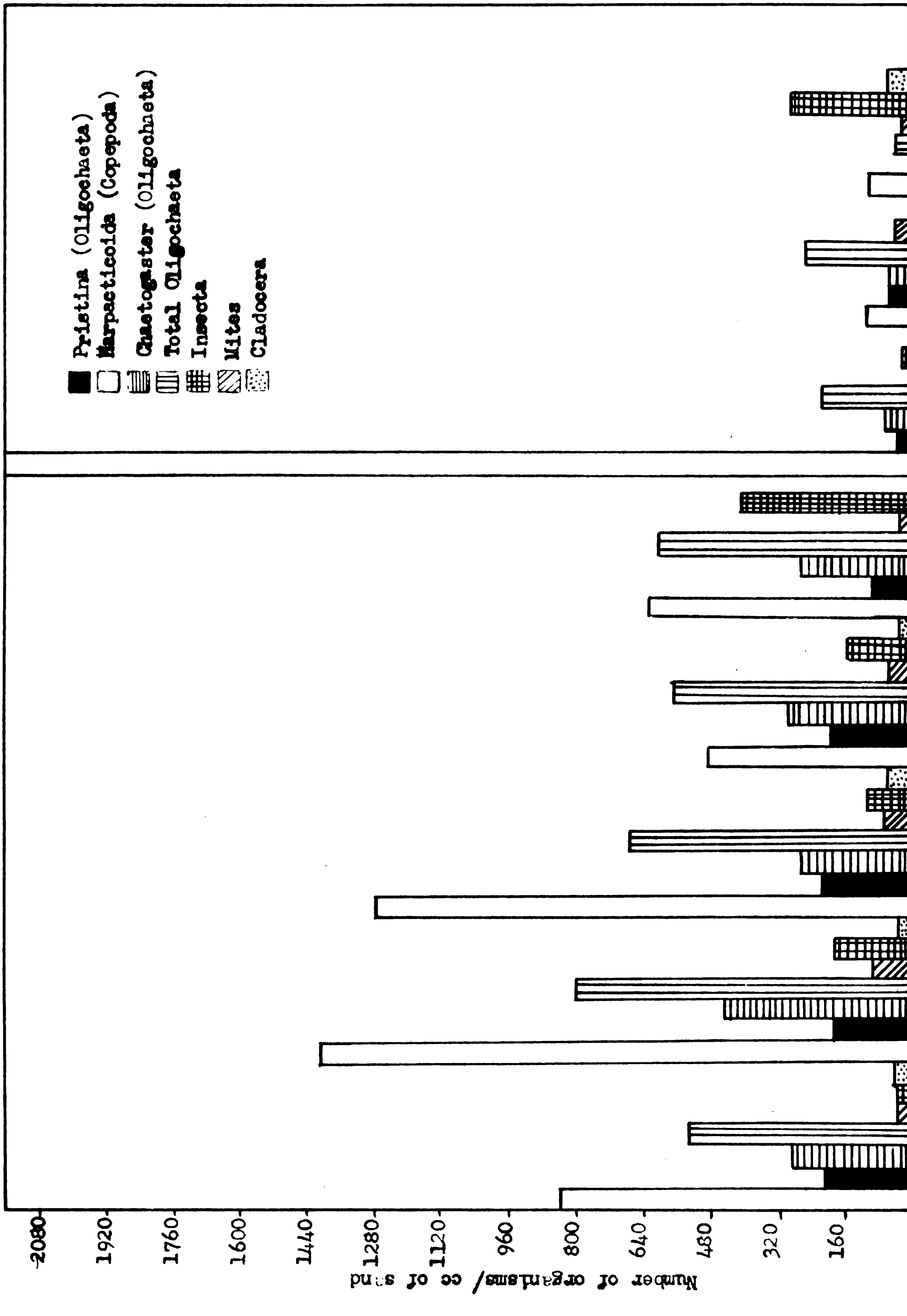

Chrysophyta
Cyanophyta
Chlorophyta
Total Testacea
Arcella
Centropyxis
Difflugia
Other Protozoa
Rotifera
Nematoda
October 18 T1
October 22 T2
October 28 T3
November 12 T1
December 3 T2
April 7 T1
May 1 T3
June 25 T1
July 27 T2
Number of organisms per cc. of sand

Figure 6. Seasonal distribution of Copepods, oligochaetes, insects, mites, and Cladocera.


Pristina (Oligochaeta)
Harpacticoida (Copepoda)
Chaetogaster (Oligochaeta)
Total Oligochaeta
Insecta
Mites
Cladocera
October 18
T1
October 22
T2
October 28
T3
November 12
T1
December 3
T2
May 1
T3
June 25
T1
July 27
T2
2080
1920
1760
1600
1440
1280
1120
960
800
640
480
320
160
Number of organisms/ cc of sand

Faunal and Floral Lists

Floral Lists

I. Chlorophyta
  O: Chlorococcales
    Pediastrum sp.
    Sorastrum sp.
    Quadrigula sp.
    Scenedesmus sp.

  O: Zygnematales
    Mougeota sp.
    Netrium sp.
    Closterium sp.
    Cylindrocystis sp.
    Tetmemorus sp.
    Staurastrum sp.
    Euastrum sp.
    Micrasterias sp.
    Cosmarium sp.
    Spirogyra sp.
    Micricystis sp.
    Zygnema sp.
    Gomphosphera sp.
    Synecoccoccus sp.

II. Euglenophyta
  O: Euglenales
    Euglena sp.

III. Chrysophyta

IV. Cyanophyta
  O: Chroococcales
    Merismepedium sp.
    Gloeocystis sp.

  O: Oscillatoriales
    Oscillatoria sp.
    Lyngbya sp.

Faunal Lists

I. Protozoa
  O: Testacealobosa
    Arcella vulgaris Ehrenberg
    A. discoides Ehrenberg
    Centropyxis aculeata (Ehr.) Stein

C. constricta (Ehr.) Penard
C. arcelloides Penard
C. ecornis (Ehr.) Leidy
Difflugia urceolata Carter
D. lebes Penard
D. corona Wallich
D. lobostoma Leidy
D. oblonga Ehrenberg
Hyalosphenia elegans Leidy
Qualdrulella sp.
Nebela sp.
Cyphoderia sp.
Euglypha cristata Leidy
Euglypha sp.

II. Turbellaria

III. Nematoda

IV. Gastrotricha

V. Rotifera
O: Bdelloida
Philodinidae

O: Ploima
Keratella cochlearis
Kellocottia sp.
Trichocerca sp.
Colurella sp.
Lecane mucronata
Lecane sp.
Monostyla sp.

VI. Tardigrada
O: Eutardigrada
Macrobiotus dispar Murray
Hypsibius granulifer (Thulin) Marcus

VII. Annelida
O: Plesiopora
Aeblosoma sp.
Stylaria sp.
Chaetogaster sp.
Pristina osborni (Walton)
P. breviseta (Bourne)

VIII. Arthropoda
O: Cladocera

O: Malacostraca
Hyalella azteca (Saussure)

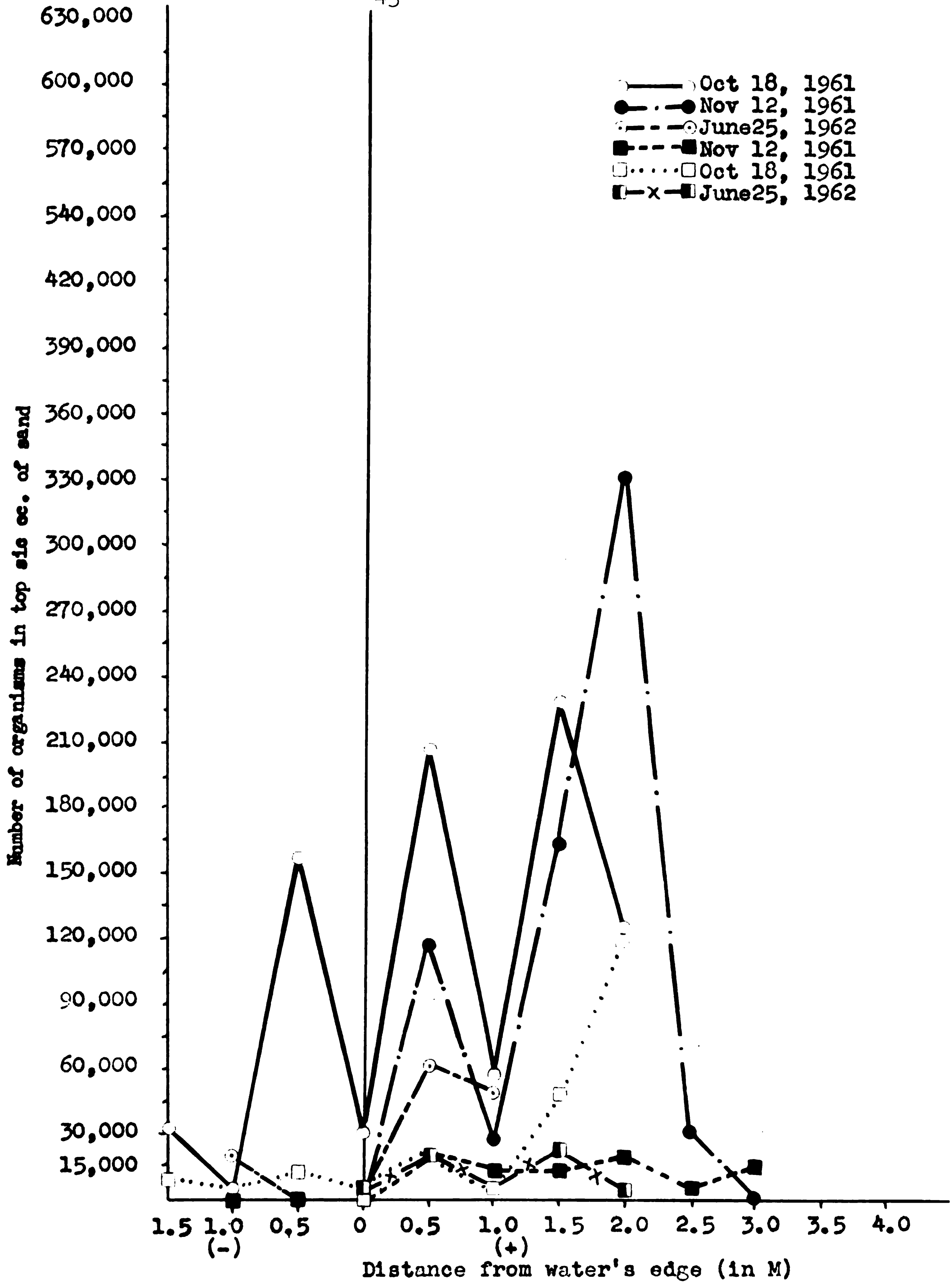
O: Copepoda
Pastenocaris brevipes Kessler
P. delameri Chappius
Elaphoidella bidens coronata (Sars)

C: Insecta
O: Collembola
Pondura aquatica (L.)

O: Diptera
F: Tentapedidae
F: Delicapodidae
F: Chaeronomidae

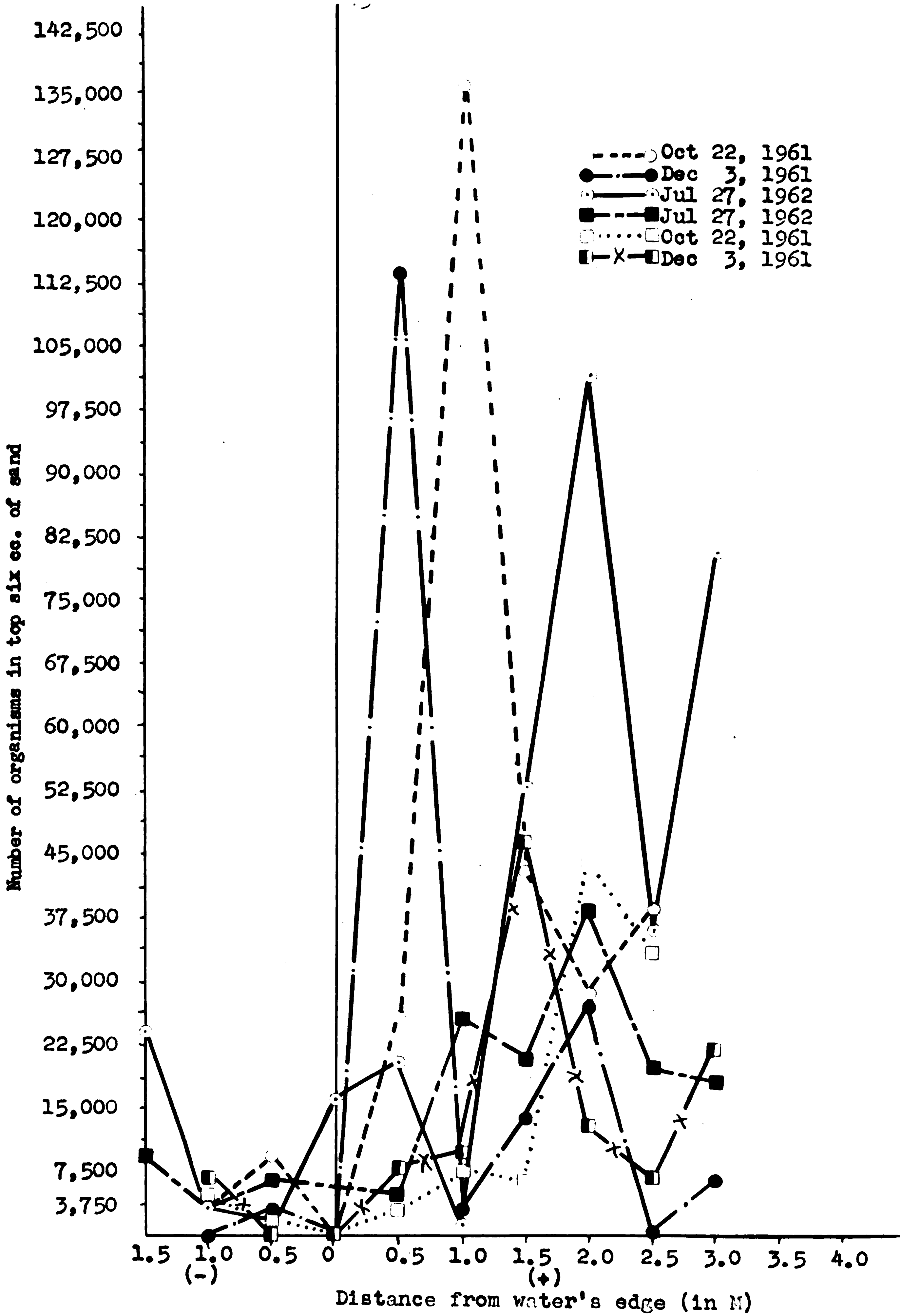
O: Acari
Oribatidae

Figure 7. Horizontal distribution of algae (solid line) and the combined populations of Protozoa, Rotifera, Nematoda, and Tardigrada, in transect 1. Total numbers of organisms in the top six cc.



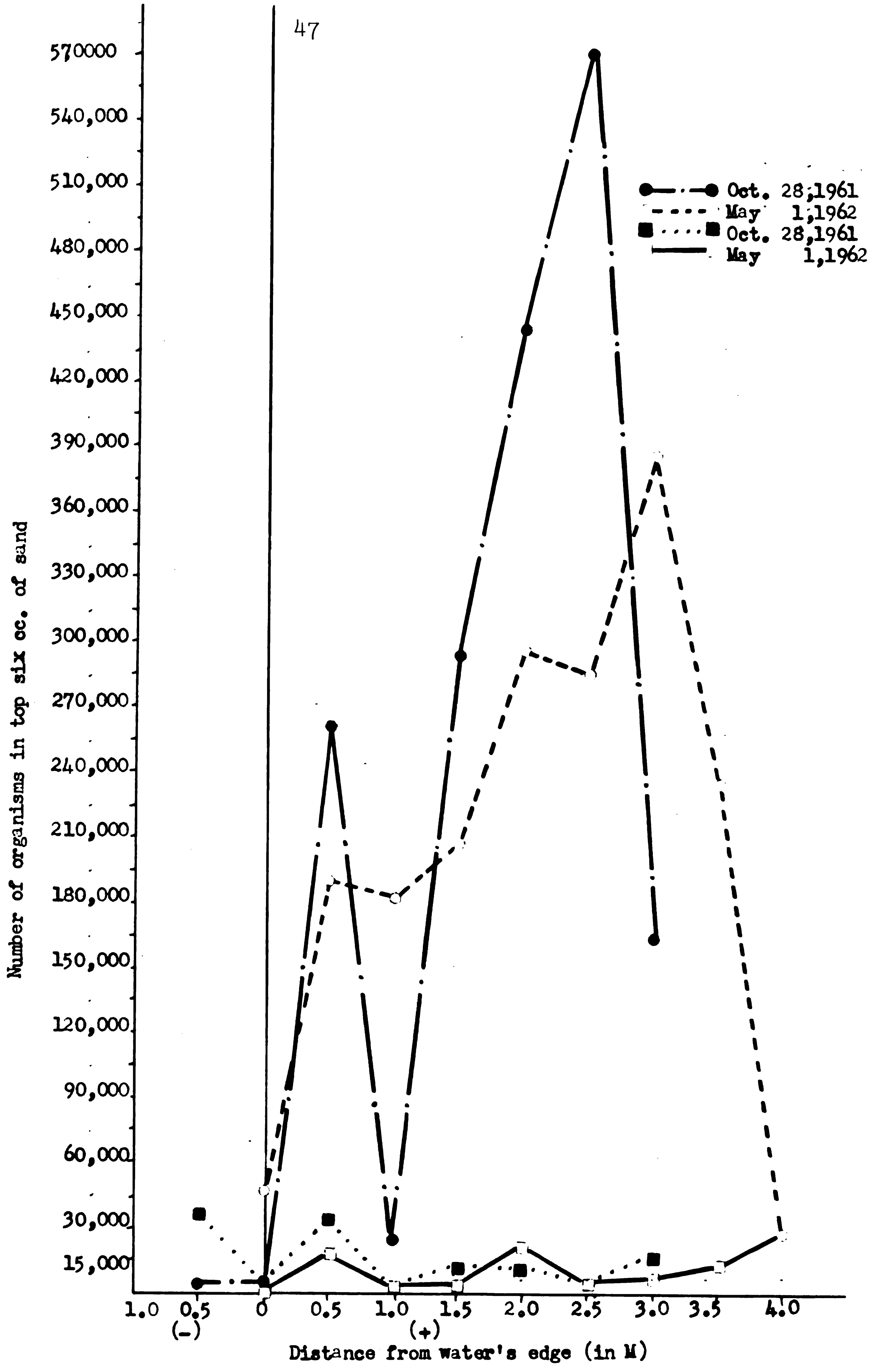
630,000
600,000
570,000
540,000
420,000
390,000
360,000
330,000
300,000
270,000
240,000
210,000
180,000
150,000
120,000
90,000
60,000
30,000
15,000
Number of organisms in top six cc. of sand
Oct 18, 1961
Nov 12, 1961
June25, 1962
Nov 12, 1961
Oct 18, 1961
June25, 1962
1.5 1.0 0.5 0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0
(-)
(+)
Distance from water's edge (in M)

Figure 8. Horizontal distribution of algae (solid line) and the combined populations of Protozoa, Rotifera, Nematoda, and Tardigrada in transect 2. Total numbers of organisms in the top six cc.



142,500
135,000
127,500
120,000
112,500
105,000
97,500
90,000
82,500
75,000
67,500
60,000
52,500
45,000
37,500
30,000
22,500
15,000
7,500
3,750
Number of organisms in top six cc. of sand
Oct 22, 1961
Dec 3, 1961
Jul 27, 1962
Jul 27, 1962
Oct 22, 1961
Dec 3, 1961
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in M)

Figure 9. Horizontal distribution of algae (solid line) and the combined populations of Protozoa, Rotifera, Nematoda, and Tardigrada in transect 3. Total numbers of organisms in the top six cc.


570000
540,000
510,000
480,000
450,000
420,000
390,000
360,000
330,000
300,000
270,000
240,000
210,000
180,000
150,000
120,000
90,000
60,000
30,000
15,000
Number of organisms in top six cc. of sand
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in M)
Oct. 28,1961
May 1,1962
Oct. 28,1961
May 1,1962

Protozoan Distribution

Because of the fact that all protozoans except the testaceous rhizopods were too fragile to survive the particular treatment used for extracting psammon organisms, the following discussion includes only the latter. However, in the preliminary observations of "live" sand samples, a considerable protozoan fauna was noticed, especially of the Ciliata (e. g. Hypotricha and Holotricha) and Mastigophora groups. Previous studies, for the reason given here, also have included only a discussion of the Testacea; a thorough ecological study of psammon protozoa is thus needed although a major problem of extracting these organisms exists.

The genus *Centropyxus* sp. was, by and large, the most abundant of the Testacea in the Mud Lake psammon. Considerable populations of both *Arcella* sp. and *Difflugia* sp. were also present in some collections. *Centropyxis aculeata* (Ehrenberg) Stein was the common species of this genus; though *C. constricta* (Ehr.) Penard was also present in some numbers. *Euglypha* sp., *Hyalosphenia* sp., *Quadrulella* sp., *Cyphoderia* sp., and *Nebela* sp. were other genera of Testacea which occurred in small numbers in the sand.

Horizontal distribution: As seen from Fig. 9 the greatest concentration of Testacea was in the landward portions of the beach between (+) 0.5 and 2.5 m. This roughly concurred with Pennak's (1940) findings. In contrast to the horizontal

TABLE 7.--Distribution of testaceous rhizopods.

Date and transect	Depth (cm.)	(-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5
Oct. 18, 1961 1.	1		1600	1600	9600		8000	1600	8000	16000			
	2		3200	*	*	1600	6400		20800	9600			
	3		1600				1600	1600	12800	4800			
	4					1600		*	6400				
	5			*									
	6												
	7												
	8								*				
	9												
	10												
	11												
	12								*				
Nov. 12, 1961 1	1			*	*	*	6400	6400	4800	8000	9600	9600	
	2				*		4800	3200	6400	6400		6400	
	3				*		1600		*	4800			
	4									1600			
April 7, 1962 1.	1					3200		3200	*	3200			
	2							6400		*			
	3				1600			*					
	4												

TABLE 7.--(Continued)

Date and transect	Depth (cm.)	Distance From Water's Edge (in meters) (-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5	4
June 25, 1962 1.	1			1600		1600	12800	*	8000	1600				
	2					*	3200	4800	11200	*				
	3						1600		3200					
	4							*						
	5													
	6						1600							
Oct. 22, 1961 2.	1			3200	*	0	1600		3200	32000	1600			
	2			1600	*		*	*	*	9600	*			
	3			*	*			1600	*	1600	3200			
	4				*			*	1600		9600			
	5							3200	1600					
	6								4800					
Dec. 3, 1961 2.	1			3200			1600	4800	24000	4800		8000		
	2			*			3200	1600	6400	4800	*	3200		
	3			3200			*	*	*	1600		4800		
	4						*		*		3200	4800		
	5						*		*		1600	1600		
	6								*		1600			

TABLE 7.--(Continued)

Date and transect	Depth (cm.)	Distance From Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
July 27, 1962 2.	1		6400	3200	3200	4800	4800	8000	8000	50400	19200	8000		
	2		*	*		1600		1600	3200	6400	*	9600		
	3		*			3200				1600				
	4		3200			1600								
	5		*											
	6													
Oct. 28, 1961 3.	1				*	3200	16000	7600	4800	*	3200	8000		
	2				*		8000	*	1600	4800	*	4800		
	3				27200	*	3200	3200	4800	3200	1600			
	4				3200		*							
	5				6400									
	6				*		*							
	7				*		*							
	8						4800							
May 1 1962 3.	1						11200	4800	1600	6400	3200	4800	4800	1600
	2					*	6400	*		11200			1600	1600
	3						*	*					3200	8000
	4							*					1600	8000
	5							*						24000
	6													

distribution of oligochaetes and copepods, the distribution of Testacea seemed to be generally characterized by more than one peak and by a fairly stable population throughout each transect. Vertical distribution: Most Testacea were found in the top centimeter of sand, their numbers rapidly decreasing below this level in virtually every transect (Fig. 10). Tests were found to a depth of 12 cm. However, since one cannot determine from a test whether the animal had been alive or not, one cannot be certain that living testacea wandered to this depth.

Seasonal distribution: The testaceous rhizopods were in general most abundant in the October (T1, 2, 3) collections and least abundant in the April samples. High numbers of a particular group in one portion of the beach at one season did not necessarily mean high numbers of the same group in other portions of the beach (e. g. Arcella sp. populations for October varied considerably between T1, 2, 3). Also, high numbers of a particular genus at one time did not necessarily mean correspondingly high numbers of other Testacea in a particular transect.

Centropyxis sp. consistently appeared as one of the more abundant of the Testacea on nearly every transect and at virtually all times. Populations of this genus remained fairly stable throughout the season compared to the variance in numbers of the other common Testacea (Fig. 4). Peak Centropyxis sp. populations occurred in the October 18,

Figure 10. Horizontal distribution of testaceous rhizopods in the top five cc of sand.

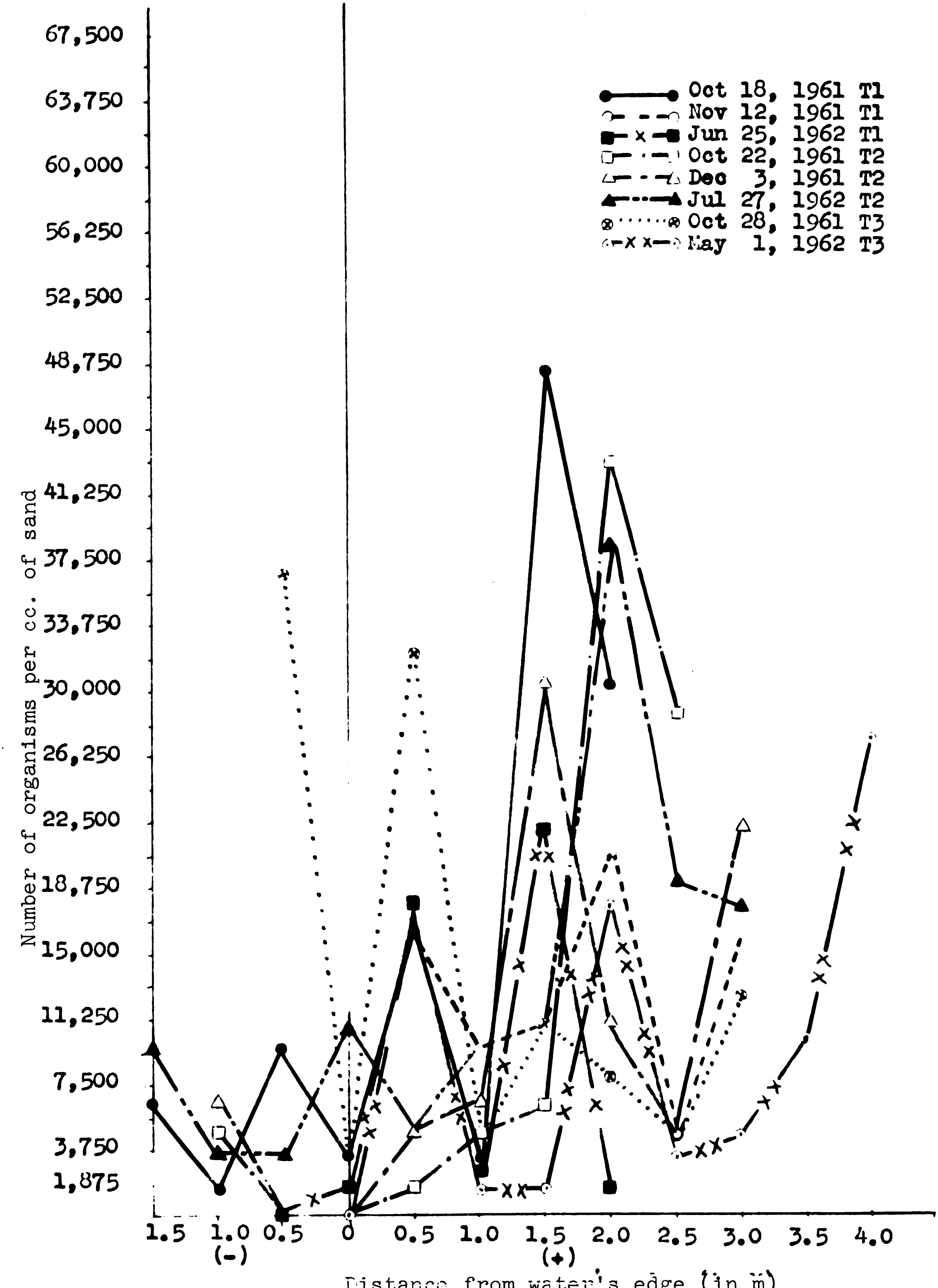
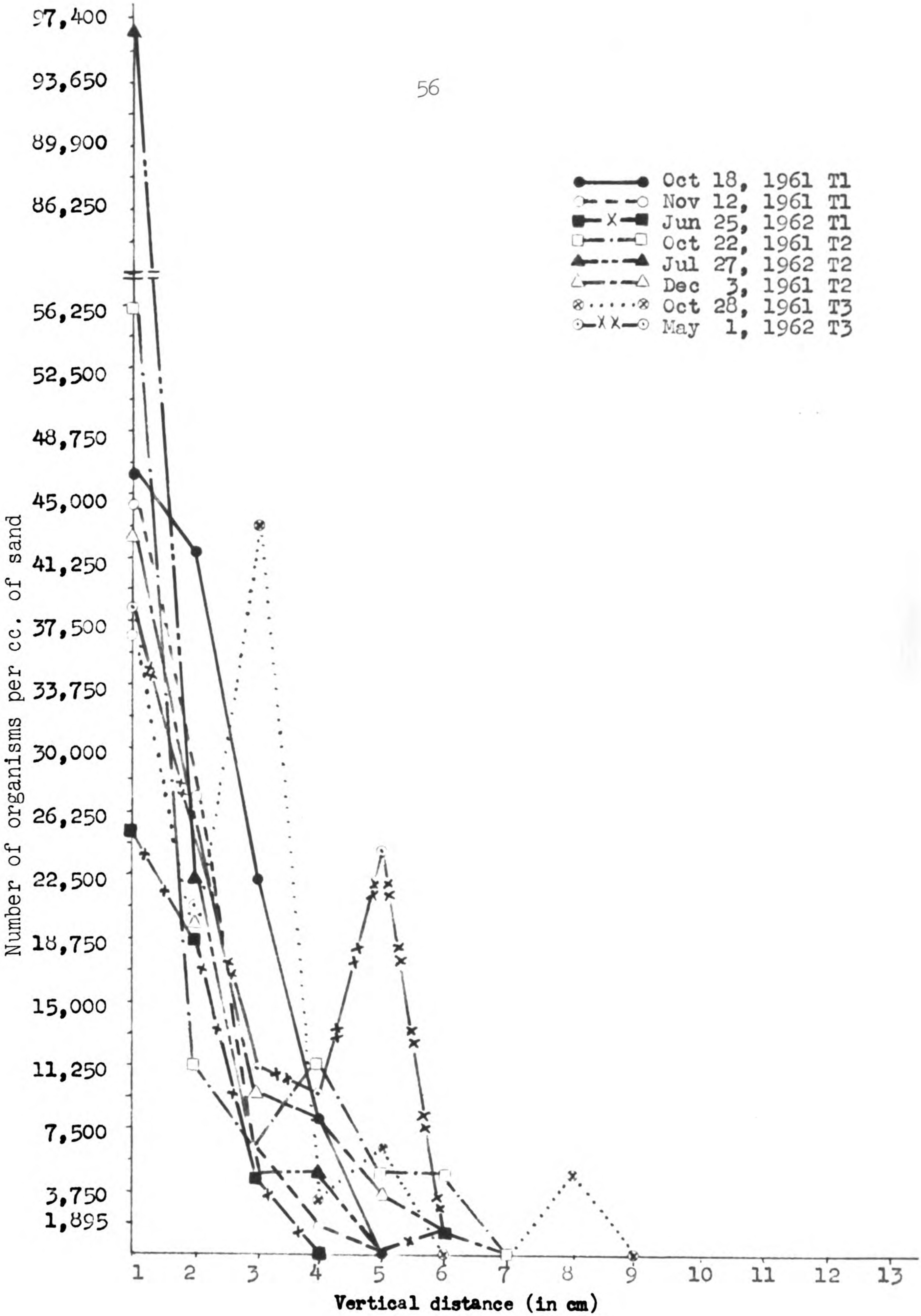

67,500
63,750
60,000
56,250
52,500
48,750
45,000
41,250
37,500
33,750
30,000
26,250
22,500
18,750
15,000
11,250
7,500
3,750
1,875
Number of organisms per cc. of sand
Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Dec 3, 1961 T2
Jul 27, 1962 T2
Oct 28, 1961 T3
May 1, 1962 T3
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in m)

Figure 11. Vertical distribution of testaceous rhizopods.


97,400
93,650
89,900
86,250
56,250
52,500
48,750
45,000
41,250
37,500
33,750
30,000
26,250
22,500
18,750
15,000
11,250
7,500
3,750
1,895
Number of organisms per cc. of sand
Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T3
May 1, 1962 T3
1
2
3
4
5
6
7
8
9
10
11
12
13
Vertical distance (in cm)

October 22, and July 27 collections while the low numbers were found in the December 3 and April 7 collections. Arcella sp. was found in the highest numbers in October 18 but decreased in subsequent collections to a low in November and December; there was then a slow increase in numbers in April, May, and June to again a maximum in July. Difflugia sp., excepting a population high in the October collection, remained at fairly low numbers (absence from the graph does not indicate absence of an organism from the sand but, rather, that its numbers were too few to show up in the count). Other Testacea (including a considerable number of Euglypha sp. and individuals of the genera Hyalosphaenia sp., Quadrulella sp., and Cyphoderia sp.) were present in low numbers in October 18 and 22 but reached higher population levels in succeeding collections. Few of the last mentioned genera were found in the April collection, their numbers increased in the May, June, and July collections (Fig. 4).

Nematoda Distribution

Populations of this phylum remained fairly stable in the psammon, and, though widespread, nematodes were never present in sufficient numbers within any one transect to graph distributional tendencies. Nematodes were found horizontally along the entire psammon and, as in Pennak (1940) the greatest numbers occurred in the hygro- and

TABLE 8.--Nematoda distribution

Date and transect	Depth (cm.)	Distance From Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Oct. 18, 1961 1.	1		*	*	*		*		*					
	2		*	1600	*		*		*	*				
	3			*	*	*	*	*	*	*				
	4													
Nov. 12, 1962 1.	1			*	*		*				*	*		
	2				*		*	1600		*				
	3				*		*		*					
	4													
April 7, 1962 1.	1						*	*	1600					
	2							*	*	*				
	3							*						
	4													
June 25, 1961 1.	1			1600	*	*	*	1600						
	2						*	*	1600	*				
	3							*		*				
	4													
	5			*										
	6			*										
Oct. 22, 1961 2.	1				1600		*	*	*		*			
	2			1600	*	*	*		*	1600	*			
	3			*	*			1600	*	*	3200			
	4				*			*	*	*	*			
	5				*	*	*	1600		*				

TABLE 8.--(Continued)

Date and transect	Depth (cm.)	Distance From Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Dec. 3, 1961 2.	1					*	*	*	1600			*		
	2						*	*		*	*	*		
	3						*	*		*		*		
	4						*				1600			
	5										*			
	6										*			
July 27, 1962 2.	1		*	*	3200	*	*	*	1600		*	*		
	2		*	*	*				*		*	*		
	3		*			*	*							
	4		*											
	5		*											
	6													
Oct. 28, 1961 3.	1					*	*	*	*	1600		4800		
	2					*	1600	*	*			*		
	3					*	*		*		1600	*		
	4				*	*	*		*	*				
	5				*							*		
	6				*		*							
May 1, 1962 3.	1					*	*	*	*	1600	*	1600	3200	*
	2					*	*	*		*	*		*	*
	3						*					*	1600	*
	4									*			*	*
	5													*
	6													

eupsammon regions. Though most individuals inhabited the top 3 cm. of sand, there was a considerable number of occurrences below that depth down to 6 cm.

Seasonal distribution of nematodes followed that of the testacea with low populations in the winter and high in the summer months (Figure 4).

Rotifera Distribution

Excepting the copepods this is a psammon group which has received comparatively much attention by past workers, consequently considerably more is known of Rotifera psammolittoral ecology than of the other major groups found in the sand. Wiszniewski (in Neel, 1948) in Poland and Meyers (1936) and Pennak (1940) in this country have done extensive studies of the psammon rotifers.

Compared to other investigations of the sand the Mud Lake psammon contained a rather meager rotifer fauna (e. g. Meyers (1936) found 145 species in New Jersey and Wiszniewski (in Pennak, 1940) 105 in Poland). However, in the preliminary observations of "live" sand rotifers were among the most abundant animals in the sand; most likely the treatment for extracting the organisms was too severe for the majority of this phylum.

General distribution: Due to the few numbers of both species and individuals found it was not advantageous to separate the rotifers into Wiszniewski's (in Pennak, 1940)

TABLE 9.--Rotifera distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters) (-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5	4
Oct. 18, 1961 1.	1				1600		1600	*	1600	*				
	2								1600					
	3					*	*		*	1600				
	4							*	*					
Nov. 12, 1961 1.	1						1600	1600		*				
	2					*	*							
	3													
	4													
Apr. 7, 1962 1.	1					*								
	2					*								
	3													
	4													
June 25, 1962 1.	1			*			1600							
	2													
	3													
	4													
	5													
	6													
Oct. 22, 1961 2.	1				*		1600	*	*					
	2						*	*		*	*			
	3								*		1600			
	4									*				

TABLE 9 .--(Continued)

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Dec. 3, 1961 2.	1						*	3200	*					
	2						*				*			
	3													
	4													
July 27, 1962 2.	1		*			1600	*	1600	*	*				
	2									*				
	3					1600								
	4													
	5													
	6													
Oct. 28, 1961 1.	1				*			*	*					
	2							*		*	*			
	3													
	4					*								
	5													
	6						1600							
May 1, 1962 3.	1													
	2						*			*				
	3													
	4													

psammobiotic (rotifers found only in the sand), psammophile (rotifers of the sand which also occur in the vegetation of the littoral zone), and psammoxene (rotifers characteristic of the plankton and which are accidental to the sand and unable to persist there for any length of time) ecological groups. Horizontally, rotifers of the ploimate group were found from 2.5 m. landward to 1.5 m. into the water with the majority occuring in the hygropsammon region; vertically individuals were found to a depth of 4 cm. though most inhabited the top 2 cm. of sand. Psammoxene genera such as Keratella sp. and Kellicottia sp. appeared in one or two of the samples.

Seasonally, rotifers were never abundant. Higher populations were present in the October 18 and July collections than in any of the other samples. Rotifers were low or absent from November, April, and May collections. Wiszniewski (in Pennak, 1940) reported maxima in June and September and absence of rotifers from November to April in Poland; Pennak (1940) agrees with this. Not enough counts, however, were made to determine, in a similar way, the characteristic seasonal variance of the Mud Lake Rotifera.

Tardigrada Distribution

Two species of Tardigrada inhabited the Mud Lake sand: Macrobiotus dispar Murray and Hypsibius granulifer (Thulin) Marcus. Tardigrades were found in each of the three transects

TABLE 10.--Tardigrada distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Nov. 12, 1961 1.	1			*			*		3200	*				
	2								*					
	3													
	4													
	5													
	6													
Oct. 22, 1961 2.	1						*			*	*			
	2					*	*	*						
	3			*	*									
	4													
	5													
	6													
Dec. 3, 1961 2.	1						3200	*	14400		*			
	2						*	*	*					
	3								*					
	4													
Oct. 28, 1961 3.	1				*				*					
	2													
	3													
	4													

studied, but their appearance, at least as adults, was limited to the months of October, November, and December. If this represents population maxima, the present findings differ, somewhat, from the end of May to the end of June peak that Pennak (1940) found in his sand samples. Pennak (1940) discussed distribution, general ecology, and seasonal variation of tardigrades in some detail in his Wisconsin investigation. His findings with regard to the ecology of this group in the sand are the most comprehensive thus far.

Both Neel (1948) and Pennak (1940) found great instability in the tardigrade population; Pennak (1940) in fact, states that ". . . populations of Tardigrada on any beach are almost unpredictable and that they may vary greatly over a period of time." In the Mud Lake sand tardigrade occurrence, both horizontal and vertical, was also sporadic though there was a distinctly greater number found in the landward portion of the psammon (see Table 10). Vertically this group was not found below 3 centimeters.

Oligochaeta Distribution

Very little is known of the oligochaete fauna of the sand, either of the kinds which typically inhabit the psammon, of the seasonal abundance, or of the environmental factors influencing its distribution as well as the nature of the distribution along the psammon.

TABLE 11.--Oligochaete distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Oct. 18, 1961	1		64	48	80				16	80				
	2		16	16		16	64			16				
	3		32			16	32							
	4							16						
	5													
	6													
	7													
	8													
	9													
	10													
	11								64					
	12								48					
Nov. 12, 1961 1.	1			96	160	32	64		16			0		
	2				16		32		16					
	3						48			16	16			
	4								48					
	5							16						
	6													
June 25, 1962 1.	1			16	0	0	16	32	16	16				
	2								32	16				
	3						16	16	48	48				
	4													
	5			80			16							
	6													

TABLE 11.--(Continued)

Date and transcect	Depth (cm.)	Distance from Water's Edge (in meters) (-) 2	(-) 1.5	(-) 1	(-) .5	0	(+) .5	(+) 1	(+) 1.5	(+) 2	(+) 2.5	(+) 3	(+) 3.5	(+) 4
Oct. 22, 1961 2.	1			80	64	16	80	16	112	16	16			
	2				48	48	48	96	16		32			
	3				16			32	16	32	16			
	4					16		16	16		16			
	5								16	16				
	6						16							
	7													
	8													
	9													
Dec. 3, 1961 2.	1			48		80			16			16		
	2				32		96		16	16	32			
	3			16			16	16	16					
	4						32	16		16				
	5										64			
	6						16		16		16			
July 27, 1962 2.	1		0	16	16	0	0	0	0	0	0	0		
	2													
	3													
	4													
Oct. 28, 1961 3.	1				32	16	80	32	96	48				
	2				16		64		32	48		16		
	3					16	32		16	16	16			
	4								32	16				
	5									16		16		
	6						16							
May 1, 1962 3.	1						112		0		0	0	0	0
	2							48						
	3								16					
	4							16			16			
	5													
	6													

Oligochaetes of four genera were present in the Mud Lake sand: Pristina sp., Chaetogaster sp., Aelosoma sp., and Stylaria sp.; the latter two were found only in the preliminary investigation when "live" sand samples were inspected. Of the two genera found in the study, Chaetogaster sp. was consistently the more abundant in the sand.

Horizontal distribution: Oligochaetes were distributed in nearly the same numbers lakeward as they were landward in contrast to the Copepoda and Testacea which were distinctly more abundant in the beach region as compared to the shoals. This observation agreed with that of Neel (1948). Nor did this group show a distinct preference for a particular portion of the sand in their horizontal distribution but instead were relatively evenly distributed. Therefore, in contrast to the copepod distribution, which was characterized by a peak concentration in a particular portion of the beach, oligochaetes often exibited several maxima along a transect (Fig. 11). Vertical distribution: Here again there was a marked difference between the distribution of oligochaetes and harpacticoid copepods. Whereas the copepods had an optimal population at 2 cm. below the surface, oligochaetes were most abundant in the top centimeter of sand (Fig. 12), rapidly decreasing in numbers in the deeper layers; the top 3 cm. contained the greatest numbers of oligochaetes. The greatest depth to which oligochaetes were found was 12 centimeters below the surface.

Figure 12. Horizontal distribution of Oligochaeta in the top five cc. of sand.

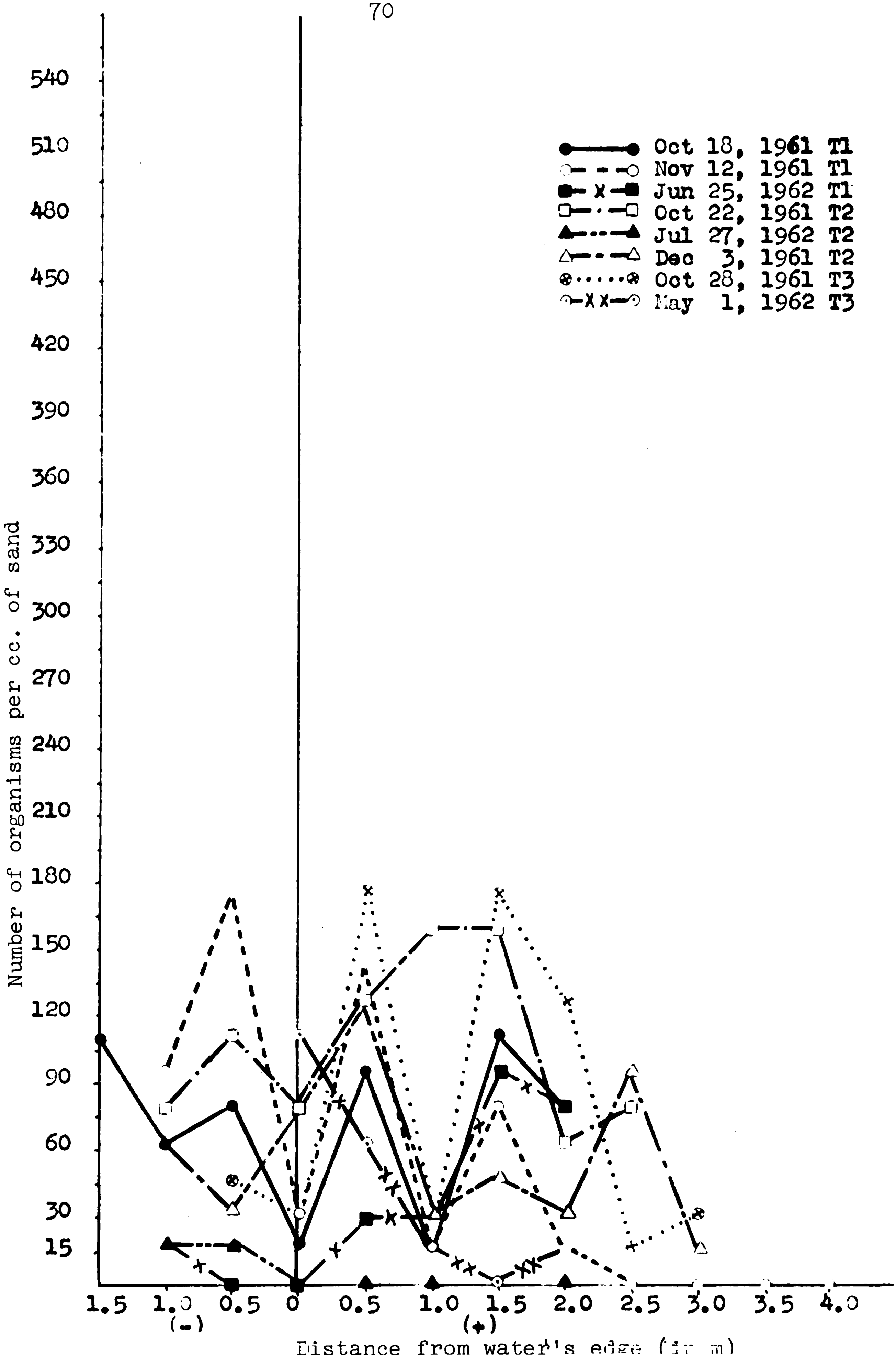
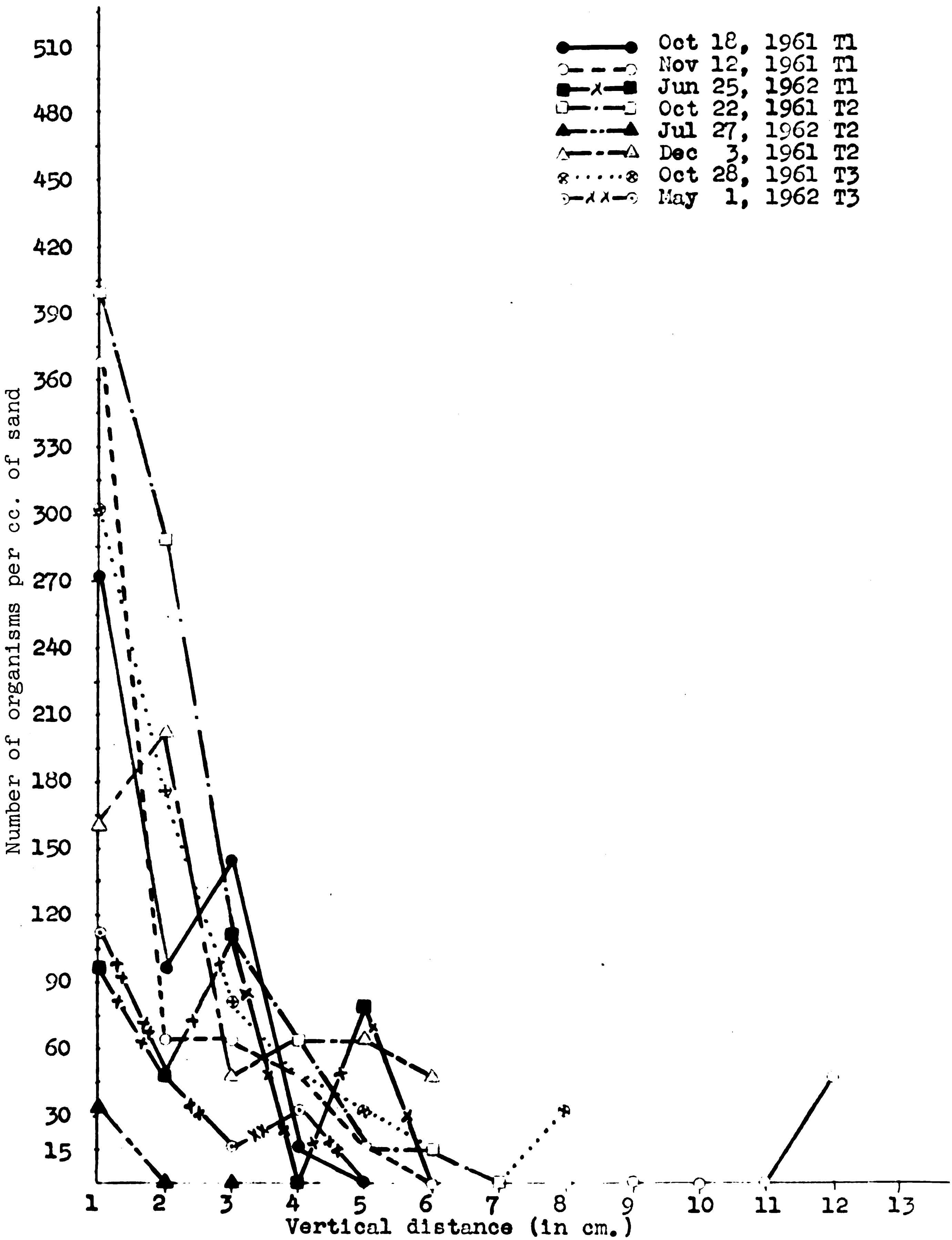

Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T3
May 1, 1962 T3
Number of organisms per cc. of sand
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
15
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in m)

Figure 13. Vertical distribution of Oligochaeta.


Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T3
May 1, 1962 T3
Number of organisms per cc. of sand
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
15
1
2
3
4
5
6
7
8
9
10
11
12
13
Vertical distance (in cm.)

Seasonal distribution: In comparison to the spring and summer collections (April-July) all of the fall and winter samples (October 18-December 3) contained high numbers of oligochaetes; the October 22 collections possessed the greatest numbers of individuals.

Copepoda Distribution

The characteristic copepod of the fresh-water beaches, with one exception belongs to the suborder Harpacticoida, a group peculiarily adapted for its existence in the sand intersticies. The three species found in the Mud Lake investigation were *Elaphoidella bidens coronata* (Sars), *Pastenocaris brevipes* Kessler, and *Pastenocaris delamari* Chappius. Neither *Canthocampus* sp.nor *Phyllognathus* sp. the only other genera often found in inland beaches, occurred in the Mud Lake psammon. According to Yeatman (recent correspondance), *Pastenocaris starretti* Pennak described from a Wisconsin lake by Pennak (1939) is identical with *P. brevipes* of Europe, and, that which Pennak listed as *P. brevipes* in the same report is actually *P. delameri.* When these misidentifications were considered, copepod fauna was identical with that Pennak had found in his study except for the absence of *E. b. coronata* from Wisconsin and *Phyllognathopus paludosus* Mrazek from Mud Lake.

In this study the nauplius larval stage was excluded from the population estimates, the figures given pertaining only to the adult individuals.

Horizontal distribution: Since it was not possible to break down the distribution of the three species, if indeed there was a difference in their vertical or horizontal inhabitation of the beach, the distribution of copepods will be discussed in terms of the harpacticoid group as a whole.

Harpacticoids occurred from (+) 3.5 m. landward to (-) 1 m. lakeward with by far the greater numbers inhabiting the (-) 5.2 m. region of the beach (see Fig. 13). This concurs with previous findings of Pennak (1940) and Neel (1948). Undoubtedly harpacticoids inhabited the sand both farther landward and lakeward but obviously conditions for their existence were optimal from .5-2 m. from the water's edge where, as mentioned by Pennak (1940), the sand is neither saturated nor too dry, as well as removed from the greater portion of wave action. Of the specimens which had been identified, *E. b. coronata* was taken from the 0, (+) 1, and (+) 1.5 m. stations, *P. delamari* from (+) 1.5-2 m., and *P. brevipes* from (-) 1.5 to (+) 2 m. Whether these species inhabit specific portions of the beach is not known. According to Neel (1948) *Pastenocaris* sp. in the Douglas Lake psammon, inhabited only the beach portion.

Vertical distribution: Vertically the most striking feature was that in virtually every transect harpacticoids exibited a distinct peak two cm. below the surface (Fig. 14). Apparently the amount of water above the two cm. depth was not sufficient for optimal copepod existence there.

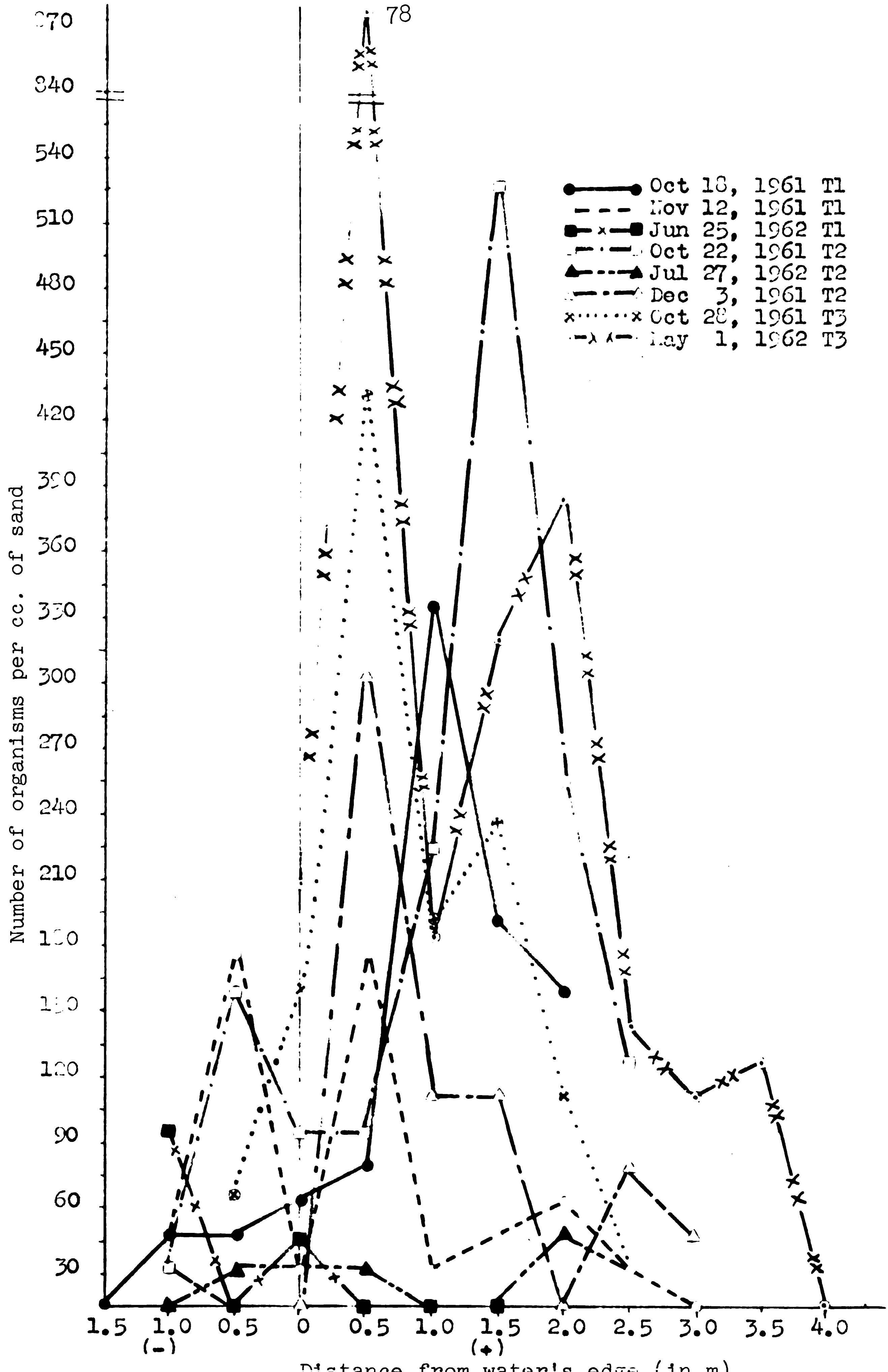
TABLE 12.--Harpacticoid copepod distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters) (-) 2	(-) 1.5	(-) 1	(-) .5	0	(+) .5	(+) 1	(+) 1.5	(+) 2	(+) 2.5	(+) 3	(+) 3.5	(+) 4
Oct. 18, 1961 1.	1		0		16					16				
	2			32	16		64	160	16					
	3					48		96	160	16				
	4							64	16	128				
	5													
	6													
	7													
	8									16				
Nov. 2, 1961 1.	1			32	48	16	32				16	0		
	2				64		96	16	32					
	3				48		32			48				
	4													
June 25, 1962 1.	1				0	16	16	0	0	0				
	2													
	3													
	4													
	5			80										
	6													
Oct. 22, 1961 2.	1				32			32	16	16	32			
	2				80	64	80	80	176	96	64			
	3				16			48	192	48	16			
	4			16	16	16		48	128		16			
	5								16	96				
	6							16	16	16				

TABLE 12.--(Continued)

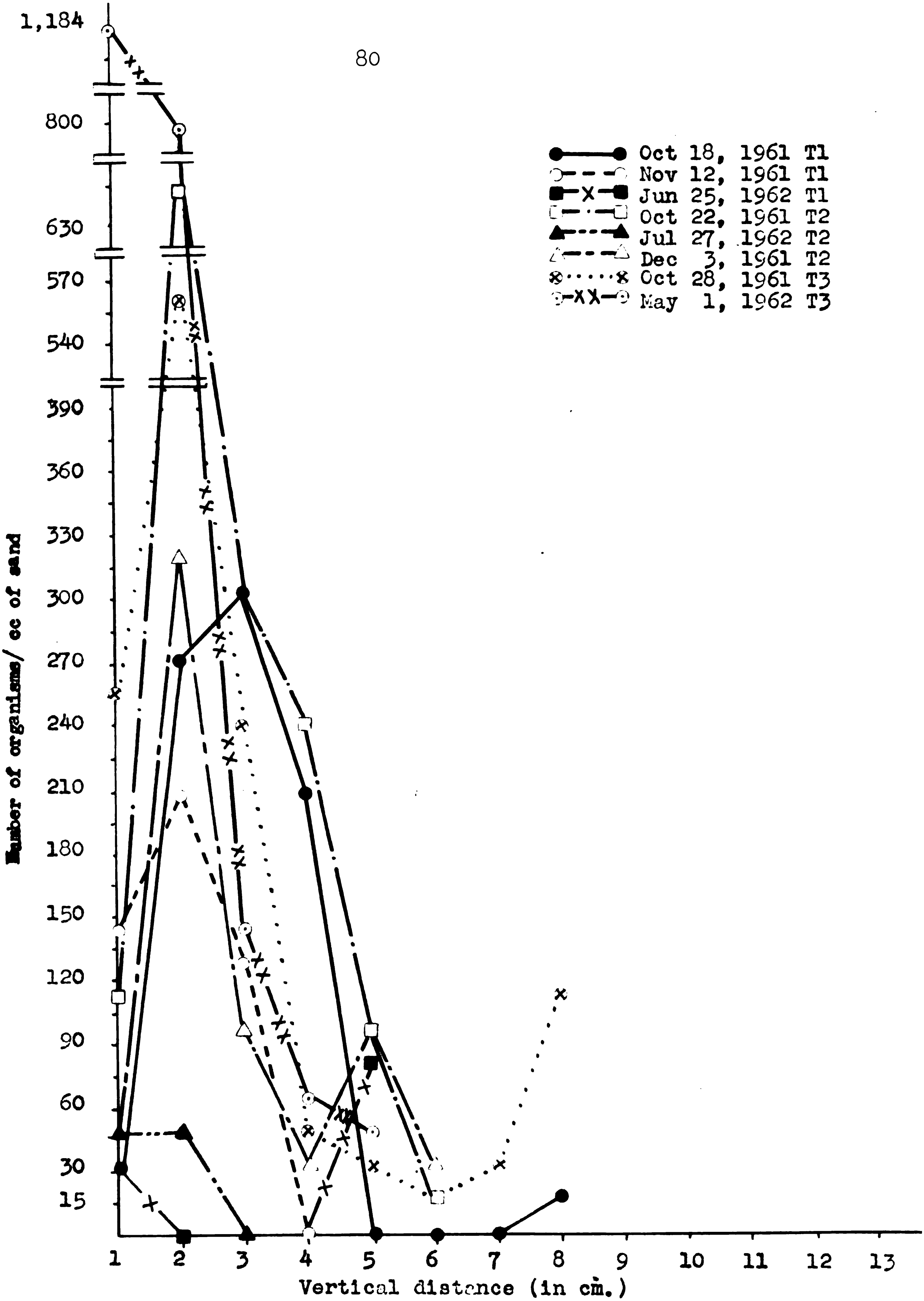
Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Dec. 3, 1961 2.	1				0	0		16	32	0		16		
	2			16			208	64			32			
	3						16	16	64			16		
	4						16		16		16			
	5						64				16	16		
	6										32			
July 27, 1962 2.	1		0	0	16		16	0	0		16	0		
	2					16				32				
	3													
	4													
Oct. 28, 1961 3.	1					64		32	96	64	16	0		
	2				16		272	144	80	32	32			
	3				48	80	64		48	16				
	4				16		48							
	5						32							
	6						16							
	7						32							
	8						112							
May 1 1962 3.	1					176	368	16	272	176	64	96	16	0
	2						448	48		144	64		96	
	3					16	64	48	16	16				
	4							48	16	16				
	5									48				
	6													

Figure 14. Horizontal distribution of harpacticoid copepods in the top five cc of sand.



78
570
540
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
Number of organisms per cc. of sand
Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T3
May 1, 1962 T3
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in m)

Figure 15. Vertical distribution of harpacticoid copepods.



Oct 18, 1961 T1
Nov 12, 1961 T1
Jun 25, 1962 T1
Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T3
May 1, 1962 T3
Number of organisms/ cc of sand
Vertical distance (in cm.)
1,184
800
630
570
540
390
360
330
300
270
240
210
180
150
120
90
60
30
15
1
2
3
4
5
6
7
8
9
10
11
12
13

Harpacticoids were found to a depth of eight cm. below the surface; they have been known to occur as deep as 11 cm. (Pennak, 1940). Whether there was a preferential vertical distribution among the three species of harpacticoids as was found in the studies of copepods inhabiting marine beaches (Nicholls, 1935) was not determined. Seasonal distribution: As with the distribution of oligochaetes along the beach, there seemed to be an indication in the data that during warmer periods harpacticoids move towards the hygro--and hydropsammon portions of the beach (Fig. 13) as well as into the vertically deeper portions of the beach (Fig. 14). Copepods were collected from every transect and at all times of the year except in the April collection. Highest populations were found in the May collection when, paradoxically, numbers of other psammon organisms were lowest (Fig. 3).

High populations were also found in October (T2, T3). lower ones in November and December, and the lowest populations occurred in the June and July collections. No copepods were found in the April collection.

Cladocera and Malacostraca Distribution

In every instance cladocerans were collected from the shoal region of the psammon, and, in nearly every instance from the top(cm. Table 6). This implies that this group was most likely an accidental visitor to the psammon rather than part of the psammolittoral fauna. In addition cladocerans,

unlike the copepods, possessed no particular morphological adaptations for life in the sand interstecies.

In two instances single individuals of Hyalella azteka (Saussure) were found. These, like the cladocerans, represented incidental elements to the psammon.

Larval Insect Malacostraca Distribution

Larval dipterans occurred in a few samples but never in great numbers. Larvae of the families Tentapedidae, Delicapodidae, and Chironomidae were found but not in sufficient numbers to discern distributional patterns. An occasional Podura aquatica L.appeared in some samples as well but these were incidental to the psammon. Neel (1948) found larvae of two Diptera families: chironomids, which were infrequent, and ceratopogonids of which eggs and larvae were common, in the Douglas Lake sand. He also found larval homophrinids (Coleoptera). Pennak (1940) found the distribution of Diptera larvae to exibit no maxima or minima along any portions of the psammon although his data, as in this study, was somewhat insufficient to make definitive evaluations.

If one were to total (from Table 13) the number of larvae found in the shoal region (+) against the number found in the beach portion (-) of the psammon, these numbers would be approximately equal indicating an even distribution throughout the sand. However, also apparent from table 13 is the fact that most of the larvae occurred in the hydro-- and hygropsammon regions; very few were found in the eupsammon.

TABLE 13.--Immature insect distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters) (-) 2	1.5	1	.5	0	(+) .5	1	1.5	2	2.5	3	3.5	4
	1		0		0	0	0	0	0	0				
Oct. 18,	2			16			0	0	0	0				
1961	3						0	0	0	0				
1.	4							0	0	0				
	1			0		0	16	0	0	0	0	0		
Nov. 12,	2									0	0	0		
1961	3				16					0	0	0		
1.	4													
	1			16	0	0	0		0	0				
June 25,	2							16						
1962	3													
1.	4													
	1			48	16	0	0	0	0	0	0			
Oct. 22,	2													
1961	3													
2.	4				16									
	5													
	1			0	0	0	0	0	0	0		0		
Dec. 3,	2													
1961	3										16			
2.	4													

TABLE 13.--(Continued)

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
	1		0	0	0	0	0	0	0	16	0	0		
July 27,	2													
1962	3													
2.	4													
	1				0	16		32	0	0	0	0		
Oct. 28,	2													
1961	3													
3.	4													
	5													
	6													
	7						16							
	8													

Seasonally, because of the lack of data, one can make only a cursory statement regarding variations: Insect larvae in the Mud Lake psammon were most abundant in the October (T2, 3) collections and least abundant in the December, April, May, and July collections (Fig. 3).

Acari Malacostrace Distribution

An arthropod group not previously reported from the psammon, but one which would be expected to occur there, was the Acari. Mites were found in every collection but two and in every transect. Though most mites were generally found in the top two cm. the distribution of these animals was sporadic, there being neither a consistent horizontal (Fig. 15) nor vertical (Fig. 16) preference for a particular region of the psammolittoral zone. Vertically, individuals were not found below four cm. Landward, mites inhabited the psammon to (+) 4 m., which was the limit of landward collection. One would anticipate mites to inhabit all portions of the psammon above the water-line, however, a considerable number occurred in the shoal region. As far as could be determined all the individuals collected belonged to the Oribatei and not to the Hydracarina (water mites). A great number of mites were collected in the psammon below the water line.

The greatest numbers of mites were found in December collections (Fig. 3) when one could expect the lowest populations. No mites were found in the April and June collections and low numbers appeared in the October 18 and May samples.

TABLE 14.--Mite distribution.

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Oct. 18, 1961 1.	1		0	0		0	0	0	0	0				
	2													
	3				16									
	4													
Nov. 12, 1961 1.	1			48	48	0	0	0	0	16	0	16		
	2				16									
	3													
	4													
Oct. 22, 1961 2.	1			16		0	0				48			
	2				32					16				
	3			16					16					
	4							16						
	5													
	6													
Dec. 3, 1961 2.	1			32	0	0	0		32	16	0	144		
	2			32				48		48		64		
	3													
	4													
July 27, 1962 2.	1		16	48	0	80	0	0	0	0	0	0	48	
	2		16	16										
	3													
	4													

TABLE 14.--(Continued)

Date and transect	Depth (cm.)	Distance from Water's Edge (in meters)												
		(-)					(+)							
		2	1.5	1	.5	0	.5	1	1.5	2	2.5	3	3.5	4
Oct. 28, 1961 3.	1				64	0	16	16	0	0	0	0		
	2													
	3													
	4													
May 1, 1962 3.	1					0	0	0	0	0	0	0		
	2													
	3												16	

Figure 16. Horizontal distribution of mites in the top five cc of sand.

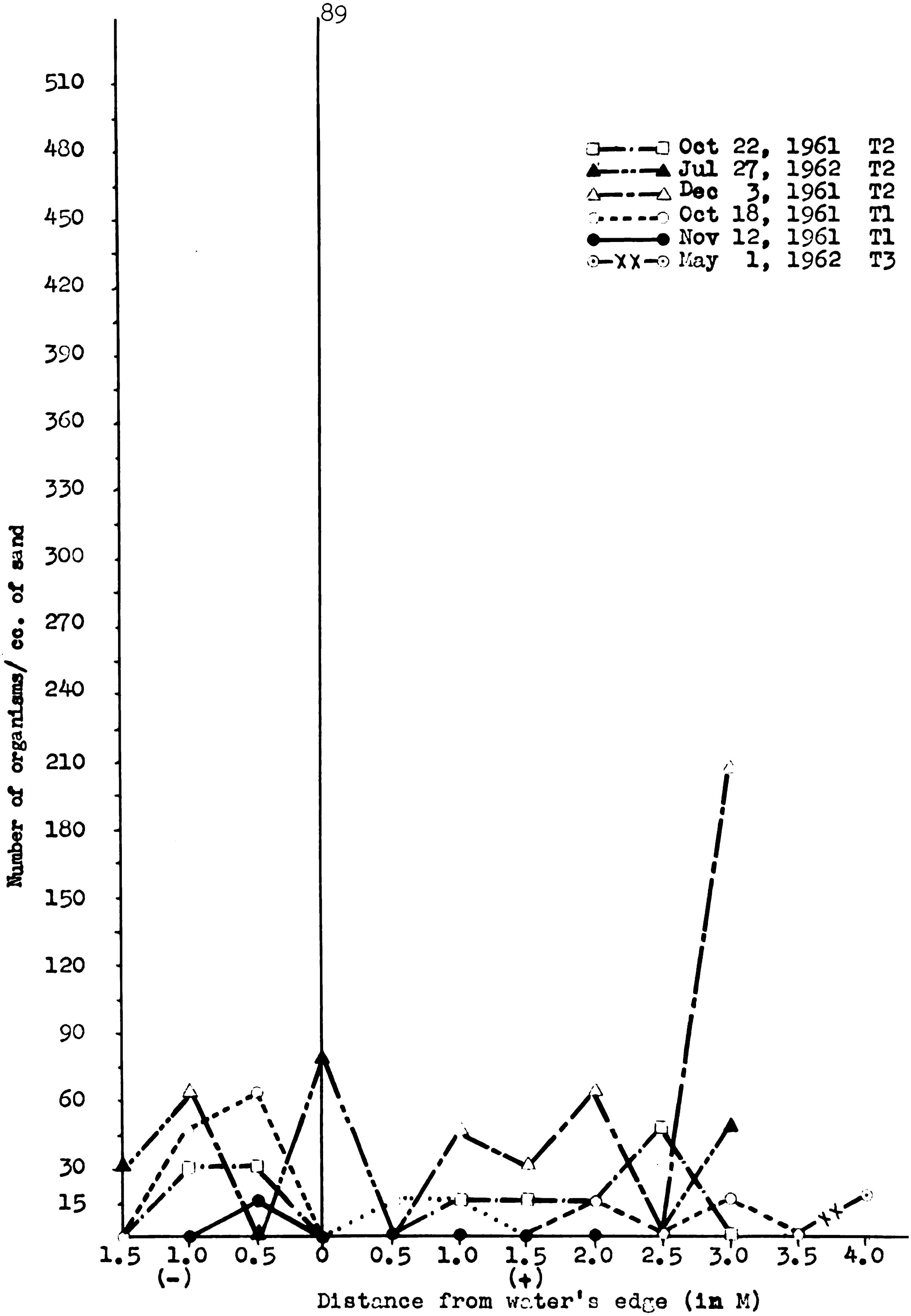
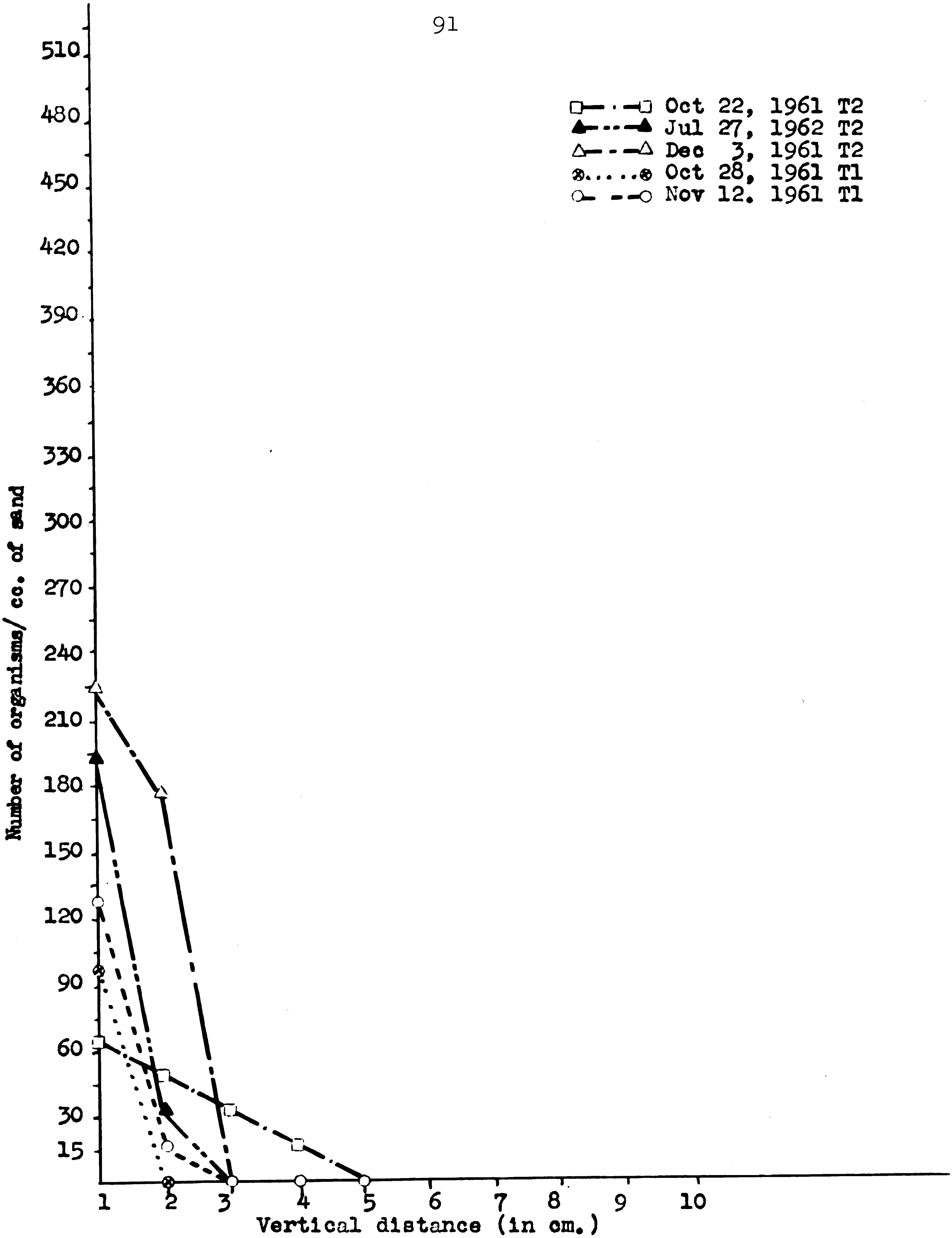

Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 18, 1961 T1
Nov 12, 1961 T1
May 1, 1962 T3
Number of organisms/ cc. of sand
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
15
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
(-)
(+)
Distance from water's edge (in M)

Figure 17. Vertical distribution of mites.



Oct 22, 1961 T2
Jul 27, 1962 T2
Dec 3, 1961 T2
Oct 28, 1961 T1
Nov 12, 1961 T1
Number of organisms/ cc. of sand
510
480
450
420
390
360
330
300
270
240
210
180
150
120
90
60
30
15
1
2
3
4
5
6
7
8
9
10
Vertical distance (in cm.)

Other Metazoa

Both gastrotrichs and turbellarians have been found in previous psammon studies Pennak (1940) and Neel (1948). Representatives of both phyla were found in considerable numbers in the preliminary investigations of unpreserved sand samples. However, as in the case of the non-testaceous protozoans, the means of extracting and preserving psammon organisms destroyed the identity of these soft-bodied specimens with the result that they could not be included in the study.

VI. SUMMARY

An ecological survey study was undertaken in 1961-1962 on the psammolittoral zone of Mud Lake (T.2 N., R.9 W., S.8, Barry Co., Michigan) investigating the seasonal distribution, spatial distribution, and some of the environmental factors influencing the organisms inhabiting capillary interstecies of the sandy zone.

Though, admittedly, there are many non-biological variables operating to restrict the vertical distribution of psammo-microorganisms, a major non-biological factor whenever it was present appeared to be the black sulfide layer. The exact importance of this stratum in restricting the vertical occurrence of organisms was not know. Other environmental factors and their variance were discussed but no correlations with population characteristics were drawn.

Biologically the following statements can be made about the Mud Lake Psammon:

1. The psammo-organisms in approximate order of decreasing abundance were:

   Algae; diatoms, blue-green, green, Euglenophyta.
   Animals; testaceous protozoa, Nematoda, rotifers, copepods, oligochaetes, mites, insects, and cladocerans.

2. Horizontal, vertical, and seasonal distribution of the major taxons occurring in the sand were discussed:

a. The population maximum for the vast majority of psammo-organisms insofar as their horizontal distribution was concerned, occurred in the middle portions of the beach (i.e. the hygro- and eupsammon).

b. Vertically, most of the organisms inhabited the top three cm. of sand.

3. Seasonal patterns in distribution were not, in most instances, distinct, though a few groups did exhibit distinct population maxima and minima at certain times of the year.

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