CEER-MA128: A STUDY OF THE PLANKTON IN LAGUNA JOYUDA, A TROPICAL LAGOON ON THE WEST COAST OF PUERTO RICO. CENTER FOR ENERGY AND ENVIRONMENT RESEARCH.

"A STUDY OF THE PLANKTON IN LAGUNA JOYUDA, A TROPICAL LAGOON ON THE WEST COAST OF PUERTO RICO" by Daniel Pesante Armstrong. This work was partially supported by The Marine Ecology Division of the Center for Energy and Environment Research, University of Puerto Rico, Mayaguez. MS Thesis, Marine Sciences, RUM UFR (1976).

TABLE OF CONTENTS:

ACKNOWLEDGEMENTS:

The author wishes to express his gratitude to Dr. Juan G. Gonzalez, Luis Raul Almodovar, Manuel Hernandez Avila and Jose M. Lopez for their assistance in correcting and their constructive criticisms. Grateful appreciation is expressed to Pablo Cabassa, Dennis Corales, Jose (Harry) Montalvo. Thanks are due to the Center for Energy and Environment Research for providing laboratory space and the use of their valuable equipment. Sincere gratitude of the author to Miriam Pesante and Terry Cabassa, who kindly did the typing of the manuscript. Special thanks go to Gabrielle Galler for providing moral support.

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 Acertia tonsa is the dominant holoplankter followed by Porcellanid larvae, a member of the meroplankton. A voracious predator, the

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. The water system of the lagoon seems to be homogeneous vertically and longitudinally in regards 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.

TABLE LIST:

TABLE LIST CONTINUED:

List of Figures:

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 forms 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 1m in diameter. The latter only comprise a small percentage of the total plankton. Biological, physical, chemical, and geological factors influence the distribution and abundance of zooplankton.

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 on planktonic populations (Hopper, 1967; 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, 1982). 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, 1964; 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 to this date. This investigation is the first attempt to describe the planktonic component of the lagoon.

Attention was focused on both the holoplanktonic and the meroplanktonic members of the community. Of particular interest was the free-living fraction of the order Copepoda (ope, 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 freshwater 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 60 to 65 families derive benefit from the different fish and shrimp caught in the Laguna Joyuda. The study might also give an insight into 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° 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 2m respectively (Figure #2). Bennett (1969) concluded that the lagoon developed from the accretion of two sandbanks which enclosed the bay and formed the lagoon.

The sediments are composed of a grayish-black mud with varying amounts of shell debris (Bennett, 1969). Sediments have a distinctive H2S smell. Bennett (1968) 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. Its banks are 78% fringed by the red mangrove.

Elfs and its prep roots provide organic nutrients and aid in trapping sediment. The lagoonal water system could be considered as a mixed polyhaline type (Venice) ranging from 18 to 30 °/g. Ene (1967), and Bennett (1969) report salinity values that range from 6 to 44 /g. Temperature values of approximately 28°C have been reported. Salinity values could be affected by intermittent changes formed during heavy rains. Rainfall varies from place to place over relatively short distances, due in part to the island's geography. Annual precipitation for the coastal region ranges from 78 to 60 inches.

The distribution of rainfall can be expressed in terms of a relatively wet and dry season, although no absolute dry season occurs. The relatively wet season extends from the month of May to November. The dry season extends from December to April (U.S.C.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 diffused through the water column.

MATERIALS AND METHODS

Field Procedures

Zooplankton samples were collected by towing a conical shape net with an opening of 0.92 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 seawater. A 12 volt battery powered pump was used for this purpose. In this way animals were concentrated at the codend of the net, in a 500 ml collecting jar. The samples were preserved with buffered formalin seawater solution. Occasionally, ctenophore blooms made a normal

"Five-minute tow is impossible; reducing the duration of the tow did not help either. When the ctenophores were present, 18-second tows were made, followed by careful counting of the ctenophores in the field. This was necessary because the relocation 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 one station had a relatively low number of ctenophores. At this station (B-?), 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 plankton samples were collected from the study area. At each of the five stations (see Figure #2), 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.

FIGURE 43. Station Location and Position of Tide Gauge.

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 4m long were driven into 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..."

The direction to the north, at which the drogue had drifted, was observed and recorded. Wind velocity was monitored simultaneously. Flow measurements at the channel that connects the lagoon with the sea were made in order to determine the sea and lagoon water changes. A drogue was initially used for this purpose but couldn't 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 couldn't 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 9.078 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 in a mangrove-protected embayment (Figure #2). The initial reading and time were registered; hourly observations were made thereafter for twenty-four hours. Temperature measurements were made using either a thermistor (U.S. model 97, accuracy of 9.897) 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 (U.S., model 33, accuracy of 0.5 °/oo). A hand-held refractometer (American Optical, temperature compensated, accuracy < 0.1) was also used, but its use was restricted to the surface. Salinity vs. depth profiles were made. Dissolved oxygen (D.O.) measurements were taken using a temperature-compensated meter (U.S., model 87, 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.

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. The mean was 45.29 and the standard.

Deviation 8.5. Knowing the revolutions the Flowmeter turned during a known time and by means of the following formula, the volume of Filter-4 real water per cubic meter can be calculated. Where: R= radius of the ring Rim = 35.0 = number of revolutions the Flowmeter turned. The number of turns per m^3 were calculated by multiplying the number of individuals in 1 mt of the aliquot by 260 ml and dividing by the volume of water.

Liters by the m. For the following My ago " where: W = number of individuals in 1 mt of me 7 Vos Vol + water filtered by the net in Number of planktons per m^3. RESULTS AND DISCUSSION Laguna Joyuda Plankton Composition Table #1 shows the types of planktons 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 "Pleurobrachia pileus" was so high that no plankton tows could be made. As seen in Table #1, the larvae of porcelain 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, though 99% of the latter were variable nauplii. Fish eggs were present 1.8% of the time. This included both round and elongated types of eggs.

The ctenophores were present 75% of the time. The masses were present 6.68% of the time during the last part of the study. This could be seen drifting around the surface. Medusae were represented as small ephyrae and adults, having...

"At a diameter of up to 0.3m, this creature, one of the largest zooplanktons, was the largest member of the planktonic community. It also occurs in the neritic waters outside the lagoon. It has been seen in the open water outside the lagoon but never of the same size in the Laguna Joyuda. Amphipods were present 27.2% of the time during the beginning of the sampling season. Sarnacte cywris was present 9% of the time; a number lower than the percentage of time nauplii were present. Plankton Analysis for each cubic meter 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 Canola of Acacia is the dominant one.

FIGURE #4. Number of Plankters per cubic meter.

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, of the genus Piyelops. 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 porcelainid larvae came second in density, from 2.0 to 368/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 12 show the densities of A. tonsa/m^2 and densities of porcellanid larvae/m^2 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 Porcellenid larvae per meter per month.

Number of A. tonsa and PORCELLANIDAE LARVAE

FIGURE #6. A. tonsa and Porcellanid larvae/m²/station (April).

FIGURE #7. A. tonsa and Porcellanid larvae/m²/station (May).

FIGURE #8. A. tonsa and Porcellanid larvae/m²/station (June).

FIGURE #9. A. tonsa and Porcellanid larvae/m²/station (September).

FIGURE #10. A. tonsa and Porcellanid larvae/m²/station (October).

FIGURE #11. A. tonsa and Porcellanid larvae/m²/station (November).

FIGURE #12. A. tonsa and Porcellanid larvae/m²/station (December).

FIGURE #13. A. tonsa and Porcellanid larvae/m²/station (January).

FIGURE #18. A. tonsa and Porcellanid larvae/m²/station (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-4 and A-1. The total density of Acartia tonsa and porcellanid larvae for each month of the year, can be seen in Figure #5. The same ‘three peaks.

As observed in Figure #4, similar patterns are evident for A. tonsa, although not as clear for porcellanid larvae. High and low population densities of A. tonsa coincide with those of porcellanid larvae, suggesting 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 this sampling period. It is clear that the plankton density rose drastically during the evening of the 20th. This increase 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, resulting in 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/m² for 24 hr. Study October 20-21, 1977.

The wind also affects Station C-2, 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 was 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 significant difference in species diversity between the lagoon and the sea waters immediately outside the lagoon. A possible

The explanation might be the following. If we take into consideration that the lagoon is: (a) a rather small body of water, (b) that it is vertically as well as longitudinally homogeneous (a 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 with the homogeneity of the lagoon, indicates 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.

As item 2 has been the object of study by Gonzalez (1973), Barlow (1982), and Ketchum (1951), 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," according to Paine (1966). However, Laguna Joyuda seems to have much simpler predator-prey relationships. Another possible factor that may contribute to the low species diversity present is that the channel...

TABLE #2. Data for various Copepods.

FIGURE #16. Channel and Outside Stations. 4B

Specimen Legend: Species details and observations.

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). Additionally, a biological barrier to zooplankton may be provided by a coral reef and a Thelzes 2 bed system immediately outside the channel.

Planktonic organisms that need to pass through these systems to enter the lagoon may effectively be reduced by predation. Throughout the year, the ctenophore Mnemiopsis gardeni was present, reaching bloom proportions on several occasions. The density range of Mnemiopsis found in this study ranged from 0 to 60/m^3. The highest density of the ctenophore was observed in 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 the total number of plankters throughout a 12-month study. The general trend exhibited by the graph indicates that as the population of ctenophores increases, 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 (1967); Burrell (1968); Miller (1970) and Kremer (1975).

Little attention has been focused on the biological importance of the ctenophore. Previously, people have been more concerned about how to solve the sampling difficulties of catching smaller

Figure #37: Total Plankton and Total Mnemiopsis per cubic meter per month.

Total Plankton (Right Scale/Inverted Scale)

There is extreme range in density of plankters when the ctenophore is around.

The abundance of the ctenophore throughout the year was observed to range from close to 0 (0.1/m^3) to up to 100/m^3. These numbers should be compared with those presented by Kremer in 1978 in a study on the distribution and abundance of the ctenophore, Mnemiopsis leidyi, in

Narragansett Bay, Rhode Island. Kremer reported observing very low numbers in winter, with 1 to 2 Mnemiopsis/$10^3/m^3$, and up to 100/m^3 during the summer. This study reveals that very high numbers of ctenophore (up to 100/m^3) were observed during the months of March, July, and August, and very low numbers during the months of April, May, and June.

Questions may arise such as: Are the smaller plankton decreasing due to ctenophore predation, or is it that the phytoplankton is not available to the zooplankton, so the latter cannot 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 Mnemiopsis is not only important for its predation on zooplankton, but it also plays a major role as a nutrient 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 consumption rates at various temperatures (Kremer, 1976), 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 18% 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 as a conduit for nutrients, recycling them back into the water column.

More as nutrient pumps, rapidly recycling materials into the water column. Kremer also indicates 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 ctenophores 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 simply 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, 1867; Burrell, 1968; Franzen, 1970; Rowe, 1971 and Aruta, 1874, tend to indicate ctenophores prefer the small zooplankton.

Bishop (1967) shows that a comb jelly can account for 24% 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 leidyi and the smaller members of the planktonic communities. Acartia tonsa (Dana), a calanoid copepod of worldwide distribution, has been found to tolerate water temperatures from -19°C to 32°C (Gonzalez, 1973). Jeffries (1962) attributed the success of A. tonsa 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 parameters like temperature and salinity. Sharp drops or rises in one or both of the latter can make a population decline.

The text is 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.

Page 87: Gouites (297%) informs that the invasion of 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 complex physiological adaptability to conditions in predictable environments. This 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 Eucyclops found in beds of Ruppia maritima. Even though A. tonsa is found dominating, which would imply that it is in a comfortable environment, it exhibits a size smaller than those found 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 Fosforente and Consett Bay, the results are...

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The animals appear to be close (Table 1). They were measured from the front tip of the cephalotorax to the tip of the caudal fin in order to compare values with those obtained previously by Gonzalez using the same method. 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%.

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%. Figure 16 shows the channel that communicates the lagoon with the open sea. Salinities of 34.0% were observed at the mouth of the channel (lagoon side) when the tide was coming in. On all other occasions the salinity values were...

Table 4. RSA Size in 8. For Three Different Localities

Narragansett, RT.

Temperature, C	Male Size	Standard Deviation	Female Size	Standard Deviation
0.08	0.02	0.08	0.06	0.08
0.08	0.03	0.08	0.02	0.08

Laguna Joyuda,

23.9	0.65	0.70	0.04	26.0
0.68	0.76	0.03	30.2	0.66

Figure 18. Temperature °C and salinity %, per...

The text, after correction:

The salinity vs. depth profiles were taken on several occasions. On August 1977, at Station B-2 (refer to Figure #3 for station location), the deepest of all five stations (1.5 m.) had salinity values of 30.5, 30.2, 20.2 per thousand at the surface, -75 m. and 1.5 m., respectively. The 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 1877, with values of 26.8, 26.5, 26.5 per thousand at the 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 gave 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. Bennett (1969) reported salinities of 35 per thousand. Garcia (1976) and Carvajales (1976) reported salinities of 20-6 per thousand, respectively. Salinity measurements taken during this study indicate that the lagoon is homogeneous in a vertical and longitudinal plane. This is due to the shallowness of the system (1.8 m) coupled with the continuous winds from the southeast which effectively mix the waters.

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.

The study (Figure #18) shows 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 #13); readings were initiated at 9 A.M. on the 20th and ended at 9 A.M. on the 21st. The extreme range in temperature for that day was from 26.5 to 21.5°C. As expected, the highest temperatures were observed during noontime, and the lowest temperatures early in the morning on the 21st. When temperature vs. depth profiles were taken, they varied from 0.0 to 0.8°C, indicating that the lagoon does not seem to be stratified in regards to temperature. Temperature drops or rises were observed.

This indicates 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 water 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 falls 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. The mean depth of the lagoon is 1.8 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 1.5m. 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.

The water column ranges from 0.3 to 0.8 m, as indicated by Tables #6 through #17 and Figure #20.

FIGURE #20. Water transparency. 87

The values clearly illustrate the high amount of suspended matter in the water column. Sediments and organic matter can be easily resuspended in the water column due to the turbulence created by the wind and the shallowness of the lagoon. A significant portion of this suspended material appears to be phytoplankton, supported by the year-round deep green color of the water. The greatest turbidity was observed when winds were blowing up to 20 km/hr. This observation aligns with Bennett's (1959) report that the highest turbidity levels were observed when water levels were at their lowest and winds were blowing from the South or Southeast. Winds from these directions cause the highest waves in the lagoon as they travel the entire length of the lagoon. Bennett (1963) also reported that the turbidity in the Laguna Joyuda is primarily due to the resuspension of bottom sediments and does not necessarily reflect the rate of sediment influx from streams and swamps of the drainage basin.

Surface currents at Laguna Joyuda were observed on two occasions to gather 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 on October 20, 1977.

Wind direction and wave formation were observed to come from the Southeast (Table #24). Wind blowing from this direction follows the trajectory covered by Stations C-1, B-2, and A-3 (Figure #3).

Table #75 shows surface current velocities varying from 0.05 to 0.1 m/sec with wind speeds ranging from 8.6 to 14.8 km/hr. These measurements were taken in the morning. Afternoon measurements indicated 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 accumulating against Station A-3. No

The current study was conducted on the bottom. 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 was carried out on March 5-6. Flow measurements were taken in the channel that connects Laguna Joyuda with the sea. A flow meter was placed in the water at .278 m from the surface; the bottom was at .55 m at that place, the deepest part of the channel. The mean depth of the channel is 238 m with a width of 3m.

According to the tide predictions (Tide Tables 1978) for March 5-6, 1978, for Puerto Rico, this is the closest place to the lagoon where tides are actually measured. The maximum range for that day was 44.5 m. However, data obtained by placing two tide gauges, one in the mouth of the channel (sides Figure 3) and the other 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 m.

Water movement observations at the channel were started at 2000 on March 5. However, the place where 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 on the surface were still and sediment stirring provided indications that the 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 on March 6, actual measurements were started using a floating object, two rods, and a chronometer. Table #25 provides the time and velocity in m/sec from 0447 to 0854 hrs. Velocities ranged from 0.0 m/sec when water was still at 2200 on March 5, to up to...

The velocity was 26m/sec at 08:20 on March 6. From the observed data, it can be estimated that the amount of water entering the lagoon for that period was 36°. This amount of water was not very significant if we consider the total volume of water in the lagoon, which is 2.82x208m^3. Tide restriction is attributed to a barrier at the mouth. As seen from the dimensions of this section, it is a shallow and narrow channel which cannot provide the lagoon with any considerable amount of seawater. Thus, the channel itself is a physical barrier for the organisms in the lagoon, making it hard for them to exit the lagoon. Similarly, plankton and nutrients from the sea are prevented from entering the lagoon in any considerable quantities.

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 an 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 20.8°/,,, 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 84.4% saturation, at mid-depth 85.88% 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 demand in the water can become a limiting factor. An increase could make oxygen

unavailable to the aquatic organisms of the lagoon. High water temperatures, high salinities (42-44°/,,), and high densities of phytoplankton can also pose a threat. Late at night, just before sunrise, the oxygen utilization by the phytoplankton can be so high.

The water can become deoxygenated. This also happens in fishponds with an overload of nutrients due to careless fertilizer management. There is low grazing pressure of zooplankton on the phytoplankton, and resuspension of anoxic sediment by heavy rains. Predation of ctenophores on the zooplankton indirectly stimulates high phytoplankton populations.

Conclusions:

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

1. The zooplankton of the Laguna Joyuda has been described for the first time.
2. The species diversity in the lagoonal system is significant.
3. Acartia tonsa is the dominant holoplankter.
4. The voracious predator is present in the lagoon and, from time to time, attains bloom proportions. It is capable of controlling Acartia 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:
   - Temperature goes up to 35°C,
   - Salinity goes up to 23 ppt,
   - Salinity goes down to 6 ppt.

APPENDIX A

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

Unknown data

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