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A STUDY OF THE PLANKTON IN LAGUNA JOYUDA, A TROPICAL LAGOON ON THE WEST COAST OF PUERTO RICO

BY

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ABSTRACT

A total of 80 plankton samples were obtained from Laguna Joyuda during March, 1977 to February, 1978. The research area is a shallow tropical brackish water lagoon. It was observed that the species diversity of the planktonic members of the community is very low. The copepod *Acartia tonsa* is the dominant holoplankter followed by porcellanid larvae, a member of the meroplankton. A voracious predator, the ctenophore *Mnemiopsis gardeni*, was found in the lagoon. It attained bloom proportions on several occasions reducing considerably the density of smaller zooplankton. The species present in the plankton seem to be circumscribed to Laguna Joyuda. There appear to be indications that the planktonic populations are biologically accommodated although physically controlled conditions may also play an important role too.

The water system of the lagoon seems to be homogeneous vertically and longitudinally in regard to temperature and salinity. The implications this homogeneity may have in providing *A. tonsa* with more efficient ways of eliminating other species of copepods are taken into consideration. Physical factors which include: temperature, salinity, turbidity, tides, surface currents and wind velocity are also discussed.

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INTRODUCTION

Zooplankton plays an important role in the aquatic food chain. The energy from the sun which has been fixed through the photosynthetic action of the phytoplankton is made available to those aquatic forms higher up in the food chain by the zooplankton. The latter form links the primary producers to the consumers along higher trophic levels.

Although most members of a planktonic community are microscopic, not larger than 1 mm., organisms such as the medusae can grow up to 1 m. in diameter. The latter only comprise a small percentage of the total plankton.

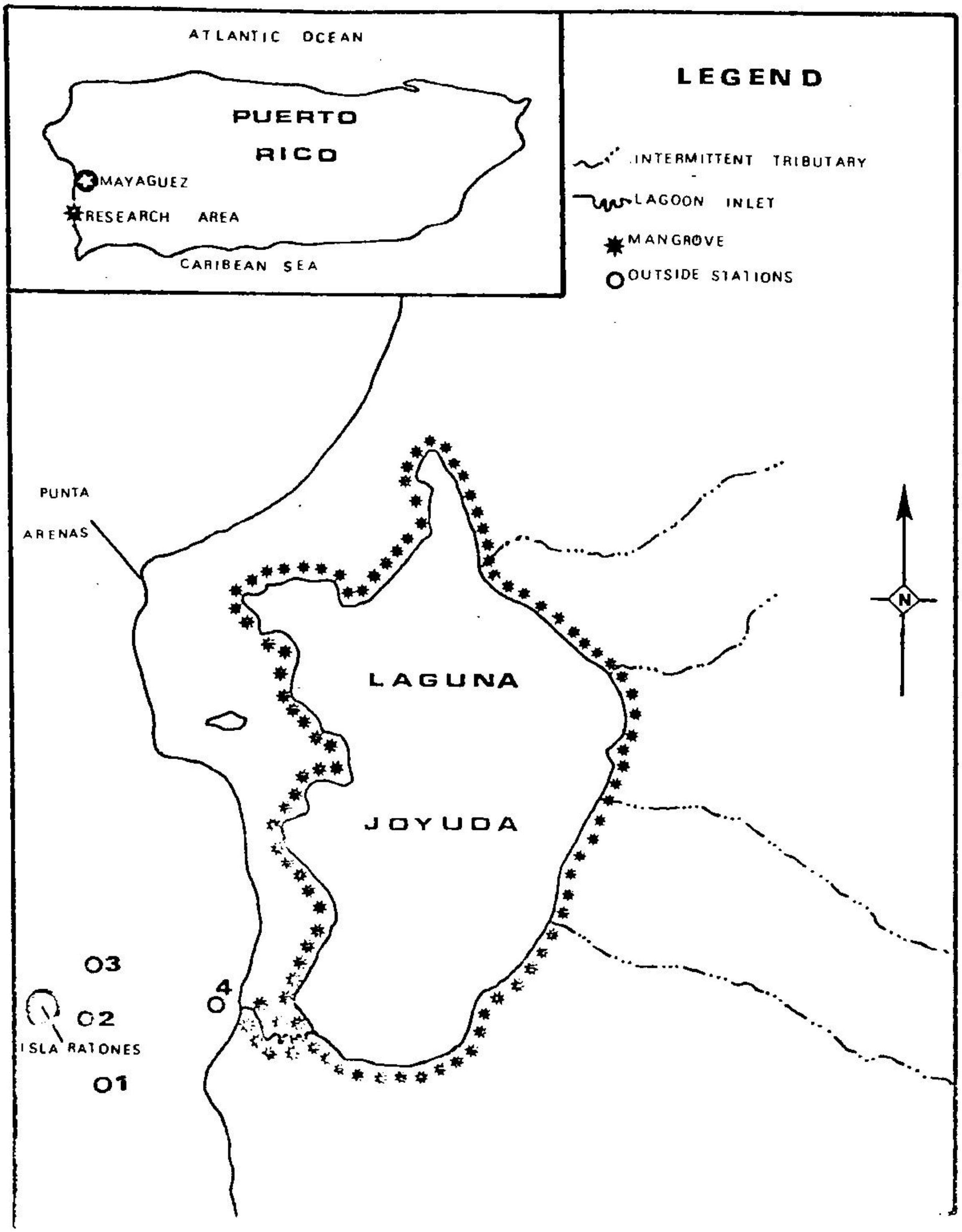
Biological, physical, chemical, and geological factors, or a combination of these, have a definite influence on the distribution of organisms. Factors such as temperature, salinity, dissolved oxygen, nutrients, predation, among others, have some impact over planktonic populations (Hopper, 1962; Jeffries, 1962; Reeve, 1964; Lock and McLaren, 1969). The degree to which one or more of these factors affect the structure of a population may determine its survival. Even in environments with similar physical conditions, population distributions are not identical (Jeffries, 1962).

By looking at the species composition together with concurrent observations of the physical factors, as well as the biological factors, the distribution patterns and population dynamics of the planktonic organisms can be determined. Through studying the oceanic and neritic water plankton, many investigators have described and analyzed different components of an ecological system and their interrelationships. (Jeffries, 1958, 1962a, 1962b; Heip, 1973; Grahame, 1976; Heip and Engels, 1977.) By determining the composition and population dynamics of a community the system can be described as biologically accommodated, physically controlled or a combination of both (MacArthur, 1955, 1965; Hutchinson, 1959; Klopfer and MacArthur, 1960, 1961; Connel and Orias, 1964; Sanders, 1968).

Therefore, the purpose of this investigation, undertaken at Laguna Joyuda on the west coast of Puerto Rico (Figure #1), is to describe the planktonic species composition and population dynamics. Physical processes were observed in order to determine the control factors: whether the lagoon has a physically controlled or a biologically accommodated community or possibly a combination of both.

Except for some short time studies related to the ecology of this lagoon (Erdman, 1963; Pagan and Austin, 1967; Bennett, 1969), no detailed investigation on plankton has been carried out as to this date. This investigation is the first attempt to describe the planktonic component of the lagoon. Attention was focussed on both the holoplanktonic and the meroplanktonic members of the community. Of particular interest was the free-living fraction of the order

FIGURE # 1. Study Area Site Localization.


ATLANTIC OCEAN
PUERTO RICO
MAYAGUEZ
RESEARCH AREA
CARIBEAN SEA
LEGEND
INTERMITTENT TRIBUTARY
LAGOON INLET
MANGROVE
OUTSIDE STATIONS
PUNTA ARENAS
LAGUNA JOYUDA
N
3
2
1
4
ISLA RATONES

Copepoda (kope, oar; pod, foot), as they comprise a major portion, usually from 80 to 85% of the total planktonic community. These microscopic crustaceans have a very wide distribution in all oceans and fresh water bodies of the world.

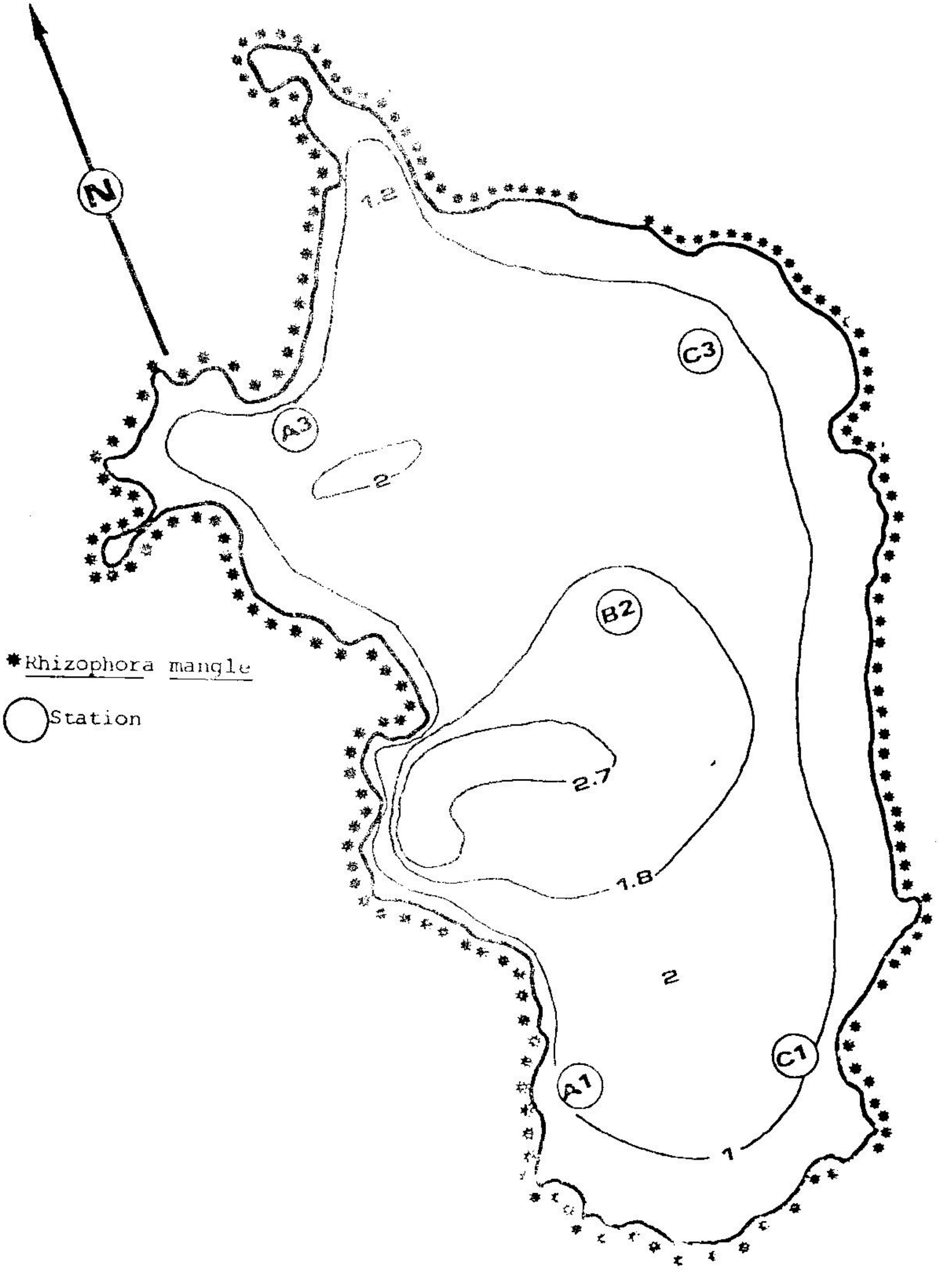
The results of the investigation might have a practical objective: generated information will be useful if the lagoon should be considered as a mariculture site in the future. Actually, from 80 to 85 families derive benefit from the different fish and shrimp caught in the Laguna Joyuda.

The study might also give an insight in some of the ecological problems which take place in analogous environments in other lagoon systems of the island.

DESCRIPTION OF STUDY AREA

Laguna Joyuda is a tropical lagoon situated on the west coast of Puerto Rico at Lat. 18° 09' N, Long. 67° 11' W, about five miles south of the city of Mayaguez (Figure #1). It has a surface area of approximately 300 acres (Pagan and Austin, 1967) with a mean depth of 1.5 m., with two deep holes of 2.5 and 2 m. respectively (Figure #2). Bennett (1969) concluded that the lagoon developed from the accretion of two sand banks which enclosed the bay and formed

FIGURE #2. Bathymetry of Laguna Joyuda Sounding in meters.


N
1.2
C3
A3
2
B2
2.7
1.8
2
C1
A1
1
Rhizophora mangle
Station

a lagoon.

The sediments are composed of a grayish-black mud with varying amounts of shell debris (Bennett, 1969). Sediments have a distinctive H_2S smell. Bennett (1969) also mentions that because of the activity of burrowing organisms there is no perceptible stratification of bottom sediments, and that mangrove swamp material is the major source of fine sediments.

Ruppia maritima, a seagrass, grows profusely along the west and south coast shores of the lagoon. It's banks are 75% fringed by the red mangrove Rhizophora mangle. The tree itself and its prop roots provide habitats for many forms of organisms and trapping of sediment.

The lagoonal water system could be considered as a mixo-polyhaline type (Venice Symposium, 1958) with salinities ranging from 18 to 30 °/₀₀. Erdman (1963); Pagan and Austin (1967), and Bennett (1969) report salinity values that range from 6 to 44 °/₀₀. Temperature values of approximately 35°C have been reported.

Salinity values could be affected by intermittent streams which are formed during heavy rains. Rainfall in Puerto Rico varies considerably from place to place over relatively short distances, owing in part to the island topography. Average annual precipitation for the Mayaguez coastal region ranges from 75 to 80 inches.

The distribution of rainfall can be expressed in terms of a relatively wet and dry season, albeit no absolute dry season occurs. The relative wet season extends from the month of May to November. The dry season extends from December to April (U.S.G.S. San Juan, P.R.).

Lagoon water is of a deep green color on a year round basis. As stated by Wilson (1965), nutrients tend to be concentrated in lagoons. The geomorphological characteristics of the lagoon tend to prevent nutrients from being exchanged with other systems outside the lagoon. Organic matter is deposited on the bottom and bacteria and fungi convert it into more nutrients which are difussed through the water column.

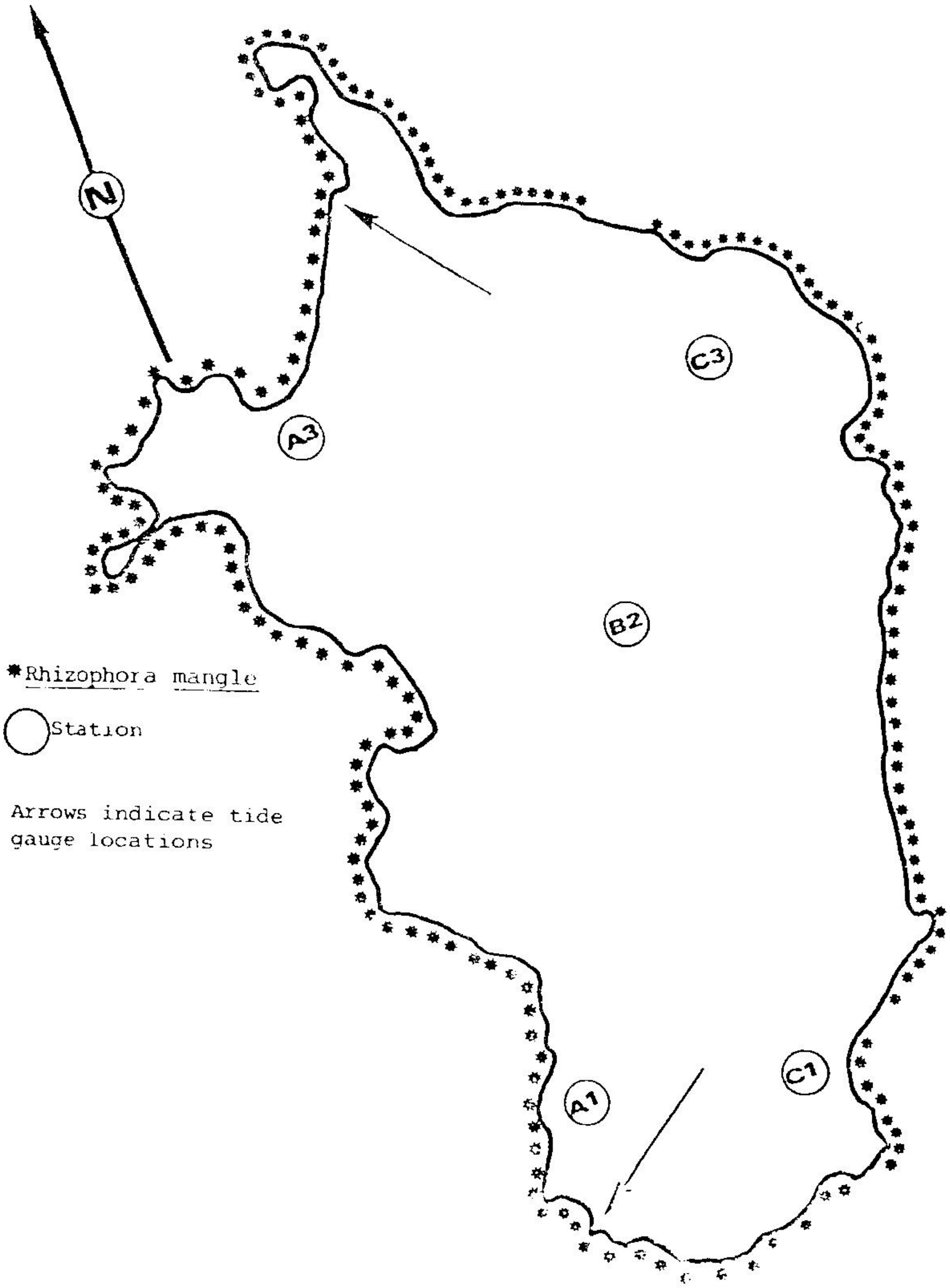
MATERIALS AND METHODS

Field Procedures

Zooplankton samples were collected by towing a conical shape net with an opening of 0.5 m in diameter and a mesh size of 202 µm. A propeller type flowmeter was attached to the net to determine the volume of sea water filtered. During the towing procedure, which lasted five minutes, the power of the boat was reduced until the net was just below the surface. Towing speed ranged from 2 to 3 knots. At the end of each tow the net was hauled in and rinsed with sea water. A 12 volt battery powered pump was used for this purpose. In this way the animals were concentrated at the codend of the net, in a 400 mℓ collecting jar. The samples were preserved with 4% buffered formalin sea water solution. Occasionally, ctenophore blooms made a normal five minute tow impossible; reducing the duration of the tow did not help either. When the ctenophores were present, 15 second tows were made followed by a careful counting of the ctenophores in the field. This was necessary because quantification of these animals in the laboratory was impossible as they become an amorphous gel a few minutes after preservation. During the month of July ctenophore populations reached bloom proportions throughout the lagoon, yet it was noticed that a station had a relatively low number of ctenophores. At this station (B-2) a regular plankton tow was possible in contrast with tows attempted at stations with heavy populations of ctenophores.

During October 20-21, 1977, a total of 30 zooplankton samples were taken in the study area. At each of the five stations (see Figure #3) a tow was made every four hours over a period of twenty-four hours. Parameters like temperature, salinity, water transparency, wind velocity, and tides were observed. Other observations which included a study of surface currents of the lagoon took place during the morning and afternoon of October 20, 1977, as opposed to regular sampling during the year which included one tow per month at each of the five stations. The following

FIGURE #3. Station Location and Position of Tide Gauge.


N
A3
C3
B2
C1
A1
*Rhizophora mangle
○ Station
Arrows indicate tide gauge locations

parameters were also observed on a monthly basis: temperature, salinity, water transparency, and dissolved oxygen.

Surface currents at the lagoon were measured on two different occasions during October 20, 1977 in order to observe whether they have any influence on the distribution of plankton at the lagoon. The following procedure was undertaken. Bamboo stakes 4 m. long were driven in the sandy-mud at a fixed location within the lagoon. A small drogue, previously balanced with lead weights, was dropped next to bamboo rod #1 and the starting time recorded. Additional rods were placed along the trajectory of the drogue. Time and distance covered were registered simultaneously. The angle with respect to north, at which the drogue had drifted was observed and recorded. Wind velocity was monitored simultaneously.

Flow measurements at the channel which connects the lagoon with the sea were made in order to determine the sea-lagoon water exchange. A small drogue was built for this purpose but could not be used since the channel is too narrow (1-2 m.), shallow (approximately 5 cm. in some places), and its banks are completely fringed with the red mangrove Rhizophora mangle. Although the drogue could not be used, the current was measured using a small floating object.

Tide measurements were made every hour for twenty-four hour periods in order to determine tidal influence on the amount of water coming in and out of the lagoon and thereby any exchange of plankton and nutrients from the sea. A meter stick placed inside a clear plastic tubing 90 x 5 cm. provided with a small 0.078 cm. perforation on the bottom for water exchange was employed. The tide gauge was secured to a bamboo stake which was driven into the mud on a mangrove protected embayment (Figure #3). The initial reading and time were registered; hourly observations were made thereafter for twenty-four hours.

Temperature measurements were made using either a thermistor (Y.S.I. model 57, accuracy of 0.5°C) or a mercury thermometer (accuracy of 0.1°C). Particular attention was paid to surface measurements, although temperature vs. depth profiles were made.

Salinity measurements were taken using a portable induction salinometer (Y.S.I. model 33, accuracy of 0.5 °/$_{oo}$). A hand-held refractometer (American Optical, temperature compensated, accuracy of 1.0 °/$_{oo}$) was also used. The use of the latter was restricted to the surface. Salinity (S °/$_{oo}$) vs. depth profiles were made. Dissolved oxygen (D.O.) measurements were taken using a temperature compensated meter (Y.S.I. model 57, accuracy of 0.1 ppm.). Measurements were taken at the surface, mid-depth, and bottom. Instrument malfunctioning affected the continuity of the data. According to manufacturer specifications all electronic instruments were calibrated prior to each field trip. Light transmission was estimated using a Secchi disk at each of the five stations.

Laboratory Procedures

Plankton samples were taken to the laboratory and washed with filtered sea water by gentle filtration through 202 µm. netting in order to remove any debris (phytoplankton, plant material, insects, etc.). Before estimates of biomass were made, all organisms larger than 1 cm. were removed (95% of these were small *Phyllorhysa*, (Medusae). Biomass was estimated as wet volume. Samples were transferred to a graduated cylinder (10-40-100-250 mℓ., depending on amount of plankton) to conform to a prefixed volume. The sample was then poured through 202 µm. netting into another identical graduated cylinder, and left to drain by gravity for periods of 1-5 minutes. The difference in volume was expressed as mℓ of zooplankton.

Densities of plankters were determined by volumetric subsampling with replacement. This procedure involves bringing the sample to a known volume (350 mℓ). With a calibrated automatic pipette, a 2 mℓ aliquot of the homogeneous sample was placed on a Bogorov counting chamber. A Bausch & Lomb 1X-7X binocular dissecting microscope facilitated the identification and counting of the specimens. Once all the animals in the counting tray were identified, each representative of that species was counted. The aliquot was then returned to the sample jar. The jar was shaken to assure a homogeneous sample, and another aliquot removed. Three aliquots from each sample were counted. The mean zooplankton density and standard deviation of the mean were calculated from these three replications.

Estimation of the volume of sea water filtered by the net was carried out by means of a propeller type flowmeter attached at 1/4 of the distance from the center of the ring, in order to prevent turbulence-induced errors. Calibration of the flowmeter was conducted in a swimming pool where the distance and time were observed for a known distance. The flowmeter was calibrated three times during the year. It turned approximately 35.3 revolutions per cubic meter of water that was filtered. Mean was 35.29 and standard deviation 8.6. Knowing the revolutions the flowmeter turned during a known time and by means of the following formula, the volume of filtered sea water per cubic meter can be calculated:

$$(A_C = \pi r^2 L)$$

where: $(L = {}^{R/}R/_{M})$

r = radius of the ring
R/M = 35.3
R = number of revolutions the flowmeter turned

The number of plankters per m^3 were calculated by multiplying the number of individuals in 1 mℓ of the aliquot by 350 mℓ and dividing that number by the volume of water filtered by the net for that tow as shown in the following expression:

$$M = \frac{N \times 350 \text{ m}\ell}{V}$$

where: N = Number of individuals in 1 mℓ of the aliquot

V = Volume of water filtered by the net in m^3

M = Number of plankters per m^3

RESULTS AND DISCUSSION

Laguna Joyuda Planktonic Composition

Table #1 shows the types of plankters found during this investigation. A total of 80 plankton samples were obtained throughout the year, 54 of them during the monthly sampling procedures, and 26 samples on a twenty-four hour study conducted during October 20-21, 1977. Samples were taken for all months except for March when the amount of the ctenophore *Mnemiopsis gardeni* (Agassiz) was so high that no plankton tows could be made.

As seen in Table #1, *Acartia tonsa* (Dana), the larvae of porcellanid crabs and other decapod zoea were present in all samples taken. Nauplii were present 90.9% of the time. This includes all nauplii found in the samples, although 99% of the latter were barnacle nauplius. Fish eggs were present 81.8% of the time. This included both round and elongated types of eggs.

TABLE #1 SPECIES COMPOSITION PER MONTH

MONTH	M	A	M	J	J	A	S	O	N	D	J	F	%
Acartia tonsa		*	*	*	*	*	*	*	*	*	*	*	100
Porcellanid Larvae		*	*	*	*	*	*	*	*	*	*	*	100
Nauplii		*	*	*	*	*	*	*	*	*	#	*	90.9
Fish Eggs		*	*	*	*	#	*	*	#	*	*	*	81.8
Fish Larvae		*	*	*	#	#	*	*	#	*	#	*	63.6
Decapod Larvae		*	*	*	*	*	*	*	*	*	*	*	100
Amphipoda		*	*	*	#	#	#	#	#	#	#	*	27.2
Mnemiopsis	*	#	#	*	*	*	*	*	*	*	*	*	75
Phyllorhiza		#	#	#	#	#	#	#	*	*	*	*	36.6
Barnacle Cypris		#	#	#	#	#	#	#	#	#	#	*	9

* Represented in the aliquot of the sample for that month.

\# Not represented in the aliquot of the sample for that month.

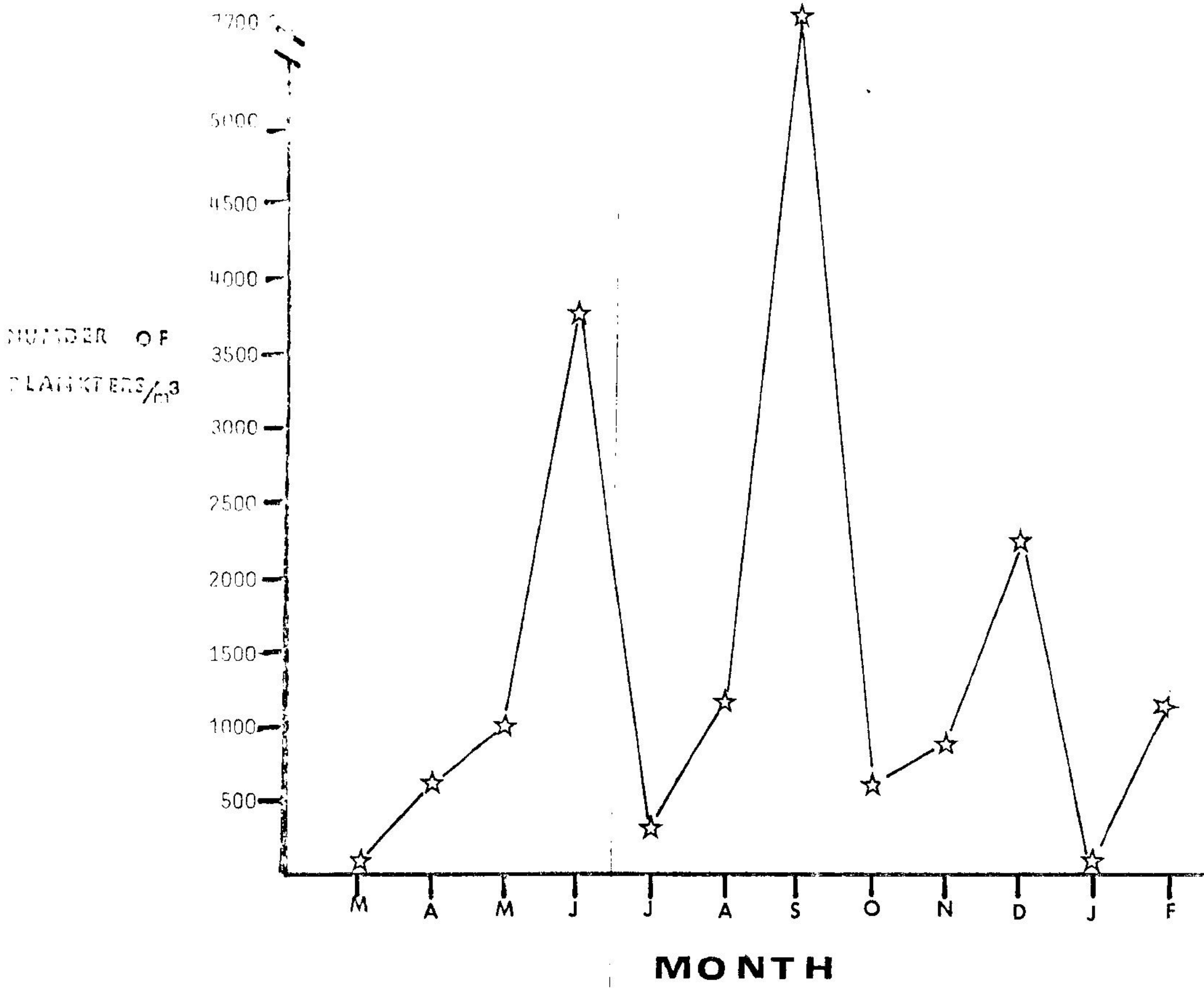
The ctenophore *Mnemiopsis gardeni* was present 75% of the time. The medusae *Phyllorhyza* was present 36.6% of the time. It was present on the samples during the last part of the study. This species can easily be seen drifting around the surface. The medusae were represented as small ephyrae and as adults, having a diameter of up to 0.3 m. This medusae, representative of the largest zooplankton, was the largest of all the members of the planktonic community. It also occurs on the neritic waters outside the lagoon. It has been seen to grow up to 1 m. in diameter outside the lagoon but never that size in the Laguna Joyuda. Amphipoda were present 27.2% of the time during the beginning of the sampling season. Barnacle cypris were present 9% of the time; a rather low number compared to the percent of time nauplii were present.

Plankton Analysis

Total number of plankton per meter cube is represented in Figure #4. A star represents the mean value of the five stations sampled. The extreme range in total plankton/m^3 noted throughout the year was from 71.0 in January, 1978 to 6,565 animals/m^3 in September, 1977. Although there are many fluctuations definite peaks are observed in which September has the highest density of plankton/m^3.

Of the plankton available in the Laguna Joyuda, the Calanoid copepod *Acartia tonsa* is the dominant one. *A.*

FIGURE #4. Number of Plankters per cubic meter.


NUMBER OF
PLANKTERS/m3
7700
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
M
A
M
J
J
A
S
O
N
D
J
F
MONTH

tonsa was represented in all samples taken. Not only does it attain the highest densities but it is the only copepod which is present regularly. During a sampling done in the summer of 1977, a 12 volt pump with a hose was run along and across a Ruppia maritima bed and another copepod was found, a calanoid of the genus Pseudocyclops. It is suspected that it stays close to the bottom thus avoiding the net as it passes by. No other plankters were found during this vacuum-cleaning process that differed from the ones already mentioned, which shows that the towing procedures were adequate and the net was sampling a representative catch of the plankton of the lagoon. The porcellanid larvae came second in density, from 2.0 to $369/m^3$ (Figure #5). Some crabs sampled from the lagoon were taken to the laboratory and identified. Porcellanid crabs were represented. A small crab of the species Petrollites armatus was found living in the mangrove roots. Large numbers of these crabs were found in the field, which could account for the high densities of porcellanid larvae present in the plankton samples.

Figures 6 to 14 show the densities of A. tonsa/m^3 and densities of porcellanid larvae/m^3 for each of the five stations sampled. Arbitrarily, we give a #1 to the station with the highest density value. A #5 to the station with the lowest density value. By adding up the column under each station and to this final value, we give a #1 to the station with the highest density and a #5 to the lowest, FIGURE #5. *Acartia tonsa* and Porcellanid larvae per cubic meter per month.

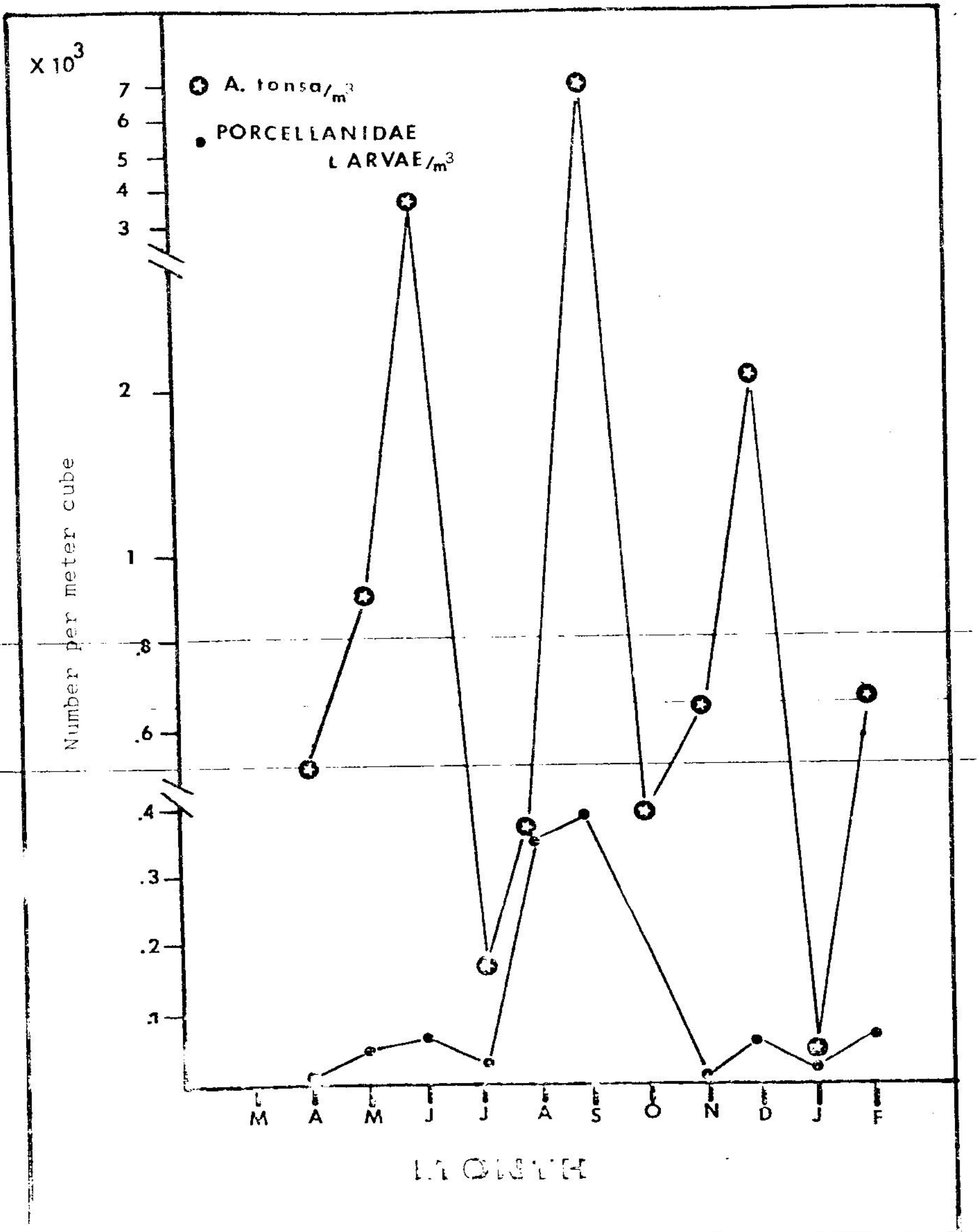

X 10^3
7
6
5
4
3
2
1
.8
.6
.4
.3
.2
.1
A. tonsa/m^3
PORCELLANIDAE LARVAE/m^3
Number per meter cube
M
A
M
J
J
A
S
O
N
D
J
F
MONTH

FIGURE #6. _A_. _tonsa_ and Porcellanid larvae/m^3/station (April).

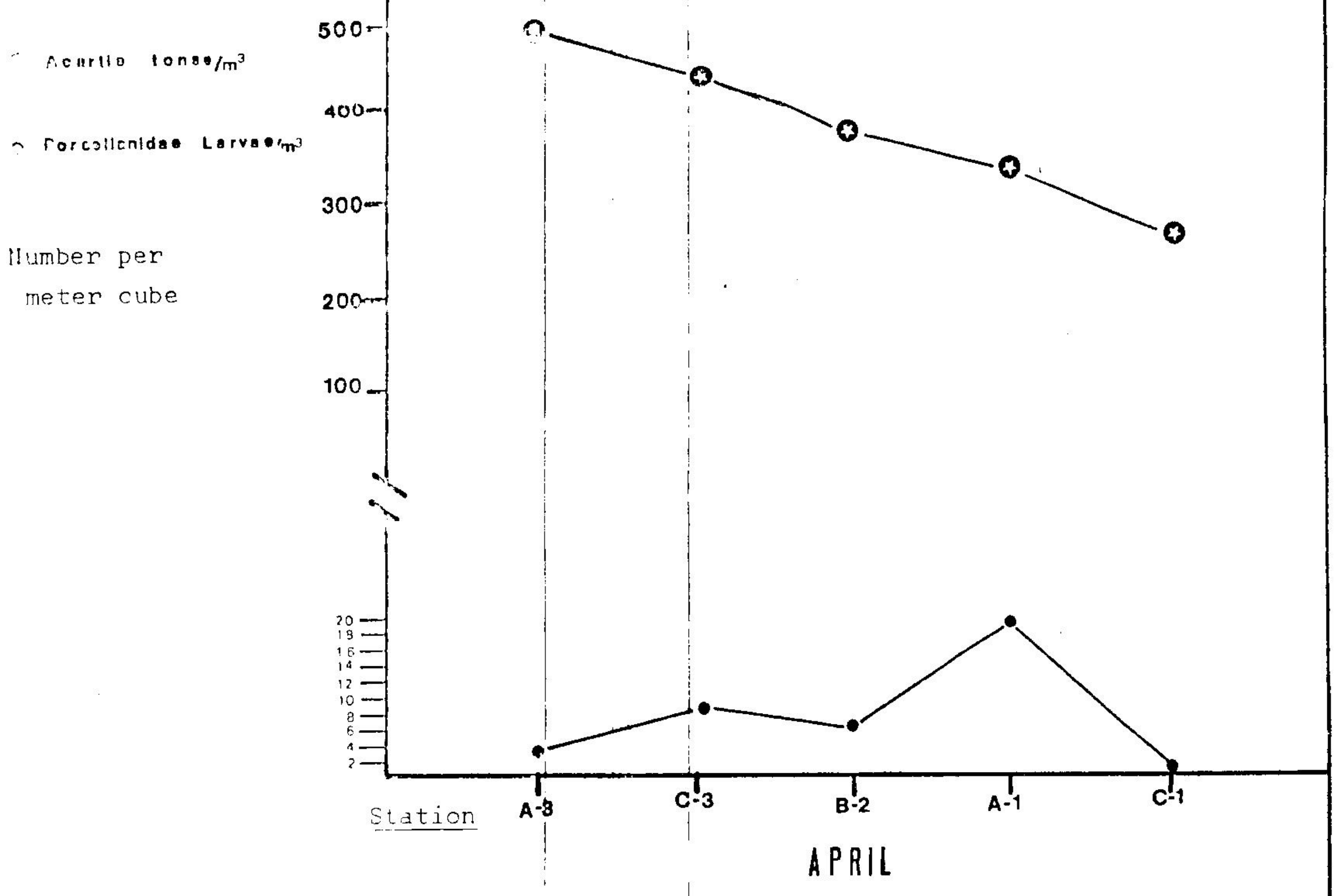

Acartia tonsa/m³
Porcellanidae Larvae/m³
Number per meter cube
500
400
300
200
100
20
18
16
14
12
10
8
6
4
2
Station
A-3
C-3
B-2
A-1
C-1
APRIL

FIGURE #7. *A*. *tonsa* and Porcellanid larvae/m^3/station (May).

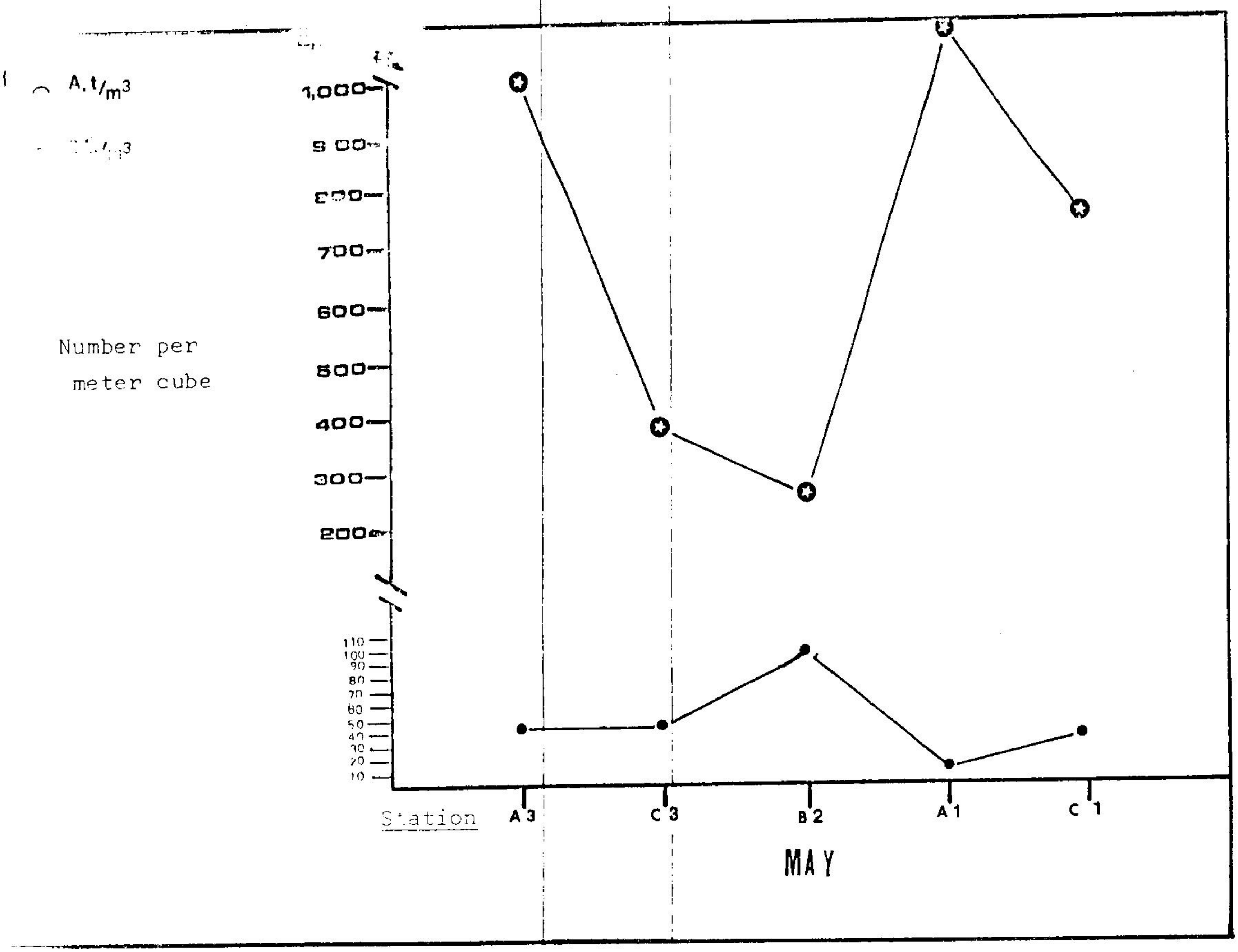

A.t/m^3
Number per meter cube
1,000
900
800
700
600
500
400
300
200
110
100
90
80
70
60
50
40
30
20
10
Station
A 3
C 3
B 2
A 1
C 1
MAY

FIGURE #8. A. tonsa and Porcellanid larvae/m^3/station (June).

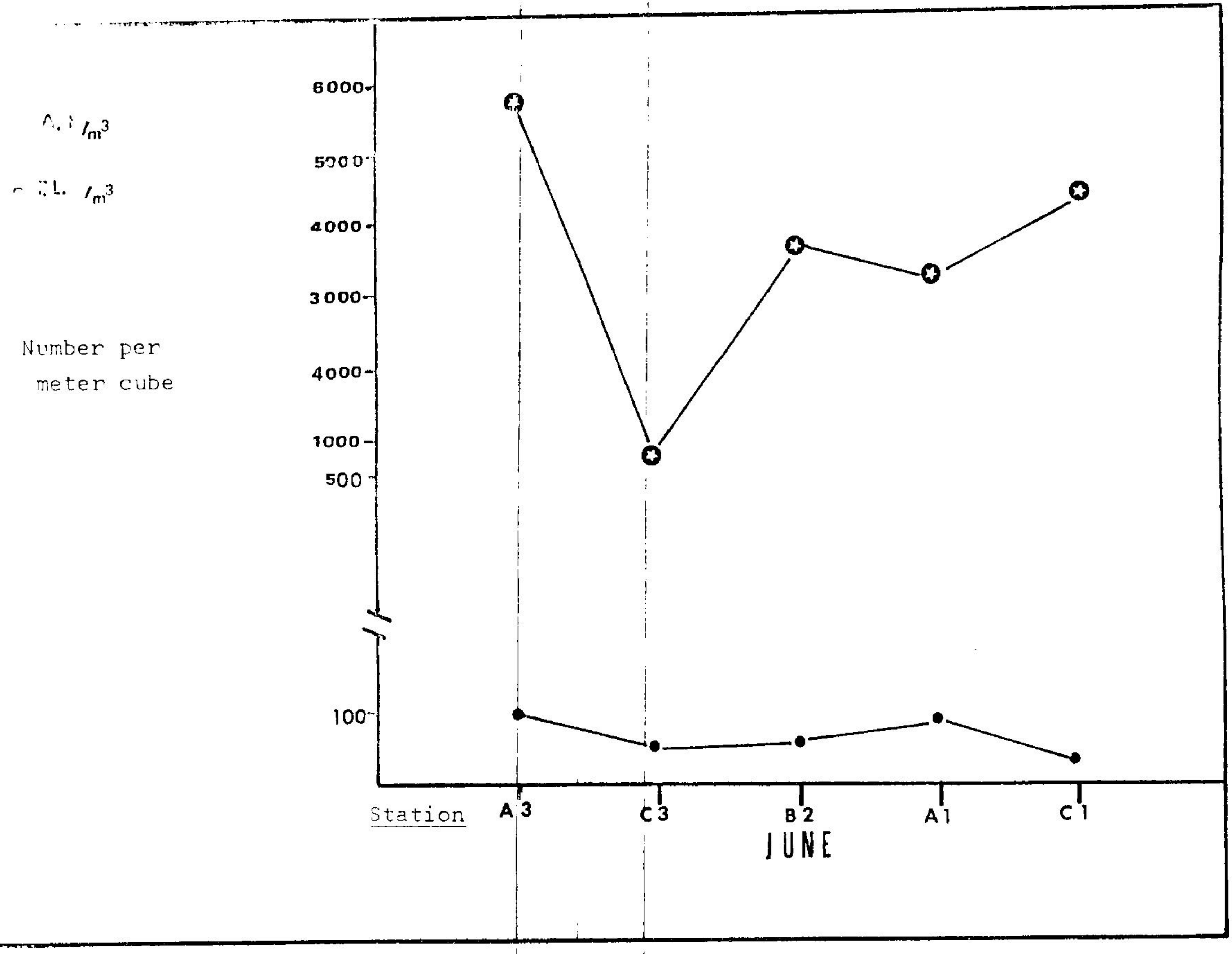

A.I /m3
L. /m3
Number per meter cube
6000
5000
4000
3000
4000
1000
500
100
Station
A3
C3
B2
A1
C1
JUNE

FIGURE #9. *A. tonsa* and Porcellanid larvae/m^3/station (September).

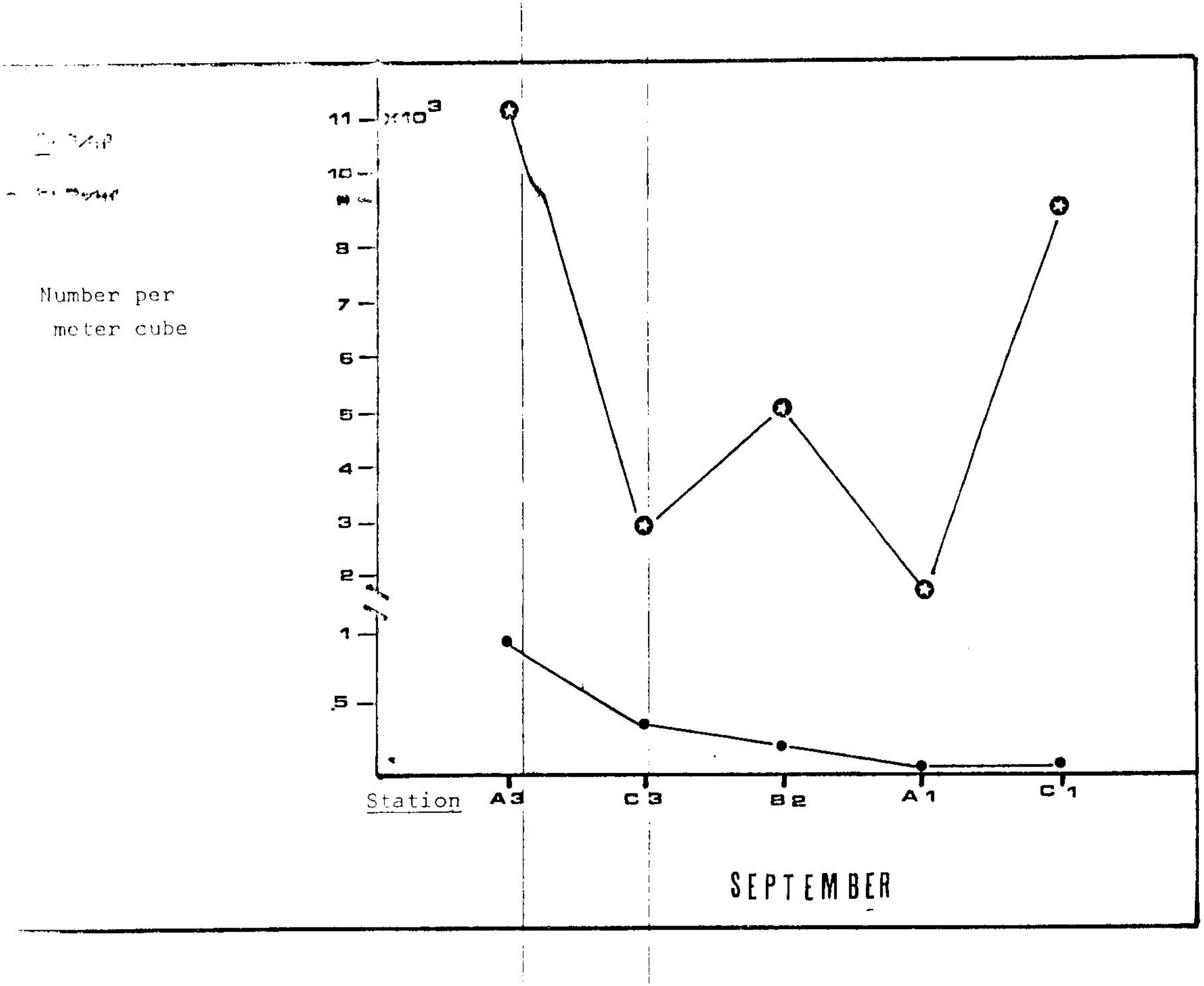
Number per
meter cube
11
10
8
7
6
5
4
3
2
1
.5
x10^3
Station
A3
C3
B2
A1
C1
SEPTEMBER

FIGURE #10. A. tonsa and Porcellanid larvae/m^3/station (October).

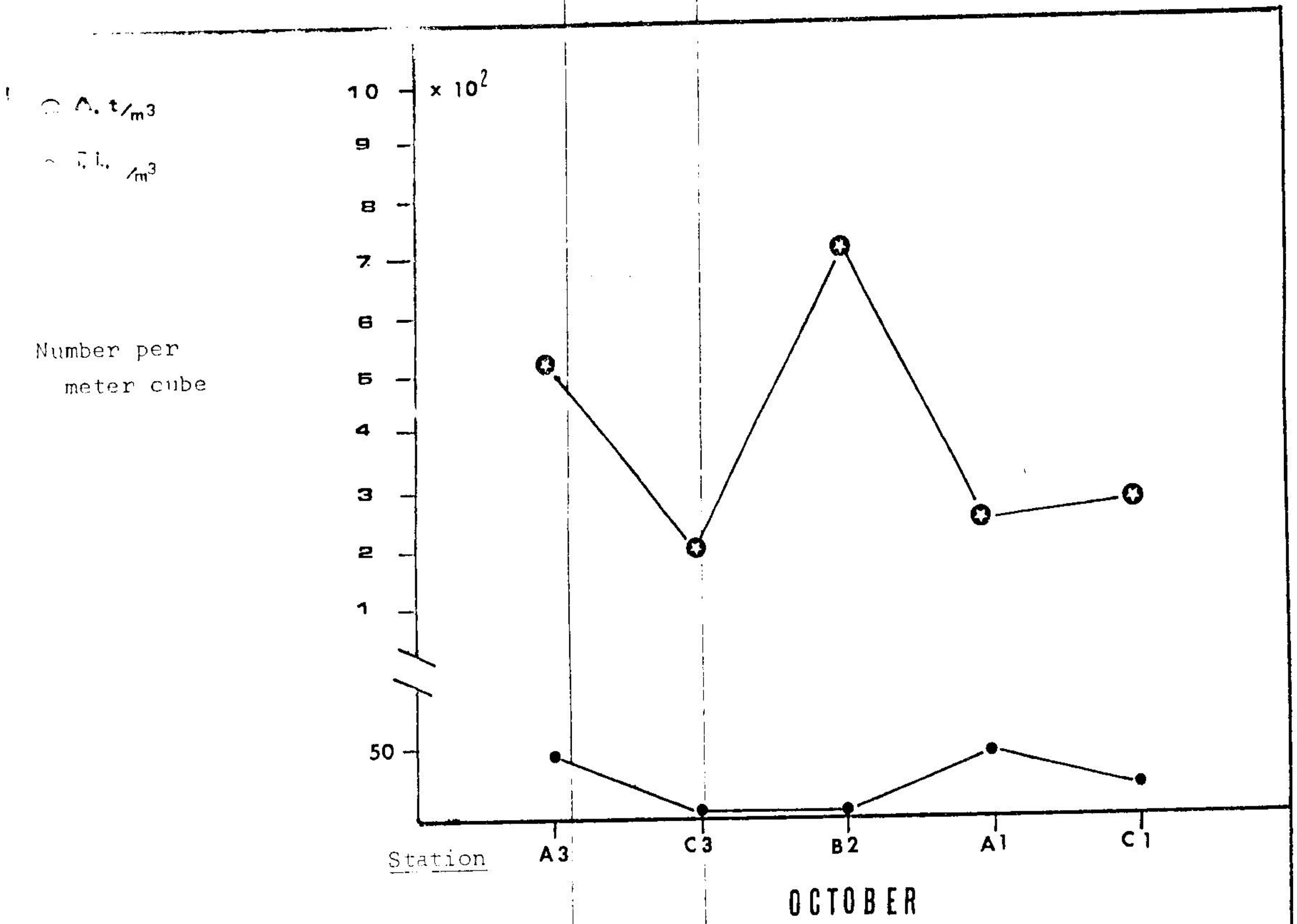

A. t/m^3
[illegible] /m^3
Number per meter cube
x 10^2
10
9
8
7
6
5
4
3
2
1
50
Station
A3
C3
B2
A1
C1
OCTOBER

FIGURE #11. *A. tonsa* and Porcellanid larvae/m^3/station (November).

FIGURE #12. *A*. *tonsa* and Porcellanid larvae/m^3/station (December).

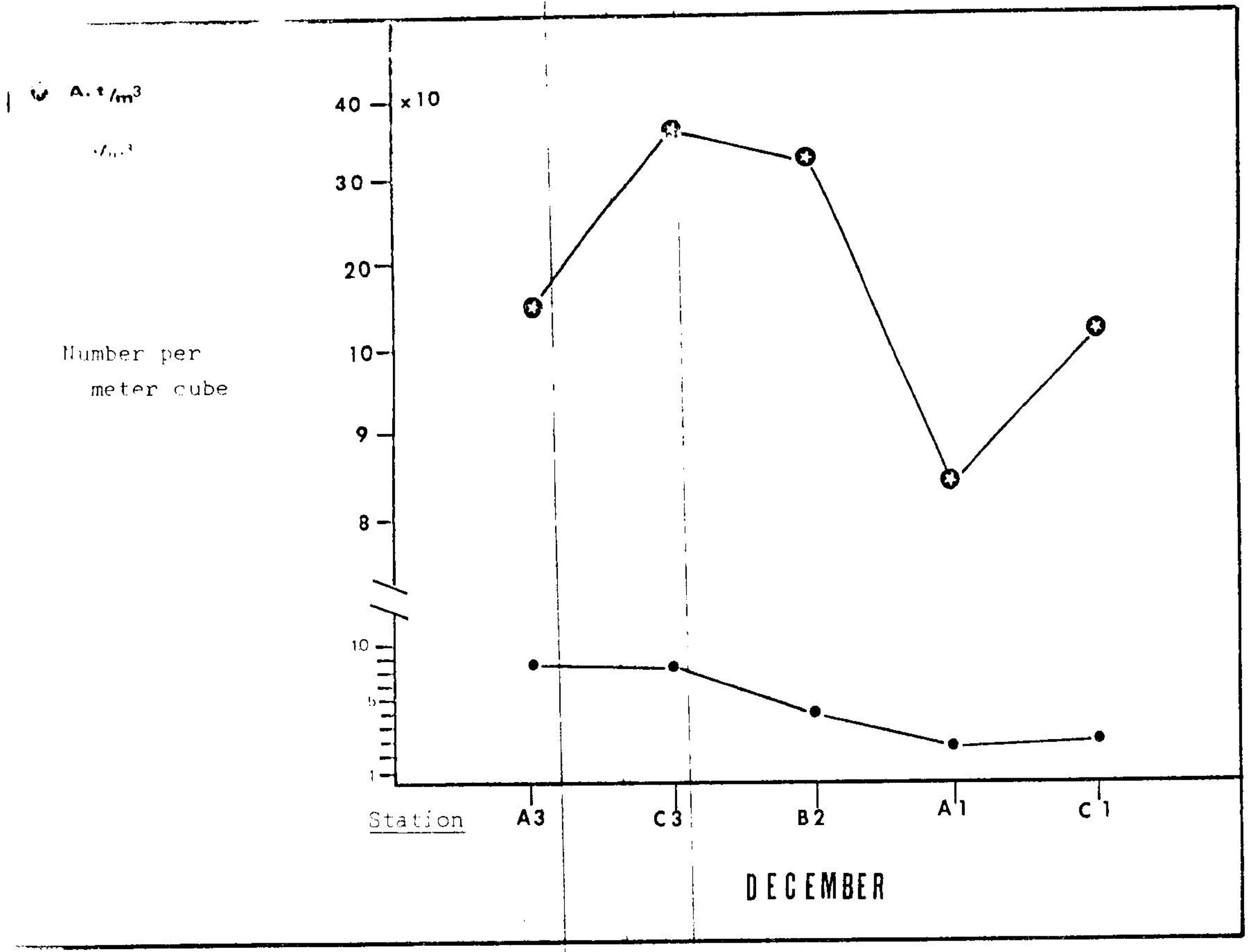

A. t /m3
/m3
Number per
meter cube
40
30
20
10
9
8
x 10
10
5
1
Station
A3
C3
B2
A1
C1
DECEMBER

FIGURE #13. *A. tonsa* and Porcellanid larvae/m^3/station (January).

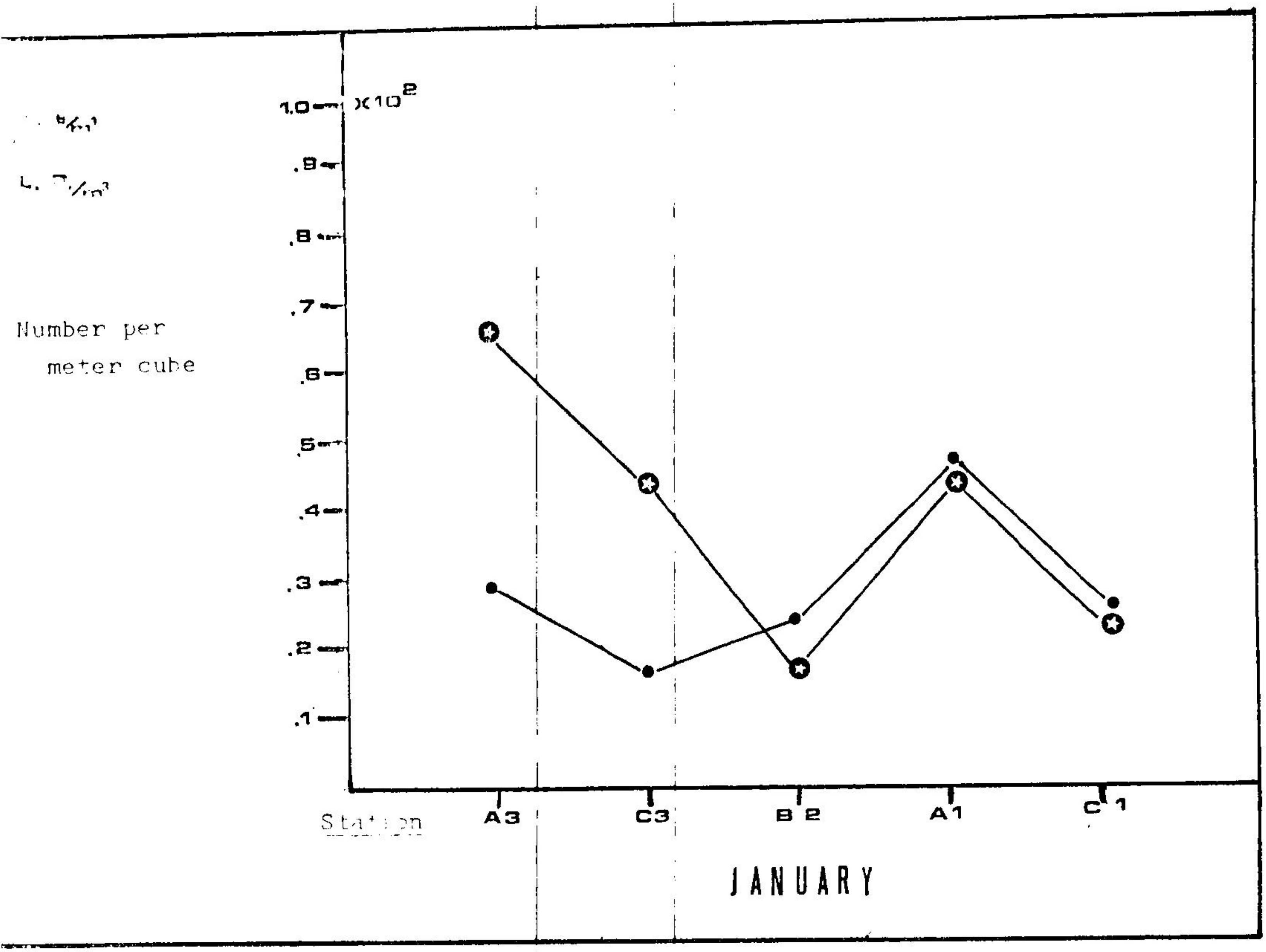
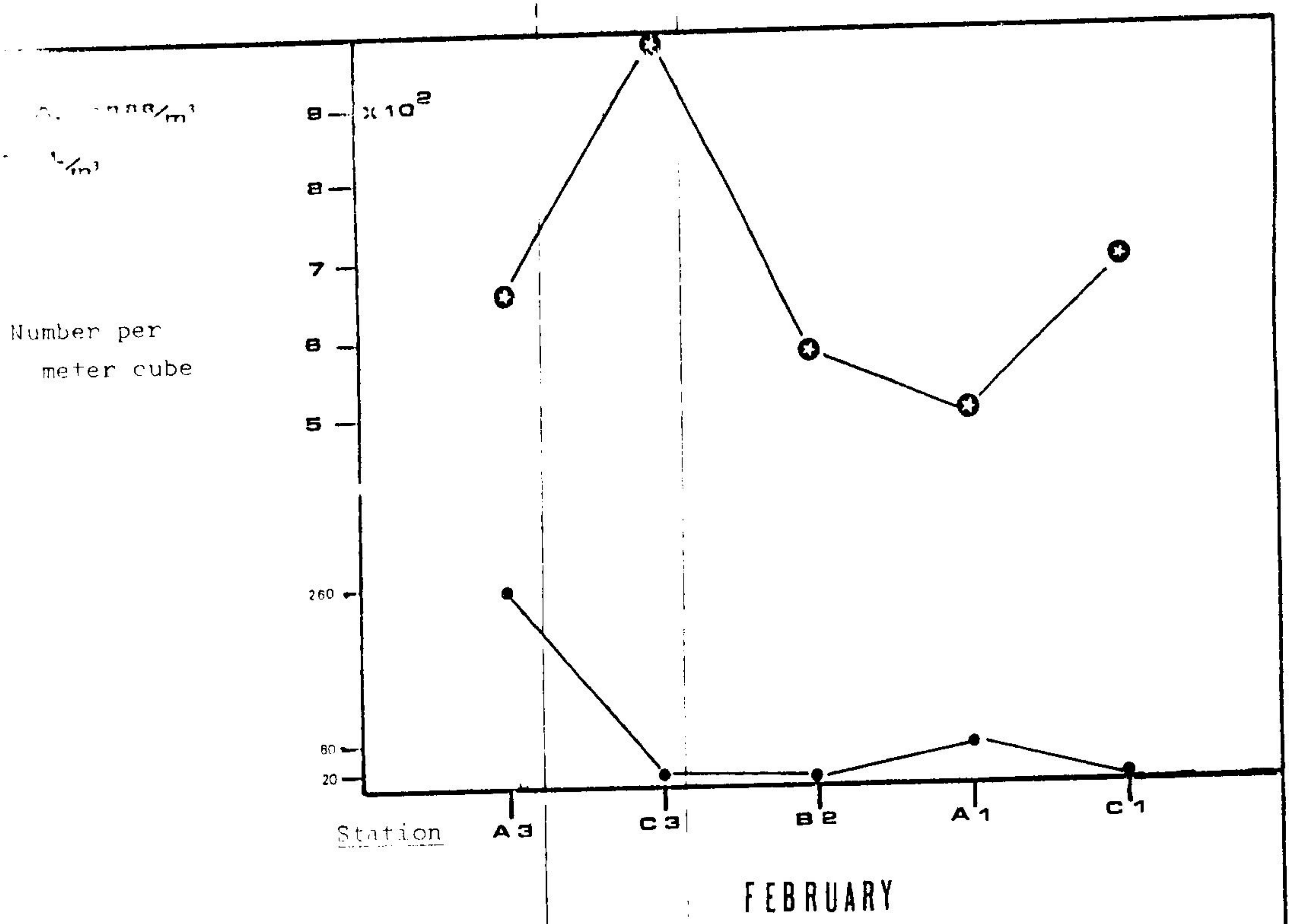

Number per
meter cube
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
X10²
Station
A3
C3
B 2
A1
C 1
JANUARY

FIGURE #14. *A tonsa* and Porcellanid larvae/m^3/station (February)

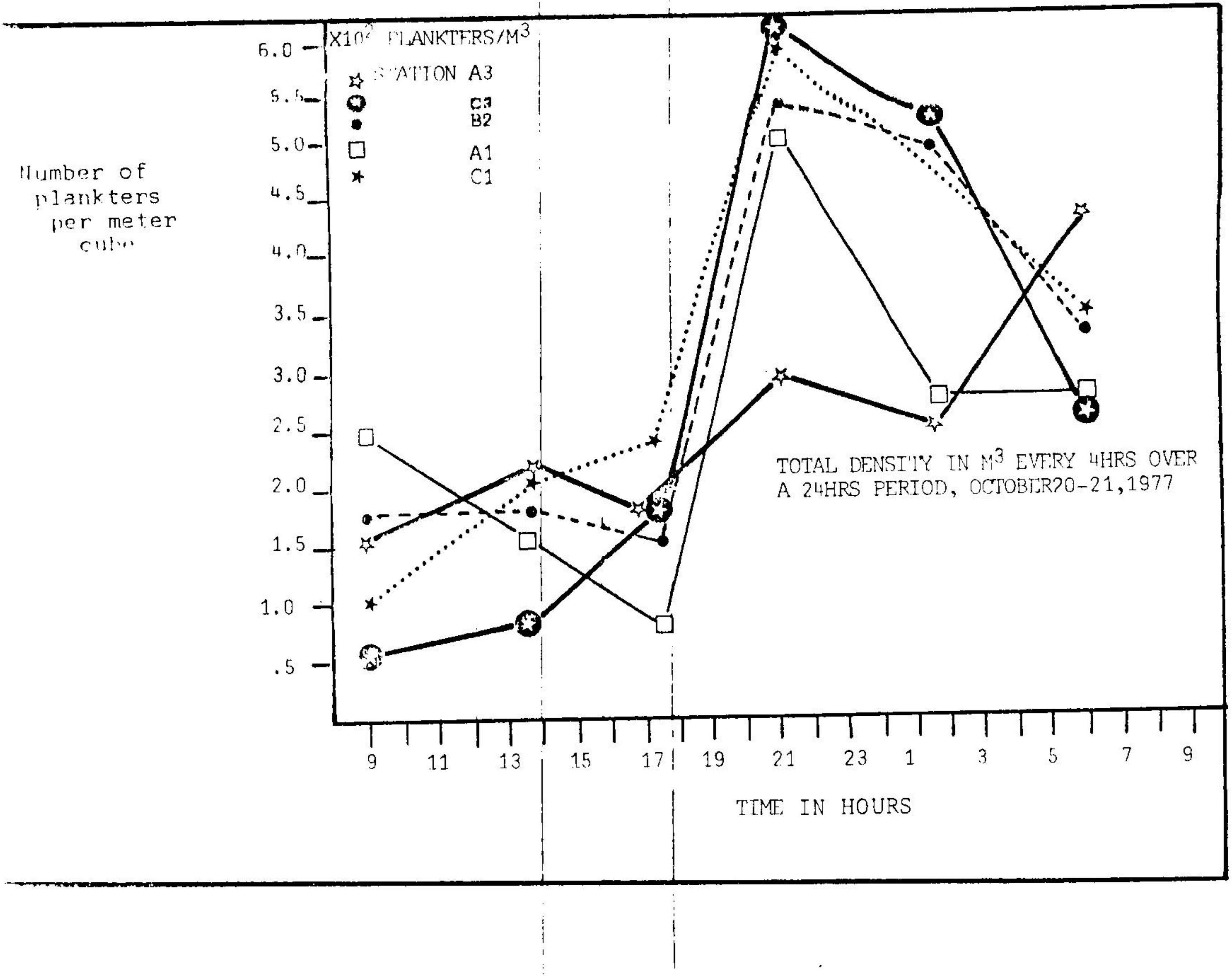

Number per
meter cube
9
x 10^2
8
7
6
5
260
60
20
Station
A3
C3
B2
A1
C1
FEBRUARY

the following pattern can be observed. Although greater fluctuations are seen for each station, Station A-3 gets the highest density values for both A. tonsa and porcellanid larvae, and Station C-1 the lowest. There seems to be no apparent pattern found for Stations C-3, B-2 and A-1. The total density of Acartia tonsa and porcellanid larvae for each month of the year, can be seen of Figure #5. The same three peaks observed in Figure #4 can be seen here for A. tonsa, although not as clear for porcellanid larvae. High and low population densities of A. tonsa coincide with high and low population densities of porcellanid larvae, indicating that they possibly have no direct influence on each other.

On October 20-21, 1977 plankton tows were made every four hours for twenty-four hours. Figure #15 shows the results of such sampling period. It is clear that the plankton density rose drastically during the evening of the 20th. This rise in density could be attributed to planktonic vertical migration. It is a well-known fact that most planktonic members of a community rise from deeper waters during nighttime and then return to deeper waters during daytime.

Wind piling of water masses is also suspected. As the waters are piled up against land, so are the plankters contained in this water, making them attain higher densities in this locality. If the wind blows from the southeast, as it usually does at the lagoon, it covers the path along

FIGURE #15. Total Plankton/m^3 for 24 hr. Study
October 20-21, 1977.


TOTAL DENSITY IN M³ EVERY 4HRS OVER
A 24HRS PERIOD, OCTOBER20-21,1977
Number of plankters per meter cube
X10² PLANKTERS/M³
STATION A3
C3
B2
A1
C1
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
9
11
13
15
17
19
21
23
1
3
5
7
9
TIME IN HOURS

Stations C-1, B-2, and A-3 (Figure #3). If the wind is continuous, it may push surface water against Station A-3. If this process prevails for a considerable amount of time, water as well as plankton may be concentrated around Station A-3. Since the lagoon is shallow it seems more probable that water piling should account for the increase in plankton densities.

During the month of February 1978, a series of four samples were taken on the outside of the channel, which connects the lagoon with the open sea (see Figure #16). Table #2 shows the species composition outside the channel. It is clear that the plankton species density in the neritic waters outside the Laguna Joyuda is higher than that for the lagoon. The question raised is why there is such a big difference in species diversity between the lagoon and the sea waters immediately outside the lagoon. A possible explanation might be the following.

If we take into consideration that the lagoon is: (a) rather small body of water; (b) that it is vertically as well as longitudinally homogeneous, (matter which will be discussed later under temperature and salinity), as shown by the salinity and temperature data; (c) that the ctenophore is a top effective predator; and (d) that Acartia is the only copepod present, we have a consistent framework that can serve as an explanation. For example, A. tonsa is found dominating all over the lagoon. This fact, coupled

TABLE #2. PLANKTONIC COMPOSITION OF THE IMMEDIATE WATERS OUTSIDE THE LAGUNA JOYUDA

Acartia lilljeborgii

Acartia spinata

Acartia tonsa

Centropages furcatus

Lucifer faxoni

Corycaeus subulatus

Corycaeus amazonicus

Corycaeus sp.

Temora turbinata

Sagitta sp.

Oikopleura sp.

Oithona oculata

Oithona plumifera

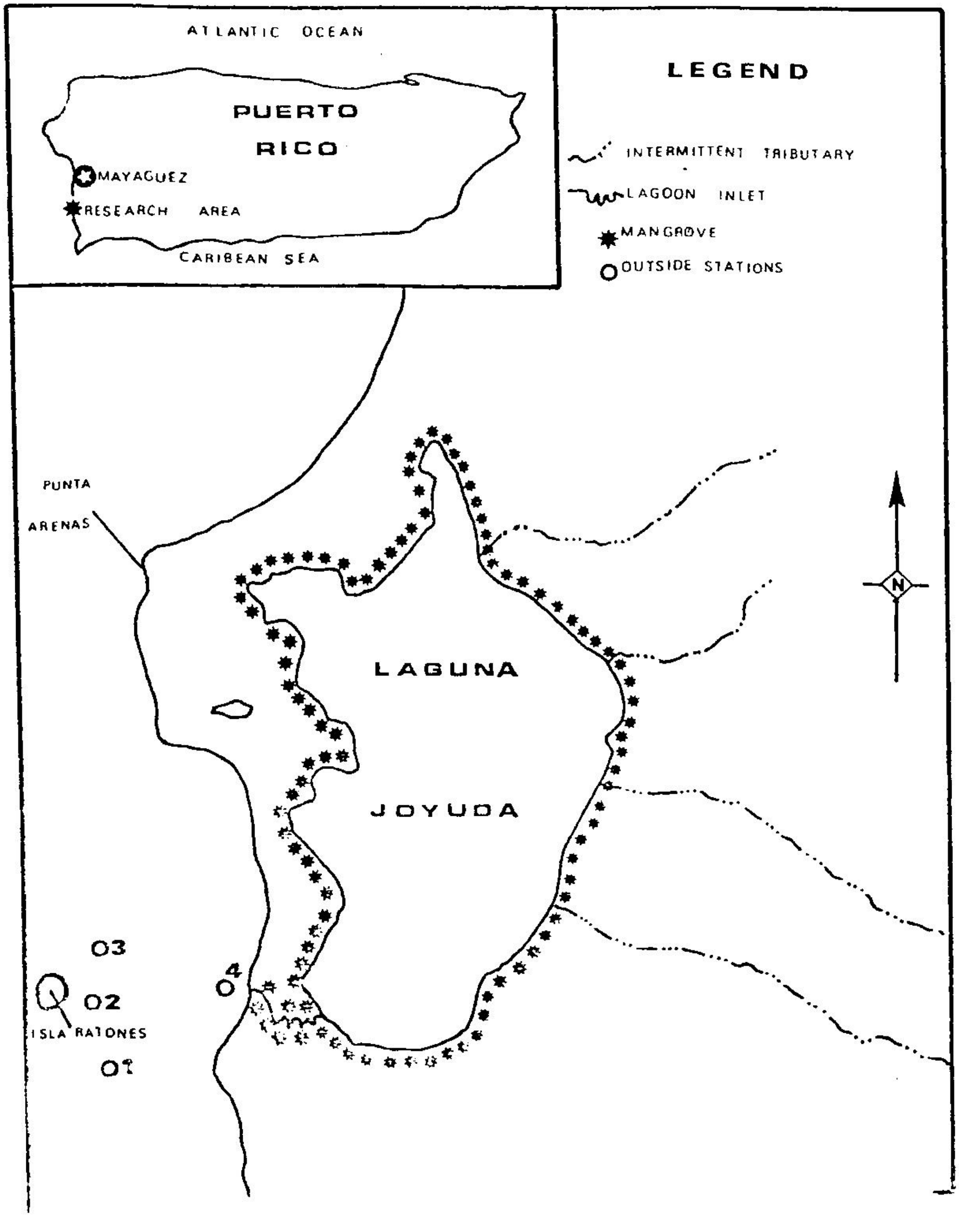
Euterpina acutifrons

Paracalanus parvus

Paracalanus crassirostris

Paracalanus aculeatus

FIGURE #16. Channel and Outside Stations.

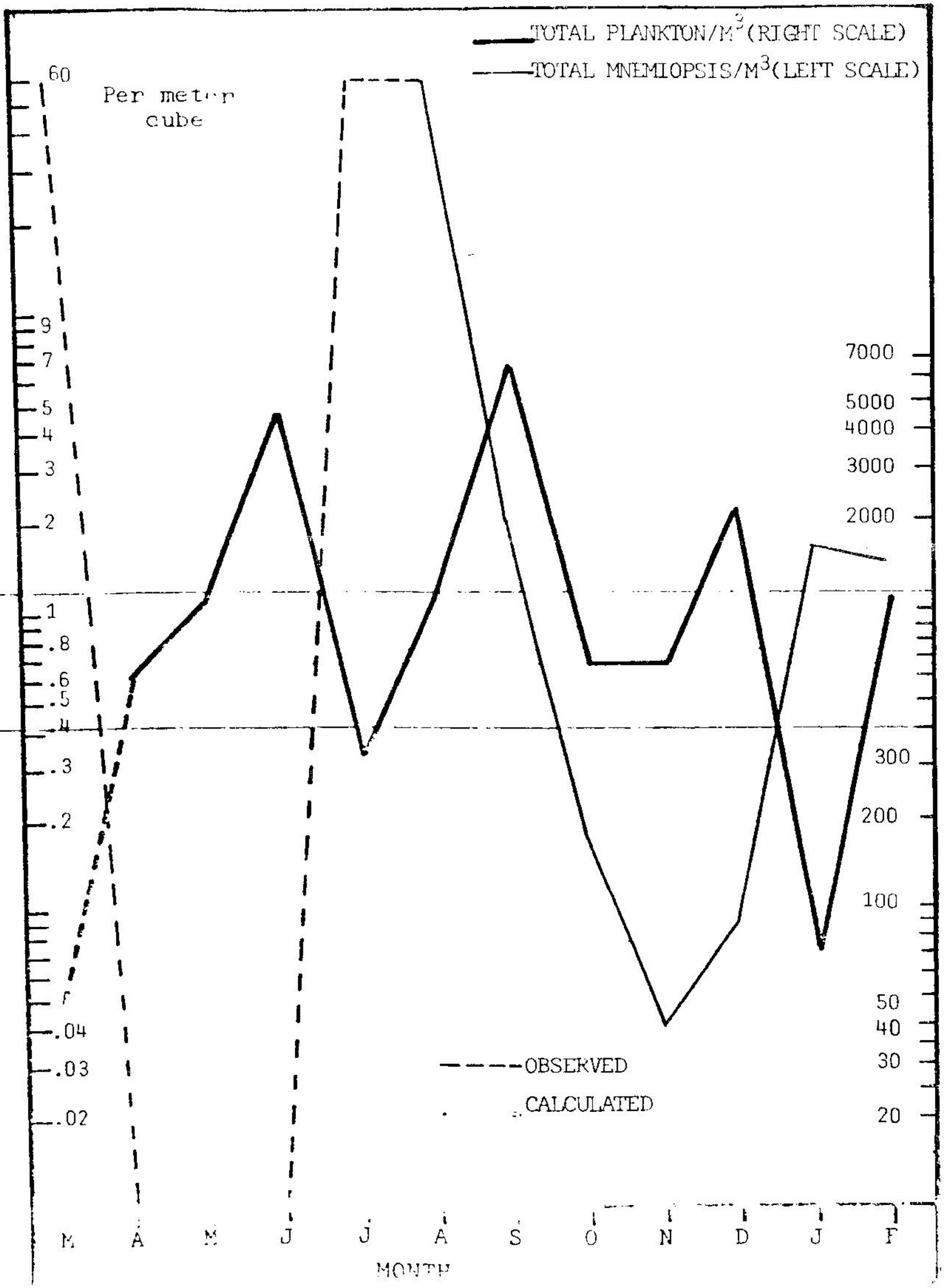

ATLANTIC OCEAN
PUERTO RICO
MAYAGUEZ
RESEARCH AREA
CARIBEAN SEA
LEGEND
INTERMITTENT TRIBUTARY
LAGOON INLET
MANGROVE
OUTSIDE STATIONS
PUNTA ARENAS
LAGUNA JOYUDA
N
3
2
1
4
ISLA RATONES

to the homogeneity of the lagoon, indicated that there is no provision of other hideouts in the lagoon for other copepods to evade the effective competition of A. tonsa; therefore, the latter can eliminate other copepod species in the lagoon. A. tonsa has been the object of study by González (1973), Barlow (1952), Ketchum (1951), and it is known that A. tonsa has very high reproduction rates, which makes it possible for them not just to occupy the lagoon system but to maintain an endemic population in the lagoon. The effectiveness of A. tonsa as an outstanding competitor can be corroborated by the fact that, when the ctenophore populations increase in the lagoon and A. tonsa populations decrease (which would leave space available for other copepod species), no other copepod species are seen to flourish. This brings an apparent contradiction with the theory that: "Local species diversity is directly related to the efficiency with which predators prevent the monopolization of the major environmental requisites by one species", Paine (1966). However, the Laguna Joyuda seems to have much simpler predator prey relationships. Another possible fact that may contribute to the low species diversity present is that the channel which connects the lagoon with the open sea is very narrow and shallow, providing somewhat of a physical barrier (refer to channel flow analysis). In addition, a biological barrier to zooplankton may be provided by a coral reef and a Thalassia bed system immediately outside the channel.

Planktonic organisms which have to pass through these systems in order to go into the lagoon may effectively be reduced by predation.

Throughout the year, the ctenophore Mnemiopsis gardeni was present, attaining bloom proportions on several occasions. The density range of Mnemiopsis/m^3 found in this study was from 0 to 60/m^3. The largest density of the ctenophore was observed for the month of March. The values for this month are higher than 60 individuals/m^3. As shown in Figure #16, the graph was extrapolated according to the highest number of ctenophores actually counted in the field, which was 60/m^3. During the months of April, May, and June 1977, no ctenophores were found in the samples at all. Figure #17 shows the general trend exhibited by the ctenophore population throughout the year in addition to the fluctuations in density per cubic meter of the ctenophore Mnemiopsis and total number of plankters throughout a 12 month study. The general trend exhibited by the graph is that, as the population of ctenophores increase, the other smaller members of the planktonic community show a population decrease. Mnemiopsis is a carnivore and its importance as a zooplankton predator has been studied by Williams and Baptist (1966); Bishop (1867); Burrell (1968); Miller (1970) and Kremer (1975). Little attention has been focused on the biological importance of the ctenophore as people have been concerned more about how to solve the sampling difficulties of catching smaller

FIGURE #17. Total Plankton and Total Mnemiopsis per cubic meter per month.


TOTAL PLANKTON/M^3(RIGHT SCALE)
TOTAL MNEMIOPSIS/M^3(LEFT SCALE)
Per meter cube
60
9
7
5
4
3
2
1
.8
.6
.5
.4
.3
.2
.04
.03
.02
7000
5000
4000
3000
2000
300
200
100
50
40
30
20
OBSERVED
CALCULATED
M
A
M
J
J
A
S
O
N
D
J
F
MONTH

plankters when the ctenophore is around. The extreme range in density of the ctenophore throughout the year was observed to be from close to 0, (0.1/m^3) to up to 100/m^3. We must compare these numbers with the ones presented by Kremer in 1978 in a study on the distribution and abundance of the ctenophore <u>Mnemiopsis leidyi</u> in Narragansett Bay, Rhode Island. She reports having observed very low numbers in winter of 1 to 2 <u>Mnemiopsis</u>/$10^4 m^3$ and up to 100/m^3 during the summer. This study reveals that very high numbers of the ctenophore (up to 100/m) were observed during the months of March, July and August and very low numbers for the months of April, May and June. Questions such as the following may arise: Are the smaller plankton going down because of ctenophore predation, or is it that the phytoplankton is not available to the zooplankton, so the latter can not flourish, as well as the ctenophore that predate on them? These questions can be answered, at least partially, if we consider that the phytoplankton does not tend to be a limiting factor in the lagoon. The water has a very deep green color all year round. The fact this water has a deep green color indicating large amounts of phytoplankton may not be significant as the phytoplankton present could not be readily available to the zooplankton.

It has been pointed out (Kremer, 1976) that <u>Mnemiopsis</u> is not only important for its predation on zooplankton, but it also plays a major role as nutrient recyclers in the water column. The impact on the turnover of nitrogen and phosphorus in the water column has been observed by Kremer (1976). She combined biomass estimates, determinations of weight-specific excretion rates at various temperatures (Kremer, 1975a), and estimates of average ambient nutrient levels in the water during a period of ctenophore abundance. Her calculations demonstrate that the daily excretion of ammonia by *Mnemiopsis leidyi* alone accounts for more than 1% of nutrients in the water column. Because of their low organic content (dry weight of 3.4% of live weight; Kremer, 1976), ctenophores do not lock up nutrients in structures, but act more as nutrient pumps, rapidly recycling materials into the water column. Kremer, indicates also that nearly half of the ctenophore nitrogen excretion may not be immediately available to the algae. Bacterial action presumably may regenerate these compounds, thus gradually returning the nutrients to the system in a more usable form. In this sense, the ctenophore have both an immediate and an indirect, positive feedback to the phytoplankton. Another way of stimulating phytoplankton growth is by predation on the zooplankton community of the system. They just filter the water as they go by, eating almost all they can find in their path; although observations done by the following researchers: Lebour, 1922; Bishop, 1967; Burrell, 1968; Frazen, 1970; Rowe, 1971 and Hiruta, 1974, tend to indicate ctenophores prefer the smaller zooplankton. Bishop

(1967) shows that the comb jellie can account for 52% of the mortality of Acartia tonsa (in vitro measurements).

Therefore, the data presented herein tends to exhibit an inverse proportional relationship between the ctenophore Mnemiopsis gardeni and the smaller members of the planktonic communities.

Acartia tonsa (Dana), a calanoid copepod of world-wide distribution has been found to tolerate water temperatures from -1°C to 32°C (González, 1973). Jeffries (1962) attributed the success of A. tonsa to such a wide array of environments, to its efficient osmoregulatory mechanism, which permits the animal to go into neritic waters and even into enclosed lagoons. Although during this investigation the temperature and salinity in the lagoon did not vary drastically as stated in the temperature and salinity section, previous investigators report extreme changes in both temperature and salinity. This could also imply that the Laguna Joyuda is a physically controlled system. Such systems are characterized by drastic changes in its physical parameter like temperature and salinity. Sharp drops or rises in one or both of the latter can make a population become totally or partially eliminated. Although the changes were not observed during this study, they seem very likely to occur if we consider the physical characteristics discussed in the following sections.

González (1974) informs that the invasion of A. tonsa, a successful species in areas of high predictability, into a physically controlled environment (a process of low probability according to Slobodkin and Sanders, (1969)), does not seem to have resulted in the elimination of other populations of this species from temperate and boreal regions. He also mentions the fact that A. tonsa has developed a rather complex physiological adaptability to conditions in predictable environments that has made it possible, through successional interaction with congeneric forms, to tolerate the new conditions without totally replacing others.

Observations conducted in the Laguna Joyuda show that A. tonsa is not just the dominant copepod, but the only one present, with the exception of a copepod of the genus Pseudocyclops found in beds of Ruppia maritima.

Even though A. tonsa is found dominating, which would imply that it is in a rather comfortable environment, it exhibits a size smaller than those found yet elsewhere. Table #3 shows the size in mm. for males and females at each of the five stations for each month. Dash lines represent samples not taken. Even though the statistical population is small (10 specimens, 5 males and 5 females from each sample were measured), the general trend is that of A. tonsa being smaller than in any other place. If we compare the standard deviations obtained for the lagoon with those of Bahia Fosforecente and Narragansett Bay, the results

TABLE #3 ACARTIA TONSA SIZE IN MM/MONTH AT EACH OF THESE FIVE STATIONS

	A3		C3		B2		A1		C1	
	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE	MALE	FEMALE
MARCH	-	-	-	-	-	-	-	-	-	-
APRIL	0.65	0.64	0.60	0.68	0.66	0.70	0.68	0.76	0.65	0.71
MAY	0.66	0.78	0.67	0.74	0.66	0.71	0.66	0.79	0.76	0.76
JUNE	0.67	0.76	0.66	0.78	0.68	0.80	0.60	0.82	0.70	0.82
JULY	0.65	0.79	-	-	-	-	-	-	-	-
AUGUST	0.77	0.86	-	-	-	-	-	-	-	-
SEPTEMBER	0.67	0.87	0.70	0.83	0.72	0.88	0.66	0.81	0.67	0.84
OCTOBER	0.65	0.74	0.67	0.77	0.65	0.80	0.70	0.83	0.65	0.80
NOVEMBER	0.65	0.72	0.62	0.78	0.70	0.78	0.66	0.74	0.63	0.76
DECEMBER	0.66	0.75	0.68	0.80	0.65	0.81	0.63	0.77	0.66	0.76
JANUARY	0.62	0.73	0.65	0.68	0.63	0.74	0.61	0.68	0.64	0.74
FEBRUARY	0.74	0.81	0.72	0.76	0.69	0.80	0.74	0.81	0.75	0.82
MEAN	0.64	0.77	0.66	0.76	0.67	0.78	0.65	0.78	0.68	0.78
STD. DEV.	0.043	0.065	0.035	0.054	0.028	0.056	0.044	0.048	0.048	0.043

appear to be close (Table #4). The animals were measured from the front tip of the cephalotorax to the tip of the caudal ramus, in order to compare values with those obtained previously by González using the same method.

Salinity

Variations in salinity values (at 12 cm. from the surface) observed at Laguna Joyuda during this investigation are shown in Figure #8. Salinities were measured in the morning hours. The extreme range in salinity noted throughout the year was from 24 to 32°/$_{oo}$.

Salinity values increased from April to May; the waters becoming slightly less saline for a short period to increase again until August, as shown in Figure #18. From the month of September to January, 1977, the general trend is that of a slight drop in salinity. Another increase is observed for February.

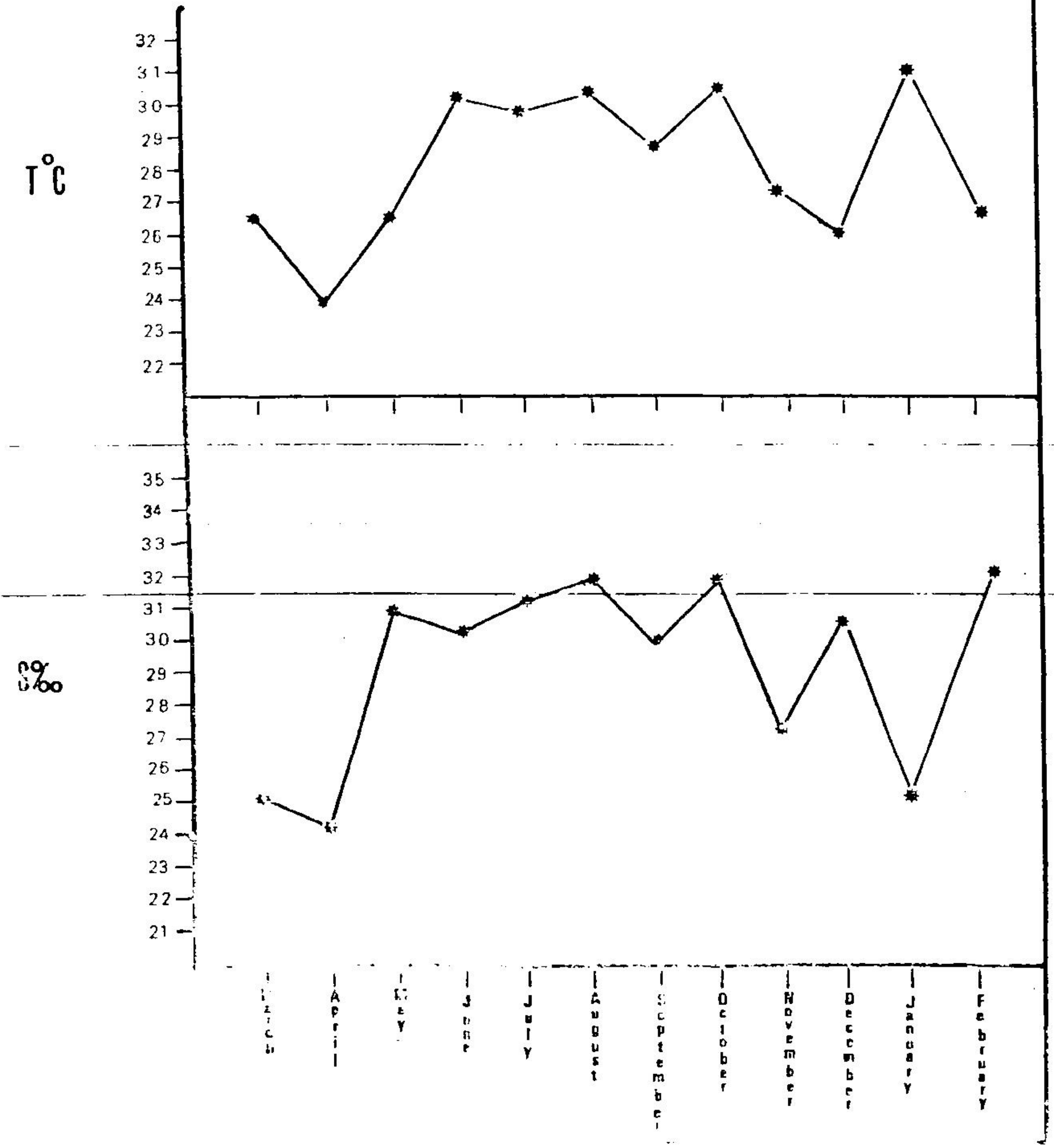
On October 20-21, 1977, a twenty-four hour study was conducted in which salinity was observed every hour, starting at 9 A.M., October 20, and ending at 9 A.M., October 21, 1977. Salinities (Figure #9) did not vary for that day, remaining around 29-30°/$_{oo}$.

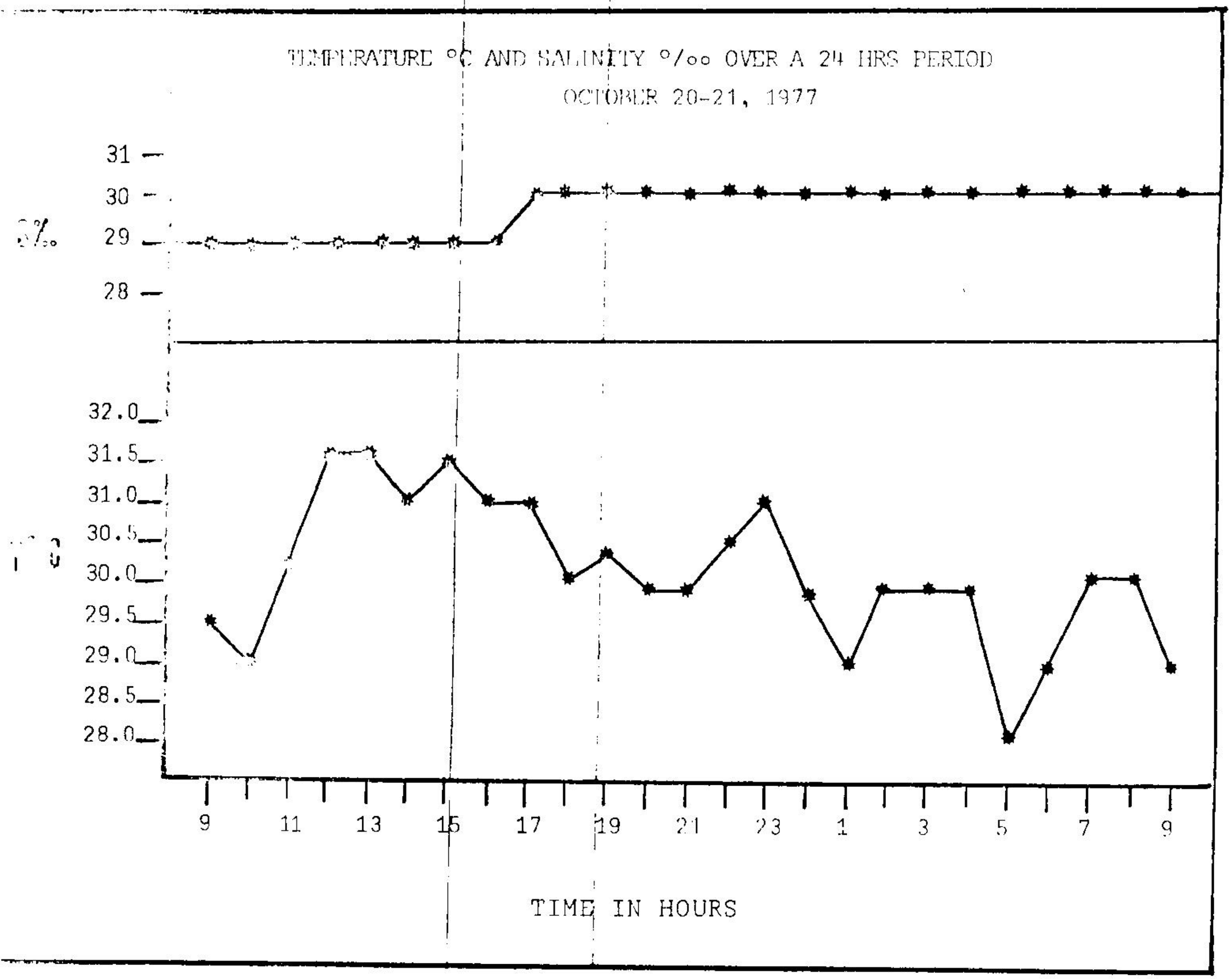
Figure #16 shows the channel that communicates the lagoon with open sea. Salinities of 34.0 °/$_{oo}$ were observed at the mouth of the channel (lagoon side) when the tide was coming in. On all other stations the salinity values were

TABLE #4 *ACARTIA TONSA* SIZE IN MM. FOR THREE DIFFERENT LOCALITIES

Temperature, C	Male Size (mm)	Standard Deviation	Female Size (mm)	Standard Deviation
NARRAGANSETT, R.I.				
20.0	1.26	0	1.27	0.08
1.0	-	-	1.28	0.01
2.5	1.20	0	1.28	0.08
1.0	1.17	0.04	1.32	0.06
3.0	1.18	0.03	1.28	0.04
7.0	1.15	0.05	1.28	0.03
14.0	1.08	0.05	1.00	0
21.2	0.98	0.07	1.09	0.08
22.0	0.90	0.03	0.836	0.02
20.5	0.93	0.06	0.98	0.08
BAHIA FOSFORECENTE, P.R.				
28.0	0.82	0.02	0.92	0.08
28.0	0.77	0.02	0.89	0.02
30.0	0.76	0.02	0.88	0.03
-	0.77	0.02	0.87	0.02
26.3	0.77	0.02	0.86	0.02
35.0	0.74	0.02	0.74	0.02
29.0	0.80	0.01	0.94	0.03
29.5	0.75	0.02	0.88	0.03
32.0	0.73	0.02	0.82	0.03
25.8	0.73	0.01	0.80	0.02
LAGUNA JOYUDA, P.R.				
23.9	0.65	0.02	0.070	0.04
26.0	0.68	0.04	0.76	0.03
30.1	0.66	0.03	0.80	0.02
28.7	0.69	0.02	0.84	0.02
30.1	0.68	0.03	0.78	0.03
27.2	0.65	0.03	0.76	0.02
26.1	0.66	0.19	0.78	0.20
24.9	0.63	0.01	0.71	0.03
29.8	0.65	0.0	0.79	0.0
30.4	0.77	0.0	0.86	0.0

FIGURE #18. Temperature °C and salinity $^{o}/_{oo}$ per month.


T°C
32
31
30
29
28
27
26
25
24
23
22
S‰
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
March
April
May
June
July
August
September
October
November
December
January
February



TEMPERATURE °C AND SALINITY °/oo OVER A 24 HRS PERIOD
OCTOBER 20-21, 1977

more or less (1 $^{o}/_{oo}$), constant for the day, the measurements taken.

Salinity vs. depth profiles were taken on several occasions. On August, 1977, at Station B-2 (Figure #3 for station location) the deepest of all five stations (1.5 m.) had the following values of 30.5, 30.2, 30.2 $^{o}/_{oo}$ at surface, .75 m. and 1.5 m., respectively. Lagoon water was slightly more saline at the surface but fairly constant throughout the water column. The same small change throughout the water column was observed again in November, 1977, with values of 26.8, 26.5, 26.5 $^{o}/_{oo}$ at surface, .75 m. and 1.5 m., respectively.

Previous investigators reported salinities which varied considerably with respect to the ones observed during this investigation. Erdman (1963) reported a fish kill at Laguna Joyuda caused by what he claimed to be natural stresses. He concluded that very low salinities were one of the factors which caused the fish kill, but gives no values for the salinity during that period. Pagan and Austin (1967) reported another fish kill thought to be caused by natural stresses; this time they considered that the most important factors were very high temperatures (35°C) and salinities of 43-44 $^{o}/_{oo}$. Bennett (1969) reported salinities of 35$^{o}/_{oo}$. Garcia (1976) and Carvajales (1976) reported salinities of 20-6 $^{o}/_{oo}$, respectively. Salinity measurements taken at Laguna Joyuda during this study indicate that the lagoon is homogeneous on a vertical and longitudinal plane. This is so because of the shallowness of the system (1.5 m) coupled with the continuous winds from the southeast which effectively mix the waters.

Temperature

Variations in surface water temperature observed at 12 cm. below surface at Laguna Joyuda during this research are shown in Figure 18, based upon temperatures measured during the morning. The mean range in temperature noted throughout the year was from 23.9 to 30.4°C, calculated from five station measurements for that day. Temperature data for this study (Figure #18) show the highest values occurred during the summer months of June, July and August. However, a high temperature of 30.4°C was observed in January.

On October 20-21, 1977, surface temperatures were observed every hour for twenty-four hours (see Figure #19); readings were initiated at 9 A.M. of the 20th, and ended at 9 A.M. on the 21st. The extreme range in temperature for that day was from 28.5 to 31.5°C. As expected, highest temperatures were observed during noontime, and the lowest temperatures early in the morning on the 21st.

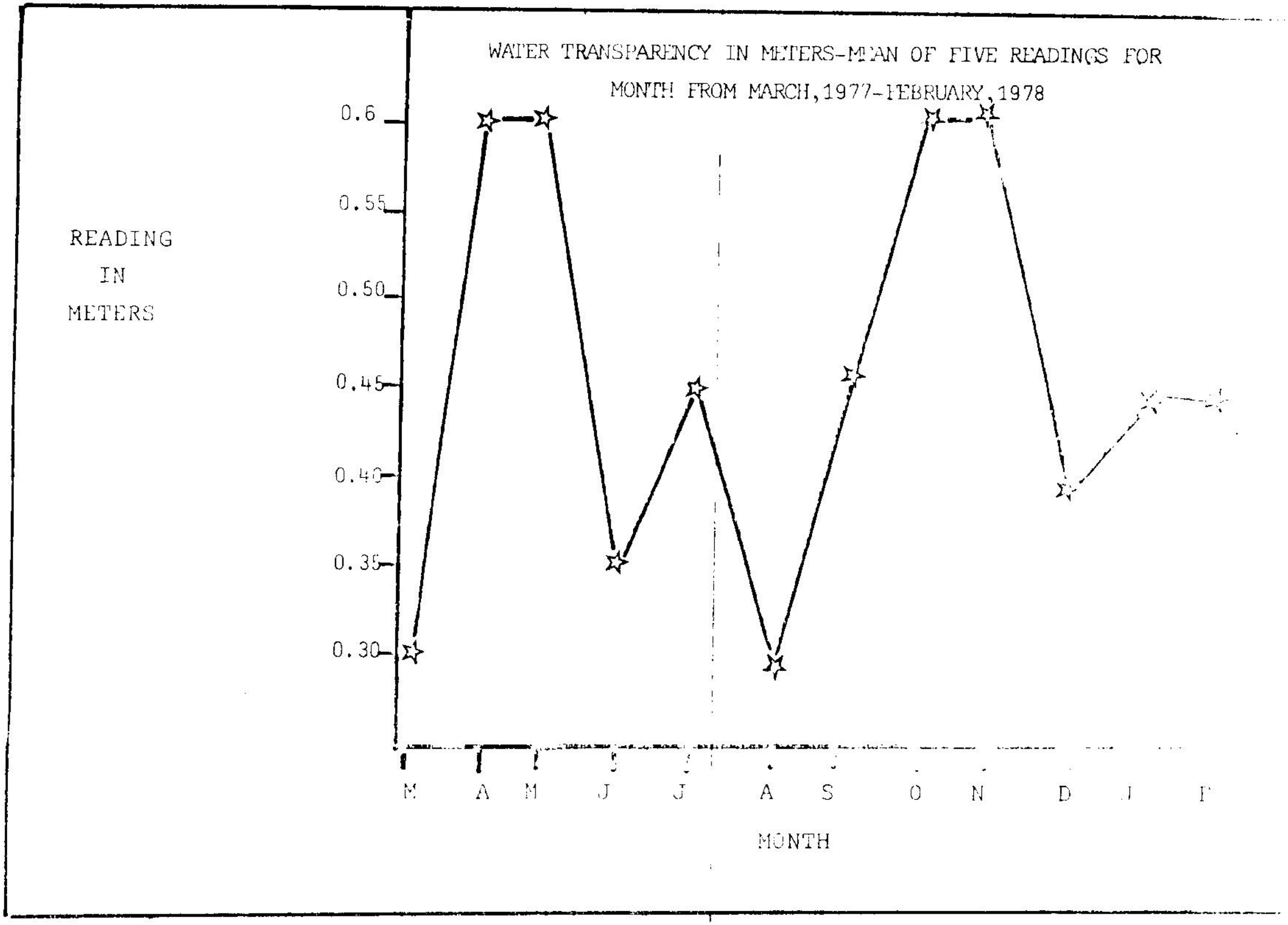
When temperature vs. depth profiles were taken, variations ranged from 0.0 to 0.8°C, indicating that the lagoon does not seem to be stratified in regards to temperature. Temperature-wise, sharp drops or rises were never observed indicating that the temperatures are fairly constant, which provides the biological populations with a less changing, more stable environment. Wind, again, plays a major role in maintaining the lagoon waters mixed. However, under certain circumstances the temperature of the waters may go up to 35°C and probably higher if low wind speeds blow for a series of days, together with the fact that very little rain pours down during the dry season. Although the rainwater itself cools the water to a certain extent, it is the long summer days with clear skies and little wind which are of major importance in raising the water temperature. Another factor to be considered is depth.

Figure #2 shows the bathymetry of the lagoon. Mean depth of the lagoon is 1.5 m. The shallowest part of the lagoon being on the east side and the deepest parts include two holes of 2.5 and 3.3 m on the northwest and west side of the lagoon. Therefore, the lagoon is fairly shallow. which makes it easier for the wind to mix the waters. The ratio of exposed surface to depth is rather large, 300 acres with a mean depth of 1.5 m. This exposes a lot of surface area to radiation which makes it easier to heat and cool.

Water Turbidity Measurements (Secchi Disk)

Amount of suspended matter in the water column is reported in Tables #6 through #17 and Figure #20. Extreme values noted throughout the year were from 0.3 to 0.6 m.

FIGURE #20. Water transparency.



WATER TRANSPARENCY IN METERS-MEAN OF FIVE READINGS FOR MONTH FROM MARCH,1977-FEBRUARY,1978

These values show very clearly the high amount of suspended matter in the water column. Although sediments and organic matter can be resuspended in the water column very easily by the turbulence created as a result of the wind and the shallowness of the lagoon, a big portion of this suspended material seems to be phytoplankton. The year-round deep green color of the water supports this assumption. The greatest turbidity was observed when winds were blowing up to 20 km/hr. This was also observed by Bennett (1969) who states that the highest values for turbidity were observed when water level was lowest and winds were blowing from the south or southeast. Winds from this direction cause the highest waves in the lagoon since they travel along the entire length of the lagoon. Bennett (1969) also reports that turbidity in the Laguna Joyuda is due primarily to resuspension of bottom sediments and does not necessarily reflect the rate of sediment influx from streams and swamps of the drainage basin.

Surface Current Analysis

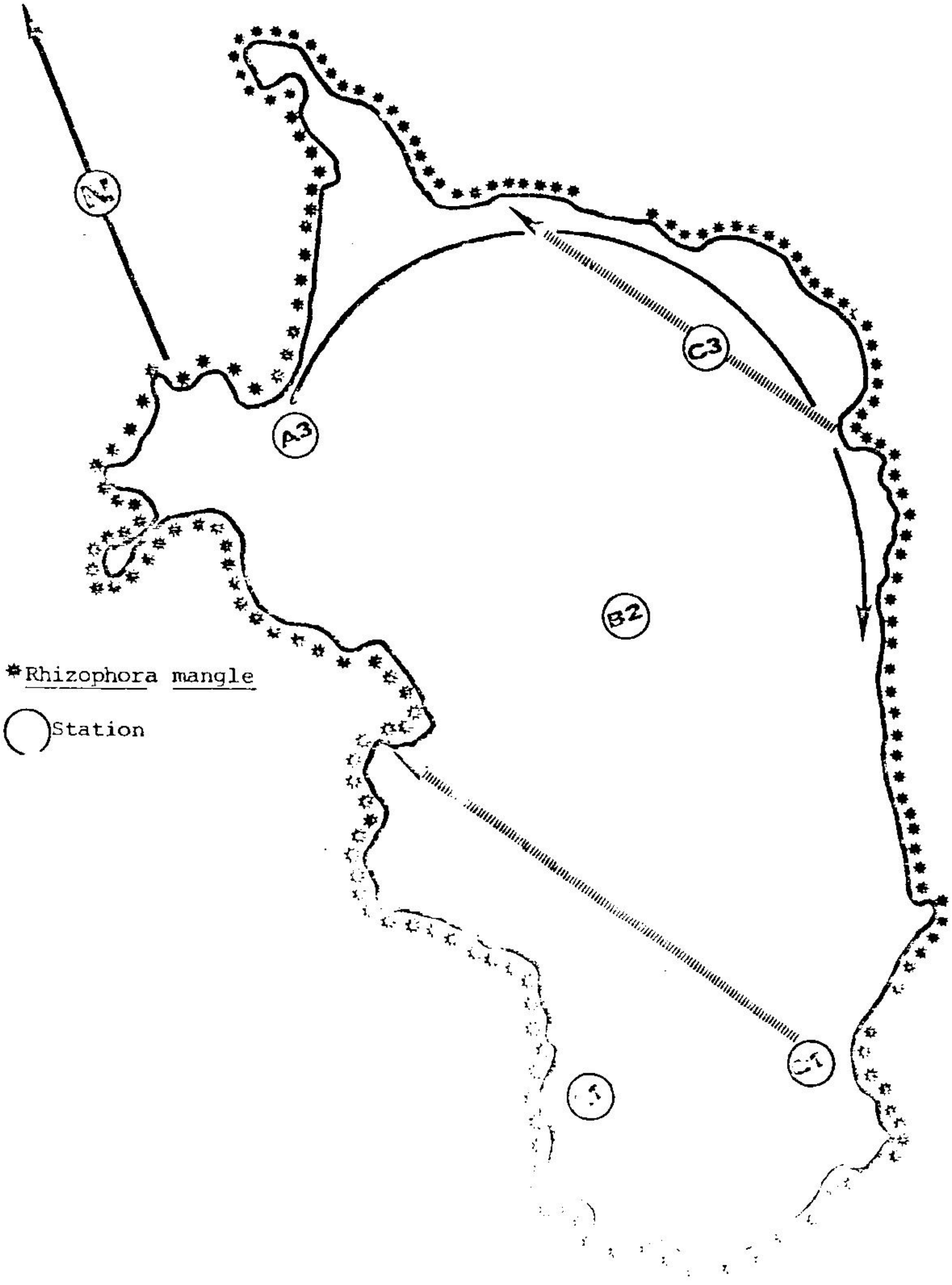
Surface currents were observed at Laguna Joyuda on two occasions in order to try to obtain information on the possible effects water currents may have on the distribution of the planktonic members of the lagoon. Table #1 shows the data obtained during October 20, 1977. Wind direction and waves formed were observed to come from the southeast (Table #24). Wind blowing from this direction is along the trajectory covered by Stations C-1, B-2, and A-3 (Figure #3).

Table #25 shows surface current velocities which varied from 0.05 to 0.1m/sec with wind speed ranging from 9.6 to 14.5 km/hr. These measurements were done in the morning. Afternoon measurements gave surface current speeds from 0.01 to 0.05 m/sec with wind velocities from 0.0 to 19.8 km/hr. Surface water seems to be piled up against Station A-3. No bottom current study was done. It is speculated, based on visual observations, that the water sinks and is deflected to the east towards Station C-3, or goes under and back towards the southeast (Figure #21).

Channel Flow Analysis

On March 5-6, flow measurements were done in the channel that connects the Laguna Joyuda with the sea. A flowmeter was placed in the water at .275 m. from the surface; the bottom was at .55 m. at that place, the deepest part of the channel. The mean depth of the latter is .35 m., with a width of 3 m. According to the tides predictment (Tide Tables 1978) of March 5-6, 1978, for Puerto Rico, this is the closest place to the lagoon in which tides are actually measured. The maximum range for that day was .445 m., however, data obtained by placing two tide gauges, one in the mouth of the channel (lagoon side; Figure #3) and the other

FIGURE #21. Possible path for currents.
Lighter broken lines represent surface current.
Black line represents bottom current.


A3
C3
B2
C1
*Rhizophora mangle
Station

tide gauge at the north end of the lagoon, showed that during the twelve hours the tides were observed on hourly intervals, the tide only rose 0.3 cm.

Water movement observations at the channel were started at 2000 on March 5; however, the place we were stationed did not provide a suitable place for observations. At 2200 the flowmeter was installed at a new site close to the mouth of the channel (sea-side). Water movement was zero. Objects floating in the surface were still and sediment stirring provided indications that bottom water was also still. At 0030, water started moving in the channel; however, it alternated directions. This was observed for 2 hours at the end of which the flow was almost unidirectional into the lagoon. At 0447 of March 6, actual measurement was started using a floating object, two rods, and a chronometer. Table #25 provides the time and velocity in m/sec from 0447 to 0851 hrs. Velocities ranged from 0.0 m/sec when water was still at 2200 on March 5 to up to 0.16m/sec at 0620 on March 6.

From the observed data, it can be estimated that the amount of water coming into the lagoon for that period was $3468m^3$. This amount of water was not very significant if we consider the total volume of water in the lagoon, which is $1.82X10^6m^3$.

Tide restriction is attributed to a sill at the mouth of the lagoon (sea-side). As seen from the dimensions of the channel in the first paragraph of this section, it is a shallow and narrow channel which cannot provide the lagoon with any considerable amount of sea water. Thus, the channel itself is a physical barrier for the organisms in the lagoon, making it hard for them to go out of the lagoon. Likewise, plankton and nutrients from the sea are prevented from coming into the lagoon in any considerable quantities.

Dissolved Oxygen

Dissolved oxygen (D.O.) vs. depth measurements data are shown in Tables #15 and #17. Instrument malfunction prevented a large set of data. The values for December, 1977, and February, 1978, indicate extreme range in dissolved oxygen for these two months (1.4 to 6.6 mℓ/ℓ, respectively). A value of 6.6 mℓ/ℓ was the highest, but normal D.O. values ranged close to 5 mℓ/ℓ. The value of 1.4 mℓ/ℓ could be attributed to deoxygenated water coming from a pigpen near the station (A-1) or to other unknown causes. At a temperature of 26.1°C and a salinity of $30.8^{\circ}/_{oo}$, the water should exhibit saturation at 4.66 (Richard and Corwin, 1956). Therefore, according to their method of calculation, at the surface we get a value of 94.4% saturation, at mid-depth 85.8% saturation, and at the bottom (1.5 m.) 77.68% saturation, which shows that the lagoon is rather well oxygenated. However, under special cases, like the ones enumerated below, oxygen deficient water can become a limiting factor. A combination of two or more of these factors could make oxygen unavailable to the aquatic organisms of the lagoon.

1. High water temperatures.
2. High salinities (43-44°/$_{oo}$).
3. High densities of phytoplankton. Late at night, just before sunrise, the oxygen utilization by the phytoplankton can be so high that the water can become deoxygenated. This also happens in fishponds with an overload of nutrients due to careless fertilizer management.
4. Low grazing pressure of zooplankton on the phytoplankton.
5. Resuspension of anoxic sediments by heavy rains.
6. Predation of ctenophores on the zooplankton indirectly stimulating high phytoplankton populations.

CONCLUSIONS

As a result of the observations made from March, 1977, to February, 1978, the following conclusions could be drawn:

1. The zooplankton of the Laguna Joyuda has been described for the first time.

2. The species diversity in the lagoonal system is very low.

3. *Acartia tonsa* is the dominant holoplankter.

4. The voracious predator *Mnemiopsis* is present in the lagoon and, from time to time, attains bloom proportions. It is capable of controlling *A. tonsa* populations.

5. The species present in the plankton are endemic to the Laguna Joyuda.

6. Plankton-wise, the Laguna Joyuda is a very unique system, having a rather simple predator-prey relationship.

7. It seems that the planktonic populations are biologically accommodated, although physically controlled conditions are not disregarded.

8. Temperature and salinity measurements indicate that the lagoonal system is homogeneous on both planes. This homogeneity provides no hideouts for other copepods to exploit, which facilitates the exclusion of other species by *Acartia tonsa*.

9. Physical parameters, mainly temperature and salinity, were not limiting factors in regulating the populations of the planktonic community. However, the physical characteristics (area, depth, location, etc.) tend to imply that these factors could become limiting ones if:

(a) temperature goes up to 35°C,

(b) salinity goes up to 33-44°/$_{oo}$,

(c) salinity goes down to 6°/$_{oo}$.

APPENDIX A

Data from March, 1977 through February, 1978. Includes Tables #6 to #16.

TABLE #5 MARCH, 1977, THROUGH FEBRUARY, 1978

	STATION					
MARCH	A-3	C-3	B-2	A-1	C-1	Mean
Temperature- C	25.9	26.4	26.1	26.9	26.7	26.4
Salinity-%	25	25	25	25	25	25
Secchi-m	0.3	0.3	0.3	0.3	0.3	0.3
Acartia tonsa-/m^3	-	-	-	-	-	-
Porcellanid Larvae/m^3	-	-	-	-	-	-
Wet Biomass-ml	-	-	-	-	-	-
Total Plankton/m^3	-	-	-	-	-	-
A. tonsa size in mm	-	-	-	-	-	-
A. tonsa size in mm	-	-	-	-	-	-

- Not observed for that month

DA ARCH 1977 THROUGH FEBRUARY 1978

APRIL	A-3	C-3	STATION B-2	A-1	C-1	Mean
Temperature- C	23.9	23.9	23.9	23.9	24.0	23.9
Salinity-‰	24	24	24	24	24	24
Secchi-m	0.6	0.6	0.6	0.6	0.6	0.6
Acartia tonsa/m^3	600	534	465	436	257	458
Porcellanid Larvae/m^3	3	8	6	20	1	8
Wet Biomass-ml	80.8	55.3	78.6	43.0	61.5	65.8
Total Plankton/m^3	764	807	574	487	426	612
A. tonsa size in mm	0.65	0.60	0.67	0.68	0.66	0.65
A. tonsa size in mm	0.65	0.68	0.70	0.76	0.72	0.65

TABLE #7 OM MARCH 1977 THROUGH FEBRUARY 1978

MAY	STATION A-3	C-3	B-2	A-1	C-1	Mean
Temperature- C	26.0	26.0	26.0	26.0	26.2	26.0
Salinity-%	28	32	31	31	32	30
Secchi-m	0.6	0.6	0.6	0.6	0.6	0.6
Acartia tonsa/m^3	1017	383	260	2114	766	908
Porcellanid Larvae/m^3	42	43	102	14	37	47
Wet Biomass-ml	16.0	8.0	19.0	8.0	7.5	10.2
A. tonsa size in mm	0.67	0.67	0.66	0.66	0.77	0.69
A. tonsa size in mm	0.79	0.74	0.71	0.80	0.76	0.76

TABLE #8 OM MARCH 1977 THROUGH FEBRUARY 1978

	STATION					
JUNE	A-3	C-3	B-2	A-1	C-1	Mean
Temperature- C	29.9	30.6	30.8	31.0	30.5	30.1
Salinity-%	31	31	31	29	30	30
Secchi-m	0.4	0.4	0.4	0.4	0.4	0.4
<u>Acartia tonsa</u>/m^3	5773	862	3647	3194	4483	3591
Porcellanid Larvae/m^3	98	43	55	94	35	63
Wet Biomass-ml	16.0	6.0	11.0	12.0	9.0	10.8
Total Plankton/m^3	5946	950	3766	50	50	3726
<u>A. tonsa</u> size in mm	0.67	0.67	0.69	0.61	0.70	0.67
<u>A. tonsa</u> size in mm	0.77	0.79	0.80	0.82	0.83	0.80

TABLE #9 DATA FROM JULY 1977

JULY	STATION A-3	C-3	B-2	A-1	C-1	X
Temperature- C	29.5	29.5	30.0	30.2	30.0	29.8
Salinity-%	31.5	31.0	31.0	31.0	31.5	31.2
Secchi-m	.45	.45	.45	.45	.45	.45
Acartia tonsa/m^3	178.8	-	-	-	-	-
Porcellanid Larvae/m^3	24.3	-	-	-	-	-
Wet Biomass/ml	18.0	-	-	-	-	-
Total Plankton/m^3	327.6	-	-	-	-	-
A. tonsa	.65	-	-	-	-	-
A. tonsa	.79	-	-	-	-	-

- Not observed

TABLE 10 DATA FROM AUGUST 1977

	STATION					
AUGUST	A-3	C-3	B-2	A-1	C-1	X
Temperature- C	30.5	31.0	30.0	30.0	30.3	30.4
Salinity-‰	32.0	32.0	32.0	33.0	32.0	32.0
Secchi-m	0.3	0.3	0.3	0.3	0.3	0.3
Acartia tonsa/m^3	-	-	-	386.4	-	-
Porcellanid Larvae/m^3	-	-	-	369.7	-	-
Wet Biomass/ml	-	-	-	20.0	-	-
Total Plankton/m^3	-	-	-	1167.4	-	-
A. tonsa	.78	-	-	-	-	-
A. tonsa	.86	-	-	-	-	-

- Not observed

TABLE #11 DATA FROM SEPTEMBER 1977

	STATION					
SEPTEMBER	A-3	C-3	B-2	A-1	C-1	X
Temperature- C	28.5	29.0	29.0	28.5	28.3	28.7
Salinity-%	31.0	30.0	30.0	30.0	30.0	30.2
Secchi-m	.45	.45	.45	.45	.45	.45
Acartia tonsa/m^3	11,144.9	2841.3	5092.2	1191.26	8715.8	5941
Porcellanid Larvae/m^3	930.4	369.7	185.3	57.2	84.31	325.38
Wet Biomass/ml	76.0	19.0	34.0	-	13.0	-
Total Plankton/m^3	12,813.4	3435.5	5405.4	2048.2	9121.3	6564.8
A. tonsa	.67	.71	.73	.67	.68	.69
A. tonsa	.88	.83	.88	.82	.84	.85

- Not observed

DATA FROM OCTOBER 1977

	STATION					
OCTOBER	A-3	C-3	B-2	A-1	C-1	X
Temperature- C	30.1	30.2	30.5	31.1	31.0	30.1
Salinity-%	32.0	32.0	32.0	32.0	32.0	32.0
Secchi-m	0.6	0.6	0.6	0.6	0.6	0.6
Acartia tonsa/m^3	235.1	200.9	723.6	514.8	278.5	390.6
Porcellanid Larvae/m^3	444.4	27.2	24.5	405.1	108.4	235.9
Wet Biomass/ml	19.5	3.0	5.0	26.0	6.0	11.9
A. tonsa	0.66	0.68	0.65	0.70	0.72	0.68
A. tonsa	0.74	0.77	0.81	0.84	0.81	0.79

TABLE #12 DATA FROM NOVEMBER 1977

NOVEMBER	STATION A-3	C-3	B-2	A-1	C-1	X
Temperature- C	27.0	27.0	27.3	27.3	27.6	27.2
Salinity-‰	27.0	27.5	27.5	27.5	27.0	27.3
Secchi-m	.6	.6	.6	.6	.6	.6
Acartia tonsa/m^3	374.1	306.8	605.3	1722.2	292.2	660.12
Porcellanid Larvae/m^3	5.8	0.0	4.45	0.0	0.0	2.07
Wet Biomass/ml	1.0	0.8	1.3	16.0	0.8	3.98
Total Plankton/m^3	422.5	318.2	648.3	1754.4	304.4	689.5
A. tonsa	0.65	0.62	0.70	0.67	0.63	0.65
A. tonsa	0.73	0.78	0.79	0.74	0.77	0.76

TABLE #14 DATA FROM DECEMBER

DECEMBER	STATION A-3	C-3	B-2	A-1	C-1	X
Temperature- C	25.8	26.2	26.2	26.2	26.2	26.1
Salinity-%	29.0	29.0	32.0	32.0	32.0	30.8
Secchi-m	0.4	0.4	0.4	0.4	0.4	0.4
Dissolved Oxygen ml/l						
surface	5.3	3.7	3.5	4.7	4.6	4.4
mid-depth	4.2	3.5	3.7	4.7	4.0	4.0
bottom	4.5	3.6	4.2	1.4	4.4	3.6
Acartia tonsa/m^3	1497.8	3667.9	3180.3	834.7	1062.0	2782.0
Porcellanid Larvae/m^3	87.9	82.5	48.1	24.1	28.4	54.2
Wet Biomass/ml	11.0	12.0	8.0	3.5	6.0	8.1
Total Plankton/m^3	1654.1	3868.5	3334.4	958.7	1213.3	2205.8
A. tonsa	0.66	0.69	0.65	0.64	0.67	0.66
A. tonsa	0.76	0.81	0.81	0.78	0.77	0.78

FROM JANUARY 1978

	STATION					
JANUARY	A-3	C-3	B-2	A-1	C-1	X
Temperature- C	24.6	24.9	25.0	25.0	25.3	24.96
Salinity-%	30.0	30.0	31.5	31.5	32.0	31.0
Secchi-m	0.45	0.45	0.45	0.45	0.45	0.45
Acartia tonsa/m^3	63.3	44.9	24.2	45.5	25.0	40.58
Porcellanid Larvae/m^3	29.7	16.0	14.2	47.1	26.9	26.8
Wet Biomass/ml	3.6	2.5	2.5	2.3	5.0	3.18
Total Plankton/m^3	95.3	63.2	44.3	98.2	54.8	71.2
A. tonsa size in mm	0.63	0.66	0.63	0.61	0.65	0.64
A. tonsa size in mm	0.73	0.69	0.75	0.68	0.74	0.72
Mnemiopsis/m^3	-	-	-	-	1.63	-

- Not observed

TABLE #16 DATA FROM FEBRUARY 1978

	STATION					
FEBRUARY	A-3	C-3	B-2	A-1	C-1	X
Temperature- C	26.3	26.3	26.4	26.6	26.9	26.5
Salinity-%	32.0	32.0	32.0	32.0	32.0	32.0
Secchi-m	0.45	0.45	0.45	0.45	0.45	0.45
Dissolved Oxygen ml/l						
surface	6.2	6.4	6.0	6.5	5.4	6.1
mid-depth	5.6	6.2	6.5	6.2	5.0	5.9
bottom	5.8	6.2	6.6	6.2	5.4	6.0
Acartia tonsa/m^3	653.83	998.72	581.5	682.46	504.2	684.9
Porcellanid Larvae/m^3	258.6	18.19	122.5	43.84	6.34	89.89
Wet Biomass/ml	20.0	3.0	7.0	6.0	2.5	7.7
Total Plankton/m^3	1201.32	1358.38	1033.2	1149.6	808.23	1110.15
Mnemiopsis/m^3	0.915	0.17	0.93	2.6	2.79	1.48
Phyllorhyza/m^3	0.048	1.81	0.21	0.71	0.027	0.433

APPENDIX B

Data of twenty-four hour study for October 20-21, 1977. Includes Tables #17 to #22.

TABLE #17 L[illegible] 24-HOUR STUDY FOR OCTOBER 20-21, 1977

OCTOBER	STATION A-3	C-3	B-2	A-1	C-1
Temperature- C	29.5	29.8	29.4	29.4	29.0
Salinity-°/₀₀	29.0	29.0	29.0	29.0	29.0
Secchi-m	0.5	0.8	0.7	0.6	0.6
Acartia _tonsa_/m^3	235	200	723	514	278
Porcellanid Larvae/m^3	444	27	24	405	108
Wet Biomass/ml	19.5	3.0	28.0	26.0	6.0
Total Plankton/m^3	734	252	797	1057	548
Time	0915	0945	1000	1020	1040

TABLE [illegible] DATA OF 24-HOUR STUDY [illegible] OCTOBER 20-21, 1977

OCTOBER	STATION A-3	C-3	B-2	A-1	C-1
Temperature- C	30.3	30.5	30.5	30.3	30.5
Salinity- °/oo	29	29	29	29	29
Secchi-m	0.4	0.5	0.5	0.4	0.4
Acartia tonsa/m^3	288	228	448	402	323
Porcellanid Larvae/m^3	696	52	58	180	1539
Wet Biomass/ml	56	5.5	6.0	-	160
Total Plankton/m^3	1041	331	648	707	1892
Time	1305	1329	1345	1402	1416

DATA OF 24-HOUR STUDY FOR OCTOBER 20-21, 1977

OCTOBER		STATION			
	A-3	C-3	B-2	A-1	C-1
Temperature- C	30.5	31.0	30.5	30.5	30.5
Salinity-°/oo	30	30	30	30	30
Secchi-m	0.5	0.5	0.5	0.6	0.5
Acartia tonsa/m^3	580	207	40	321	861
Porcellanid Larvae/m^3	230	535	892	88	36
Wet Biomass/ml	-	36.0	76.0	-	11.5
Total Plankton/m^3	867	809	1192	437	968
Time	1703	1723	1732	1752	1807

TABLE #20 DATA OF 24-HOUR STUDY FOR OCTOBER 20-21, 1977

OCTOBER	STATION A-3	C-3	B-2	A-1	C-1
Temperature- C	29.9	29.9	29.9	30.0	30.0
Salinity-°/oo	30	30	30	30	30
Secchi-m	*	*	*	*	*
Acartia tonsa/m^3	485	4584	2506	1886	5761
Porcellanid Larvae/m^3	374	474	1481	332	363
Wet Biomass/ml	57.0	32.0	90.0	25.0	13.0
Total Plankton/m^3	926	5185	4201	2407	6399
Time	2056	2114	2135	2151	2225

* No measurements were done at night.

TABLE #21 -HOUR STUDY FOR OCTOBER 20-21, 1977

OCTOBER	STATION A-3	C-3	B-2	A-1	C-1
Temperature- C	29.9	30.0	30.0	29.9	29.9
Salinity-°/oo	30	30	30	30	30
Acartia tonsa/m^3	1707	3921	4110	967	-
Porcellanid Larvae/m^3	455	343	165	230	-
Wet Biomass/ml	47.0	29.5	19.0	13.0	-
Total Plankton/m^3	2337	4462	4623	1279	-
Time	0052	0118	0136	0157	-

- Sample not taken

TABLE #22 [illegible] OF 24-HOUR STUDY FOR OCTOBER 20-21, 1977

	STATION				
OCTOBER	A-3	C-3	B-2	A-1	C-1
Temperature- C					
Salinity-$^{\circ}/_{oo}$					
Acartia tonsa/m^3	1285	1870	976	548	1268
Porcellanid Larvae/m^3	347	33	170	635	57
Wet Biomass/ml	28.0	11.0	20.0	37.0	18.5
Time	0606	0625	0638	0656	0712
Mnemiopsis/m^3	-	-	-	15	-

- Not observed

APPENDIX C

TABLE #23 WIND SPEED DATA FOR OCTOBER 20, 1977

From	To	Speed km/hr	Direction
1052	1101	9.6 - 12.9	S.E.
1101	1111	9.6 - 12.9	S.E.
1111	1118	11.2 - 14.5	S.E.
1118	1124	11.2 - 14.5	S.E.
1124	1150	11.2 - 14.5	S.E.
1150	1157	11.2 - 14.5	S.E.
1157	1204	8.0 - 11.2	S.E.
1515	1530	16.1 - 19.3	S.E.
1550	1557	11.2 - 14.5	S.E.
1557	1603	9.6 - 11.2	S.E.
1603	1609	9.6 - 12.9	S.E.
1609	1615	6.4 - 9.6	S.E.
1615	1631	6.4 - 8.0	S.E.
1651	1654	4.9 - 6.4	S.E.
1654	1703	6.4 - 8.0	S.E.
1703	1706	0 - 0	
1706	1714	0 - 0	
1714	1751	0 - 0	

TIDE DATA FOR OCTOBER 20, 1977
Readings in Centemeters

Time	Reading
0948	37.5
1042	38.0
1133	37.5
1150	37.7
1258	37.7
1351	37.7
1450	37.8
1550	38.0
1719	38.0
1946	38.0
2220	37.8
0020	37.8
0120	37.6
0220	37.4
0520	37.6
0620	37.4
0720	37.0

TABLE #24 ACE CURRENT DATA FOR OCTOBER 77

Angle	Time	Time Difference (sec)	Distance Traveled by Drogue (m)	Velocity (m/sec)
325	1057-1107	600	33.8	0.06
325	1106-1115	540	29.3	0.05
325	1115-1121	390	22.0	0.06
325	1121-1131	600	47.6	0.08
325	1131-1138	420	33.8	0.08
325	1138-1147	540	54.9	0.10
340	1543-1552	540	25.6	0.05
340	1552-1605	780	25.6	0.03
340	1605-1620	900	31.1	0.03
340	1620-1630	600	22.0	0.04
340	1630-1722	3120	18.3	0.01

For wind velocity and direction see Table #23.

TABLE #25 CHANNEL WATER VELOCITY DATA FOR MARCH 5-6, 1978

TIME	VELOCITY(m/sec)	DEPTH(m)
0443	0.0575	0.29
0445	0.0771	0.29
0446	0.0658	0.29
0446	0.0827	0.29
0447	0.0799	0.29
0515	0.1349	0.29
0516	0.1308	0.29
0517	0.1392	0.29
0518	0.1660	0.29
0520	0.1599	0.29
0521	0.1349	0.29
0524	0.1660	0.29
0543	0.1660	0.29
0600	0.1468	0.29
0602	0.1101	0.29
0603	0.1458	0.29
0605	0.1340	0.29
0606	0.1270	0.29
0608	0.1255	0.29
0609	0.1349	0.29
0610	0.1401	0.29
0610	0.1439	0.29
0611	0.1366	0.29
0612	0.1383	0.29
0613	0.1439	0.29
0614	0.1660	0.29
0615	0.1439	0.29
0616	0.1439	0.29
0619	0.1270	0.29
0620	0.1660	0.29
0700	0.1542	0.29
0701	0.1542	0.29
0702	0.1553	0.29
0703	0.1439	0.29
0704	0.1542	0.29
0705	0.1599	0.29
0705	0.1520	0.29
0706	0.1488	0.29
0716	0.1332	0.29
0717	0.1262	0.29
0725	0.1270	0.29
0727	0.1255	0.29
0738	0.1420	0.29
0739	0.1542	0.29
0740	0.1270	0.20

#7a (continued)

TIME	VELOCITY(m/sec)	DEPTH(m/sec)
[illegible]	0.1255	0.29
[illegible]	0.1439	0.29
[illegible]	0.1309	0.29
[illegible]	0.1024	0.29
0837	0.0799	0.29
0838	0.0846	0.29
0839	0.0863	0.29
0840	0.0938	0.29
0841	0.0938	0.29
0842	0.0771	0.29
0843	0.0575	0.29
0844	0.0591	0.29
0845	0.0696	0.29
0846	0.0644	0.29
0848	0.0719	0.29
0850	0.0616	0.29
0851	0.0514	0.29

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