MEMOIR 1: MIAMI GEOLOGICAL SOCIETY

A SYMPOSIUM OF RECENT SOUTH FLORIDA FORAMINIFERA

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THE ECOLOGY AND DISTRIBUTION OF LIVING PLANKTONIC FORAMINIFERA IN THE STRAITS OF FLORIDA

by

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ABSTRACT

Seasonal, diurnal, and depth distribution patterns of living planktonic foraminiferal populations from the Florida Straits have been analyzed to determine their relationships to measured environmental parameters. Maximum seasonal foraminiferal concentrations were found in January and July. Maximum populations were measured in the 50 and 150 meter depth range, commonly associated with the 26°C isotherm, and restricted to a temperature range from 22°C to 30°C. A vertical diurnal population migration was observed, with maximum concentrations occurring during daylight hours in the near-surface waters. No apparent relationship was found to exist between foraminiferal distribution and nutrient concentration, determined from phosphate measurements. Phytoplankton concentrations and foraminiferal distribution patterns coincided. Seasonal, depth, temperature and salinity preferred ranges have been established for the foraminiferal species occurring in this study.

INTRODUCTION

Interest in the study of deep-sea marine sedimentary phenomena and their relationships to interpretation of ancient marine environments has recently provided considerable new information relating to these topics. In particular, accelerated collection of deep-sea sediment cores, both by conventional means and by deep-sea drilling techniques, has produced much new sedimentary and paleontologic data. For these data to be correctly interpreted a re-evaluation of many classic or traditional concepts is required, and correspondingly, the development of new interpretational criteria is desirable.

Characteristically, fossil faunas of planktonic Foraminifera have been interpreted with little or no knowledge of the ecology of their living counterparts. It is apparent that meaningful interpretations of fossil populations of these organisms is highly dependent upon information which may be obtained only by ecologic and zoogeographic studies of living representatives of this group. It is the purpose of this study to document the temporal and vertical population distribution of these forms within the waters of the Florida Straits, and further, to speculate on the environmental-faunal relationships which are shown to exist in this area. It is hoped that this information may prove useful in the interpretation of Recent and near-Recent fossil populations of these organisms occurring in deep-sea cores.

METHODS OF STUDY

Field Techniques and Procedures

The plankton and hydrographic samples were collected aboard the Institute of Marine Science Research Vessel GERDA. Midday and Midnight collections were made in the Florida Straits at latitude 24°33' North and longitude 79°25' West between April, 1958 and February, 1959 in the months of April, May, June, July, September, October, December, January and February. The sampling area has been referred to as the Forty Mile Station, due to its location approximately forty miles due east of Miami. Plankton samples were collected from the surface, 38, 75, 100, 150, 200, 250, 300 and 350 meter depth levels. Thirty minute tows were made with closing plankton nets. Depth recorders were not used, and the quoted depths have been calculated on the basis of wire length and wire angle. This method at best provides only approximate depth information, although the error is probably more or less consistent throughout the study. Therefore, the quoted depths, particularly for the deeper nets, may be in error by as much as 10 percent. Hydrographic samples were collected from the surface, 50, 100, 150, 200, 300, 500 and 700 meter depth levels. It should be emphasized that collecting methods employed in this investigation, while adequate for the general interpretation of foraminiferal ecology and distribution within the context of the study, are not of a level of precision sufficiently accurate to allow more than general conclusions to be reached relating to the detailed ecology of these forms. In spite of this limitation, however, there is little reason to doubt the validity of the results which are quoted, particularly as applied to relative seasonal and vertical population characteristics or to the observed preferred environmental ranges which have been provisionally established for each species.

Laboratory Techniques and Procedures

The physico-chemical data presented in this paper are the results of analyses obtained by Drs. Eugene Corcoran and James Alexander. Their work is the basis for the environmental information included within this study and for the chemical oceanographic data. Their techniques and results are included in the Second Summary Report, Oceanic Productivity Studies, The Marine

Laboratory, University of Miami, May 1960, submitted to the Rockefeller Foundation. Additional information on nutrition and productivity is contained in the publication by Alexander (1963).

Laboratory Techniques

The planktonic Foraminifera were separated from the remainder of the plankton by means of a density separation technique modified from that described by Bé 1959. Total foraminiferal counts were made on both the high and low density fractions, although the species distribution was determined from the high density fraction only. A further discussion of the various techniques which have been applied to foraminiferal separation, and their reliability, is discussed in a paper by Boltovskoy (1966) to which the interested reader is referred. A minimum of 500 specimens from each sample were specifically identified. Where there were fewer than 500 specimens in the sample the total population was identified. Three population parameters based on these population analyses have been computed. These are the Standing Crop, the Percent of Total Population, and the Percent of Individual Population values. The Standing Crop is an absolute value, describing within the limits of the sampling error the abundance of a selected organism per unit volume of water. The Percent of Total Population value (%Tot.) and the Percent of Individual Population value (%Ind.) are both relative values. The former is derived from the relative abundance of each species compared to all other species, within a single sample. The latter describes the relative abundance of each species for each station (series of samples), relative only to itself at that particular station. It is useful in determining preferred environmental or temporal ranges for individual species, considering as it does, each species as a separate entity, relative only to itself. These three population parameters have been used to compute the seasonal, and depth preferences of the individual foraminiferal species occurring in this study, and also to define preferred seasonal and depth distribution patterns as exhibited by the total planktonic foraminiferal population.

DISCUSSION

General Characteristics of the Study Area

The Florida Straits contain the Florida Current, a major subdivision of the Gulf Stream. Depths in the Florida Straits average 450 fathoms, the main channel being defined approximately by the 400 fathom contour. The physico-chemical characteristics of the Florida Current are acquired outside the area of the Florida Straits, the water coming variously from the Equatorial Atlantic through the Caribbean via the Yucatan Channel; from the western Atlantic, via Old Bahama Channel; and from a number of areas in the Gulf of Mexico. The water at the Forty Mile Station is primarily Yucatan Water (Parr, 1937, Wennekens, 1959) as classically defined by the temperature-salinity relationships. Seasonal temperature flucturations are restricted to the upper 150 meters, with no seasonal fluctuations observed below that depth. The 24.0°C isotherm is present throughout the year at approximately 100 meters. The upper 100 meters are generally warmer than 26.0°C and exhibit a maximum temperature value in excess of 30.0°C at the surface in September. The temperature variations occurring within the upper 100 meters are predominantly seasonal. The overall salinity range to the maximum sampling depth was from 35.98 ppt to 39.96 ppt. April to July surface highs, and August to November surface lows were observed. Surface waters were generally nutrient deficient over the period of observation, suggesting little or no vertical mixing, and a rapid rate of regeneration. No seasonal phosphorus or nitrogen cycle, as occurs in temperate and northern waters, was observed. Although the values were relatively stable over the observational period, a December high and February low were measured. Consistent increase in concentration with depth was observed. Nitrogen concentration also exhibited this increased concentration with depth, as well as a surface-water high, from July through November. Marked highs also occurred in the depth range from approximately 100 to 200 meters in June, July, October and January. Below 300 meters only September and February highs were observed.

FAUNAL-ENVIRONMENTAL RELATIONSHIPS

One of the principal goals of any ecological study is to determine as precisely as possible, within the limits of the available sampling and analytical techniques, the range of environmental variation within which any particular related group or species may live and reproduce. A field environmental study is necessarily limited by the type and amount of data which can be collected in a field situation. In the present study these limitations consisted primarily of the difficulties of making high-precision collections and physico-chemical measurements in the open ocean from a relatively small vessel, as well as by the limited temporal range of the study, lasting through a period of a single year with only monthly collection of data. These limitations

restrict the reliability with which the cause-and-effect relationships existing between the experimental organism and its environment may be defined. It has been possible, however, to observe the broader aspects of these relationships by documenting a number of preferred environmental ranges for the total foraminiferal population and for a number of selected species.

Temperature

Temperature has long been recognized as one of the major controlling factors in the distribution of organisms. In the present study a maximum temperature range of 14°C was observed. Populations maxima occurred when surface water temperatures were between 26°C and 29°C. Below 100 meters only minor seasonal temperature fluctuations were measured. The maximal foraminiferal populations occurred within the upper 100 meters, with maximum values attained in January and July, at which time temperatures in this depth interval ranged from 24°C to 30°C. The measured temperature range within the upper 150 meters was 22°C to 30°C. There is some indication that total maximum populations were associated with the 26°C isotherm, exhibiting a depth depression coinciding with the level of this isotherm from May through September. There is good evidence to indicate that the maximum total foraminiferal population from June through January occurred in deeper waters than during the period from February through May. This could be related to a Spring population bloom in the upper waters during the February to May period, although corroborating evidence for this is lacking. The listed temperature ranges for each species is here considered to be the preferred range. Absolute ranges could not be estimated as there is too little temperature fluctuation in this region to objectively define the absolute limit of any species. Specimens of most species were found at all sampling depths, although a preferred depth could be established for most. The collecting technique, utilizing closing nets, tends to broaden the observed environmental limits due to contamination by specimens occurring in upper water levels while the nets are being lowered to their sampling depths. In general, the planktonic Foraminifera appear to have rather broad temperature tolerances.

It is interesting to compare the species temperature ranges measured in this study with those established by Emiliani (1954), based on isotopic analyses of fossil specimens. Of the nine species common to both studies, seven exhibit a temperature range which includes the preferred temperatures of Emiliani. These species also exhibit depth ranges either including or very close to those hypothesized by Emiliani.

Salinities

Salinities values measured within the sampling interval varied but little throughout the study. The effect of differences in salinity on planktonic Foraminifera is poorly known. The most definitive information available to date is that published by the author in two earlier papers (Jones, 1967, 1969). The ranges obtained from those studies, which were based on considerably more reliable biologic and hydrographic sampling and analyses than those of the present study, coincide generally with those measured in this study. Significant exceptions to this are discussed below under the appropriate species. Salinity appears to be a major limiting environmental factor in the distribution of the planktonic Foraminifera. The species distribution in this and the earlier studies (op. cit.) exhibited a markedly greater correspondence to variations in the salinity field than has previously been reported.

Nutrients

The data available for measurement of the nutrient concentration consist of measurements of total phosphate, inorganic phosphorus, and nitrate and nitrite nitrogen. As these parameters generally exhibit a consistent relationship one to the other, only the phosphate data will be considered in detail. Seasonal nutrient concentrations were very low, with little evidence to indicate the pronounced seasonal cycle common to higher latitudes. Maximum nutrient values were observed during the August to September and the April through May periods. Maximum surface values were measured in November and December. There is no apparent correlation between the observed foraminiferal population variations and those of phosphate-phosphorus concentration. In the water samples analyzed, inorganic phosphate varied between zero at the surface to more than 0.3 microgram-atoms-per-liter at 300 meters depth. A seasonal increase occurred in surface waters during the summer. It is apparent that no large-scale mixing occurred between the surface waters and those below the permanent thermocline. There was no measurable seasonal intrusion by different water masses. This stability suggests that the renewal of nutrients is dependent on mineralization and regeneration occurring in the upper waters (Alexander, 1963). It has been established that maximum zooplankton concentrations coincide with maximum inorganic phosphate concentrations. This is due to the dependency by zooplankton on the nutrient material in the water, which is reflected by the high phosphate values. This reasoning led Bradshaw (1959) to

investigate the relationship of planktonic foraminiferal distribution to inorganic phosphate concentration. He found a relationship which was later confirmed by Parker (1960) in their studies of Pacific planktonic Foraminifera. Smith (1963) was unable to document any such relationship in his study. The present investigation similarly shows no evidence of such a relationship, with minimal inorganic phosphate concentrations measured in the upper 150 meters where foraminiferal concentrations were greatest. Additionally, phosphate concentrations in all cases increased with depth, with maximum values at the lowest sampled depths, where measured foraminiferal concentrations were least. Seasonal measurements of this parameter also failed to demonstrate a relationship between this variable and planktonic foraminiferal concentrations.

Oxygen

The available oxygen data do not indicate a relationship to any measured foraminiferal population parameter variation. This was expected, since observed oxygen concentrations in the sampled area maintain a level which theoretically would not exert limiting effect on plankton distribution.

Light

Illumination is the most obvious factor controlling diurnal population variation, although this may in reality be a secondary effect upon foraminiferal distribution, with the phytoplankton responding directly to light and the Foraminifera responding secondarily, relative to the phytoplankton response. It has not been possible to establish whether or not the observed foraminiferal diurnal pattern is related to symbiotic zooxanthellae associated with foraminiferal protoplasm, or if it occurs due to a feeding response by the Foraminifera related to phytoplankton migration; or as the result of an entirely different factor or combination of factors. It was observed in this study that diurnal depth fluctuations occurred at depths well below those having sufficient illumination for photosynthetic activity by the phytoplankton. Whether or not these low levels of illumination are likewise too small to be used by the foraminiferal zooxanthellae is a matter of conjecture. The majority of the species of Foraminifera appeared to exhibit some degree of diurnal depth fluctuation relative to the euphotic zone. This could be due to zooxanthellae light requirements, or to a feeding pattern established by the Foraminifera which coincides with phytoplankton diurnal migration. This possibility has not been considered by previous investigations.

Phytoplankton abundances in this study were determined at each station by the measurement of chlorophyll *a*. The technique and data relating to these measurements are included in the Rockfeller Foundation Report referred to previously. The measurement of phytoplankton concentrations indicated maximum phytoplankton concentrations in the upper 100 meters throughout the year, with the greatest concentrations occurring in the 50 to 100 meter depth range. These concentrations coincide with maximum foraminiferal concentrations. The phytoplankton provide the bulk of the nutritional requirements for the Foraminifera, therefore it is not unreasonable to hypothesize the existence of a causal relationship within these two variables. The fact that the Foraminifera exhibit a diurnal pattern similar to the phytoplankton, and markedly different from that shown by the zooplankton, further suggests this possibility. To summarize, while no apparent relationship was observed between foraminiferal concentration and high nutrient values, as determined by phosphate concentrations; an apparent positive correlation was shown between foraminiferal and phytoplankton concentrations. It is suggested, therefore, that the observed diurnal pattern of the Foraminifera may be partially a consequence of a feeding response by the Foraminifera to maximum phytoplankton concentrations.

FORAMINIFERAL SYSTEMATICS AND ECOLOGY

Species Characteristics

It is not the purpose of this study to investigate the detailed systematics of this group, but rather to suggest other criteria which may be of value in understanding and interpreting the systematics of the planktonic Foraminifera. The taxonomic information included here, therefore, is minimal. The references which are cited are those most representative of the author's concept of each species, and are ones which contain adequate reviews of the prior taxonomic treatment of each species. These species are familiar to all students of this group and their definition should cause no difficulty.

Globigerina bulloides d'Orbigny, 1826 (Plate 27, Fig. 4)

Globigerina bulloides d'Orbigny, 1826, Ann. Sci. Nat., Ser. 1, v. 7, p. 277.

This form occurred but rarely. The specimens referred to this species are comparable to the forms figured by Parker (1962, Pl. 1, Figs. 1, 3), Bé (1959, Pl. 1, Figs. 15-17) and Bradshaw (1959, Pl. 6, Figs. 1-4). No specimens with the umbilical bulla as figured by Parker (1962, Pl. 1, Fig. 4) were observed. This species has been reported throughout the oceans of the world, with maximum occurrences in mid-latitudes or temperate regions, associated with the cooler oceanic waters. It occurs in tropical regions, but at low frequencies. Bradshaw (1959) suggested that it might live at greater depths in the equatorial Pacific than in higher latitudes. No evidence of this equatorial depression was observed in either the present study, or in an earlier investigation based on material from the Tropical Atlantic (Jones, 1966, 1969).

Maximum concentrations in the Florida Straits were measured in the surface to 38 meter depth-range. No seasonal depth preference was demonstrated. Maximum populations were measured in May. This species was present only in minor concentrations, at no time representing more than 3% of the total foraminiferal population. Upper-water daytime concentrations were consistently larger than nighttime concentrations. Populations were inadequate to establish preferred ranges for temperature or salinity.

Globigerina siphonifera (d'Orbigny), 1839 (Plate 25, Fig. 1)

Globigerina siphonifera d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 83, Pl. 4, Figs. 15-18.

Globigerina aequilateralis Brady, 1879, Quart. Journ. Micr. Sci., new ser., v. 19, p. 285.

Globigerina aequilateralis Brady var. involuta Cushman, 1917, U.S. Nat. Mus. Proc., v. 51, no. 2172, p. 662.

Hastigerina (Hastigerina) siphonifera (d'Orbigny), - Banner and Blow, 1960, Micropaleontology, v. 6, no. 1, p. 22, Text-Figs. 2 (lectotype), 3.

Included under this taxon are the typical "aequilateralis" form, as well as the "involuta" form of Cushman and others. These two types were separated in the population anaysis. Their observed occurrence and distribution does not justify their separation into two distinct species. Maximum concentrations were observed in the 75 to 200 meter depth range, with an overall maximum at 75 meters. Upper-water daytime concentrations were generally larger than at nighttime. This form exhibited relatively high populations during both summer and winter, with the overall maximum in July. The single preferred depth was 75 meters. The preferred temperature range was 19.5°C to 26.0°C, with a single preferred temperature of 23.5°C. The preferred salinity range was 36.14 to 36.67 ppt, with a single preferred salinity value of 36.39 ppt.

Hastigerina pelagica (d'Orbigny), 1839 (Plate 25, Figs. 3, 4)

Nonionia pelagica d'Orbigny, 1839, Voy. Amer. Merid. "Foraminiferes", v. 5, pt. 5, p. 27, Pl. 3, Figs. 13-14).

Hastigerina murrayi Thompson, 1876, Roy. Soc. London, Proc., v. 24, p. 534, Pl. 22, 23.

Hastigerina pelagica (d'Orbigny), - Brady, 1884, Rept. Voy. Challenger, Zool., v. 9, p. 613, Pl. 83, Figs. 1-8.

This species exhibited little morphologic variation. Although it is a common element of the plankton it has been reported infrequently in deep-sea surface sediments, probably because of its fragile nature which is not easily preserved in bottom sediments. A preferred depth range from 38 to 150 meters was measured, with maximum populations occurring at 75 meters. It had a maximum value of 13% of the total foraminiferal population in April and May, and a minimum in October. The Standing Crop maximum also occurred in April. Larger populations were generally found in the upper waters in daylight hours. A well defined preference for the upper 100 meters was exhibited throughout the sampling period. A preferred temperature range from 25.2°C to 27.5°C and a single preferred temperature of 25.8°C were measured. Both Bé (1959) and Bradshaw (1959) have considered this form a warm-water species. The present study agrees with their determination, but another

investigation by the author on materials collected in the Tropical Atlantic (Jones, 1966, 1969) gives conflicting data. Further analysis of the ecology of this form is therefore indicated, to resolve this apparent discrepancy. The preferred salinity range measured in the present study was from 36.12 to 36.42 ppt, with a single preferred salinity value of 36.25 ppt.

Globigerinoides conglobatus (Brady), 1879 (Plate 25, Fig. 5)

Globigerina conglobata Brady, 1879, Quart. Jour. Micr. Sci., new ser., v. 19, p. 286.

The form referred to by Bradshaw (1959) on page 42 and figured on his Plate 7, Figures 16 and 17 has been included in this taxon. The bullae observed by Parker (1962, Pl. 3, Fig. 3) were not observed on any of the specimens of this study. This form exhibited a preferred depth range from 100 to 200 meters. It was found in most of the samples, generally representing 5% or less of the total foraminiferal population. Maximum population values occurred at 150 meters. It represented 7% of the total population in July, at which time it also had its highest Standing Crop value. Daytime values in the upper 100 meters were higher than nighttime values in this depth range. It demonstrated a well-defined preference for depths greater than 100 meters. A preferred temperature range from 20.7°C to 25.2°C and a single preferred temperature value of 24.0°C were measured. A preferred salinity range from 36.28 to 36.68 ppt and a single preferred salinity value of 36.42 ppt were computed.

Globigerinoides trilobus (Reuss), 1850 (Plate 25, Figs. 6, 7, 8)

Globigerina trilobus Reuss, 1850, Denkschr. Akad. Wiss., Wien, v. 1, p. 374, Pl. 47, Fig. 11.

Globigerinoides quadrilobatus sacculifer, Parker, 1962, Micropaleontology, v. 8, no. 2, p. 229, Pl. 3, Figs. 13-15.

Globigerinoides trilobus (Reuss), forma typica, Boltovskoy, 1964, Alm. Naut., B. Aires, H. 639, p. 13-15, Pl. 2, Figs. 6-9.

Globigerinoides trilobus (Reuss), forma sacculifera (Brady), Boltovskoy, 1964, Alm. Naut., B. Aires, H. 639, p. 15, Pl. 3, Fig. 2.

Included within this taxon are two distinct morphologic types, the forma typica and the forma sacculifer, as recognized by Boltovskoy (1966) and others. On the basis of the present study, as well as an earlier one (Jones, 1967, 1969), there is evidence to indicate that these two morphotypes have different preferred environmental habitats, although with a considerable range of overlap, and that there is some justification in considering them true biologic subspecies. In this and the previously cited study (Jones, op. cit.) the preference by the forma sacculifer for colder temperatures and/or deeper water was well documented. This observation contradicts the hypothesis of Bermudez (1961) which assumed that the sac-like final chamber acted as a more efficient float mechanism than the normal chamber, and that the forma sacculifer would therefore occupy shallower waters than the forma typica.

This species exhibited a preferred range from the surface to 100 meters, with maximum values in the 75 to 100 meter interval. Its maximum Standing Crop occurred in July, although it was present throughout the year in significant numbers, representing one of the major elements of the foraminiferal population from July through November. Its preference for water-depths in the 75 to 100 meter range was marked. The forma typica was always by far the more abundant of the two forms, generally constituting 98% to 99% of the total G. trilobus population. A preferred temperature range from 24.6°C to 28.8°C was measured, with a single preferred temperature value of 26.0°C. The measured preferred salinity range was 35.98 ppt to 36.48 ppt, with a single preferred salinity value of 36.29 ppt.

Globigerinoides ruber (d'Orbigny), 1839 (Plate 25, Fig. 10)

Globigerina rubra d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 82, v. 8, Pl. 4, Figs. 12-14.

The full range of variation illustrated by Parker (1962) was observed in the samples of this study. The most common form was that illustrated by her in Plate 3, Figures 11 through 13. Variants from this form constituted only a small fraction of the G. ruber population. The colored

and non-colored (red and white) forms of this species were separated in the faunal analysis. A distribution pattern was observed which indicated a pronounced preference by the white form for deeper and/or colder waters than the red. This agrees with the distribution reported by Bé (1960) in which he reported a preference by the red form for warmer waters in the Bermuda area. There were inadequate numbers of other morphologic variants of this species to allow any conclusion as to their possible phenotypic or genetic significance.

In the present study this species was present throughout the year, but exhibited maximum population values in September. It represented almost 50% of the total population in October. Maximum concentrations occurred during the daytime, in the upper 100 meters of water. A marked preference for the surface to 100 meter depth range was demonstrated, with a maximum single value occurring at 38 meters. This form generally exhibited relatively low population values throughout the year in the range from 150 to 350 meters, with only one major exception occurring in September, where relatively high population values were measured below 100 meters. A preferred temperature range from 24.0°C to 28.8°C was measured, with a single preferred temperature value of 26.6°C. A preferred salinity range from 35.98 to 36.78 ppt was observed, with a single preferred salinity value of 36.25 ppt.

Orbulina universa d'Orbigny, 1839 (Plate 26, Fig. 1)

Orbulina universa d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 3, v. 8, Pl. 1, Fig. 1.

The interpretation of this "species" is a source of disagreement among students of the planktonic Foraminifera. Different conclusions have been drawn in regard to the significance of the "juvenile", or spiral stage occurring within the outer globular chamber. It appears that two or more species may be represented, all of which develop the characteristic enclosing globular chamber diagnostic of Orbulina universa, as commonly recognized. Bé (1958) and others have discussed this problem. In the present study only two different spiral forms were observed, one similar to Globigerina bulloides in general form and the other similar to Globigerinoides conglobatus, although neither of these spiral stages were conspecific with either of the species they have been compared to. The spiral stage similar to G. bulloides was also routinely recognized in the samples when not enclosed by the enveloping final chamber. It seems best, at the present stage of knowledge, to consider O. universa a distinct species for purposes of this ecological study, in the hope that the information presented here, combined with past and future information, may ultimately resolve the problem of the taxonomic significance of this form.

In the present study this species consistently constituted a major element of the total foraminiferal population, often occurring as the most abundant element of the population. Maximum Standing Crops occurred in July. A consistent preference was shown for the 75 meter depth level, with a preferred depth range from 50 to 150 meters. Significant numbers were found at all sampled depths, however, a preferred temperature range from 17.6°C to 27.7°C was observed with a preferred single temperature value of 23.7°C. A preferred salinity range from 36.14 ppt to 36.55 ppt was measured, with a single preferred salinity value occurring at 36.32 ppt.

Pulleniatina obliquiloculata (Parker and Jones), 1862 (Plate 26, Figs. 2, 3)

Pullenia obliquiloculata Parker and Jones, 1862, in Carpenter, Introd. Foram., p. 183.

Pullenia sphaeroides (d'Orbigny) var. obliquiloculata Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., v. 155, p. 365, 368, Pl. 19, Fig. 4a-b.

This form exhibited no significant morphologic variation in the samples analyzed, where it was found only rarely. Both adult and juvenile forms have been included in the population analyses. It has been reported from many warm-water regions of the world and had been considered by most workers to be indicative of these conditions when found as fossils.

A preferred depth-range from 50 to 200 meters was measured, with maximum population values occurring at 75 and 150 meters. It was present throughout the sampling period, but generally at low frequencies, with the exception of the January collection when large numbers of juvenile forms were observed. Maximum population values occurred consistently in the upper 150 meters. A preferred temperature range from 17.6°C to 24.6°C, and a single preferred temperature value of 21.8°C were measured. A preferred salinity range from 36.14 ppt to 36.83 ppt and a preferred salinity value of 36.51 ppt were calculated.

Sphaeroidinella dehiscens (Parker and Jones), 1865

Sphaeroidina bulloides d'Orbigny var. dehiscens Parker and Jones, 1865, Roy. Soc. London, Philos. Trans., v. 155, p. 369, Pl. 19, Fig. 5.

This distinctive species has generally been regarded as a warm-water form due to its reported occurrences in surface sediments and in the plankton. Its rarity in the samples of the present study does not conform to this concept. It occurred only rarely, in few samples at very low frequencies. Provisional depth and temperature preferred-ranges are 200 to 350 meters and 16.0°C to 20.0°C, but the small number of specimens collected make these values highly speculative.

Globorotalia crassaformis (Galloway and Wissler), 1927 (Plate 26, Figs. 4, 5, 6)

Pulvinulina crassa (d'Orbigny), - Brady, 1884 (not Rotalina crassa d'Orbigny), Rept. Voy. Challenger, Zool., v. 9, p. 694, Pl. 103, Figs. 11-12.

Globigerina crassaformis Galloway and Wissler, 1927, Jour. Pal., v. 1, p. 41, Pl. 7, Fig. 12.

?Globorotalia pseudocrassa Chapman and Parr, 1937, Australian Antarct. Exped. 1911-14, Sci. Repts., ser. C (Zool., Botany), v. 1, pt. 2, p. 115, Pl. 9, Fig. 25.

Globorotalia (Turborotalia) oceanica Cushman and Bermudez, 1949, Cushman Lab. Foram. Res., Contr., v. 25, p. 43, Pl. 8, Figs. 13-15.

Globorotalia punctulata (Fornasini), - Phleger, Parker and Peirson, 1953, Swedish Deep-Sea Exped., Repts., v. 7, Fasc. 1, p. 20, Pl. 4, Figs. 8-12.

This species has been reported from tropical regions of both the Atlantic and Pacific oceans, both in sediment samples and in the plankton. It was well represented in the present study, where it showed little morphologic variation, conforming in all respects to its traditional concept. It exhibited a marked preference for waters deeper than 100 meters, attaining a Maximum Standing Crop value at 150 meters, with significant amounts of its population present to 350 meters. It was generally rare in the upper 100 meters and completely absent in the upper 38 meters. It was present at relatively low values through most of the year, but was absent in December, January and February. A preferred temperature range from 16.0°C was calculated, with a single preferred temperature of 23.0°C. A single preferred salinity value of 36.61 ppt was measured.

Globorotalia cultrata (d'Orbigny), 1826 (Plate 26, Figs. 7, 8)

Rotalia (Rotalie) menardii d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 273, no. 26; Modeles no. 10.

Rotalia limbata d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 274, no. 30.

Rotalia nitida d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 274, no. 31.

Rotalina (Rotalina) cultrata d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 76, v. 8, Pl. 5, Figs. 7-9.

Rotalina cultrata d'Orbigny, - Banner and Blow, 1960, Cushman Found. Foram. Res., Contr., v. 11, p. 34, Pl. 6, Fig. 1.

Rotalia menardii Parker, Jones and Brady, 1865, Ann. Mag. Nat. Hist., v. 16, ser. 3, p. 20, Pl. 3, Fig. 81.

This species is a commonly occurring form in the warm and temperate oceans of the world. Boltovskoy (1962) has considered it the best warm-water indicator form in his studies of water masses of the South Atlantic. Be (1958) has reported it as occurring most abundantly in the Gulf Stream system when surface water temperatures were between 21° and 24°C. An unsuccessful attempt was made to separate this species into the two forms recognized by Bermudez (1961) as Globorotalia menardii. It was abandoned when it became apparent that such a separation was artificial, and that there was a complete morphologic gradation between these two forms.

A preferred depth range from 50 to 150 meters, and a single preferred depth value of 75 meters

was established for this species. It was present in moderate abundances throughout the sampled water column, and in the deeper portions formed a sizeable portion of the total foraminiferal population. Maximum Standing Crop values were observed in January. A preferred temperature range from 17.6°C to 27.7°C and a single preferred temperature value of 23.8°C were measured. The preferred salinity range was from 36.14 ppt to 36.57 ppt, with a single average preferred value of 36.35 ppt.

Globorotalia hirsuta (d'Orbigny), 1839

Globorotalia hirsuta d'Orbigny, 1839, in Barker-Webband Berthelot, Hist. Nat. Iles Canaris, "Foraminiferes", v. 2, pt. 2, Zool., p. 136, Pl. 1, Figs. 37-39.

This species has been considered by most students of this group to show a preference for temperate waters, being more or less intermediate between the more pronounced warm- and cold-water species. Bé (1958) has reported it occurring most abundantly when surface water temperatures were below 18°C. In the present study it occurred rarely, generally at less than 1% of the total foraminiferal population. The form most commonly observed was the "form 3" of Parker (1962), which she reported as the most common form of this species in the south Pacific plankton.

Globorotalia hirsuta formed only a minor element of the total foraminiferal population in the Florida Straits, with its only occurrence in May, at which time it showed a preference for waters within the 200 to 250 meter depth range. Based on this single occurrence the environmental ranges which are listed must be considered extremely tentative. The preferred temperature range was from 18.0°C to 21.0°C, with a maximum of the population at 20.2°C. The preferred salinity value was 36.61 ppt.

Globorotalia truncatulinoides (d'Orbigny), 1839 (Plate 26, Figs. 11, 12)

Globorotalia truncatulinoides (d'Orbigny), 1839, in Barker-Webb and Berthelot, Hist. Nat. Iles Canaris, "Foraminiferes", v. 2, pt. 2, p. 132, Pl. 2, Figs. 25-27.

This species is common in the temperate and warm water areas of the world's oceans. The specimens examined in the present study exhibited a marked constancy of form, showing essentially no morphologic variation within the samples of this investigation.

This species exhibited one of the more pronounced depth preferences documented in this study, with maximum values almost exclusively limited to the 200 meter depth level, and occurring only within a narrow depth range, from 125 to 225 meters. Although present throughout the water column in varying minor abundances, the only significant populations were restricted to depths of 200 meters or more. It occurred rarely in only minor amounts in the upper 125 meters. Maximum populations were observed in the months of January and April. A preferred temperature range from 18.8°C to 21.5°C, and a preferred average single temperature value of 20.0°C; and a preferred salinity range from 36.56 ppt to 36.85 ppt and a single average preferred value of 36.66 ppt were calculated.

Globorotalia scitula (Brady), 1882

Pulvinulina scitula Brady, 1882, Roy. Soc. Edinburgh, Proc., v. 11 (1880-82), no. 111, p. 716.

Pulvinulina patagonica d'Orbigny sp., Brady, 1884, (not Rotalina patagonica d'Orbigny, 1839), Rept. Voy. Challenger, Zool., v. 9, p. 693, Pl. 103, Fig. 7.

This species has been considered a temperate to warm water species by most previous workers. Bradshaw (1959) referred it to his "transition" fauna, and Parker (1962) found it most abundant north of 50° south latitude. It occurred only rarely in the material from the Florida Straits, where it was not recorded during most of the year, attaining its maximum concentration in October. When present, it occurred sporatically, occurring at one time or another at most sampling depths. A preferred depth of 75 meters was observed. A preferred temperature range from 24.0°C to 28.0°C, and a single preferred temperature value of 27.7°C were calculated. A preferred salinity value of 36.22 ppt was established. Due to the relative scarcity of this species these values must be considered highly tentative.

Globigerina dutertrei d'Orbigny, 1839 (Plate 27, Figs. 2, 3)

Globigerina rotundata d'Orbigny, 1826, Ann. Sci. Nat., ser. 1, v. 7, p. 277, no. 6.

Globigerina dutertrei d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 84, v. 8, Pl. 4, Figs. 19-21.

Globigerina eggeri Rhumbler, 1901, in Brandt, Nordisches Plankton, no. 14, p. 19, Text-Fig. 20.

Globigerina subcretacea Lomnicki, 1901, Naturf. Ver. Berlin, Bd. 39 (1900), Abb., p. 17.

This species, as recognized here, encompassed the full range of variation illustrated by Parker (1962), with the majority of the species conforming to the specimens figured by her on Plate no. 7, Figures 1 through 10. An attempt was made to separate the two "species" Globigerina eggeri and Globigerina dutertrei, after Banner and Blow (1960) and Bermudez (1961), but was abandoned when the complete intergradation of these two morphotypes was established, making any separating of elements other than the extreme end members of the series meaningless from any objective systematic criteria.

There is some disagreement among students of this group as to the temperature preference of this form. Both Bradshaw (1959) and Bé (1959) have suggested a cold water preference, or at least a transitional population element from cold to tropical waters. Boltovskoy (1962), on the other hand, reported it in his "warm water" group. Parker (1960) found it throughout her area of study. Jones (1966, 1969) found it abundantly in material collected from the tropical Atlantic, and established a definite tropical temperature range for it.

It occurred most abundantly in the Florida Straits from April through July, although it was present throughout the year, representing a low but significant portion of the foraminiferal population over the entire period of study. It exhibited a marked preference for the 75 meter depth level, with a preferred depth range from 50 to 100 meters. A preferred temperature range from 19.1°C to 24.8°C, a preferred single temperature value of 22.9°C, a preferred salinity range from 36.13 ppt to 36.49 ppt, and a single preferred salinity value of 36.29 ppt were calculated.

Candeiana nitida d'Orbigny, 1839

Candeiana nitida d'Orbigny, 1839, in De la Sagra, Hist. Phys. Pol. Nat. Cuba, "Foraminiferes", p. 108, Pl. 2, Figs. 27, 28.

This species has generally been reported as showing a preference for warm waters, having been found in the plankton of the temperate and tropical regions of both the Atlantic and Pacific. Its scarcity in the samples of this study was therefore unexpected. It occurred at only a single station (July) with occurrences at 38, 75, and 200 meters. Due to its scarcity no attempt has been made to calculate any of its preferred environmental characteristics.

Globigerinita glutinata (Egger), 1893

Globigerinita glutinata Egger, 1893, Abhandl. K. Bayer. Akad. Wiss. München, CL 11, v. 18, p. 371, Pl. 13, Figs. 19-21.

No specimens containing the bulla, such as those illustrated by Parker (1962, Pl. 9, Figs. 7-9 and 12-16) and by Phleger et al. (1953, Figs. 14, 15) were observed in the samples of this study. The temperature preference of this species has been a matter of controversy, with Be (1959) reporting it in his "cold-tolerant" group, and Bradshaw (1959) and Boltovskoy (1962) considering it a warm-water species. Parker (1960) found it only rarely in her study of the Pacific planktonic Foraminifera.

Although present in only limited numbers in the present study it has been possible to establish a distinct preference for warm waters, where it has demonstrated a higher average preferred temperature range than any of the other species occurring in this investigation. A marked preference for surface water was observed, with a preferred depth range from the surface to 38 meters. A preferred temperature range from 25.0°C to 28.0°C and a preferred single temperature value of 28.8°C, and a single preferred salinity value of 35.98 ppt were calculated.

Total Population Characteristics

Analyses of the monthly total foraminiferal Standing Crop at the Forty Mile Station show the following characteristics: January and July highs, with relatively low values in June, December and February; July and January highs corresponding in general with the total zooplankton high values which are known to occur in this area in the late Spring and Winter. The Foraminifera did not show any demonstratable relationship to the temporal population of any other zooplankton group analyzed, (Rockefeller Report) nor did they correspond with the total zooplankton highs and lows as measured volumetrically. The generally higher daytime than nighttime values for the total foraminiferal population were well documented.

Calculations of the average total Standing Crop in the upper 350 meters demonstrated maximum values for January and July within the 50 to 150 meter depth range. Relatively high near-surface values throughout the year were well shown (Figure 1).

The average total foraminiferal Standing Crop for all samples collected at the Forty Mile Station over the full period of the study indicated maximum average concentrations at 75 meters, with the maximum day value at 100 meters and the maximum night value at 75 meters. Day values were considerably higher than night values in the upper 125 meters, with the night values greater or very close to the day value from 125 to 350 meters. An increase in the Standing Crop values from the surface to a maximum at 75 to 100 meters, followed by a corresponding decrease to a minimum value at 350 meters was observed. The markedly higher daytime values occurred only within the euphotic zone, decreasing rapidly below that level. Some controversy has existed concerning the photic response of the planktonic Foraminifera. The present investigation indicates a positive photic response, with their maximum concentrations occurring in the upper waters during the daylight hours.

The planktonic Foraminifera exhibited different distributional patterns than any other measured planktonic element. The majority of the zooplankton occurred below the euphotic zone during the daytime, when the Foraminifera were most abundant in this zone. Seasonal zooplankton highs in the summer and winter show a general correspondence to those demonstrated by the Foraminifera.

Population analyses of the individual species of Foraminifera have revealed preferred seasonal, depth, temperature and salinity ranges. These data have been discussed under the appropriate species, and are summarized in Table 1 . The preferred depth ranges listed are those within which a significant portion of the population consistently occurred, while the maximum population depth (single preferred value) is the single value at which the majority of the specimens of each species was found. The depth of maximum population occurrence is probably a more reliable index to preferred depth than the preferred depth range, which in most cases included 100 meters or more. The preferred-depth single values and ranges for selected species are shown graphically in Figure 2. The single preferred values for temperature and salinity are considered a more reliable index to the actual species preference than are the preferred ranges for these values.

This investigation is one of few studies yet completed which attempts to define the specific depth-distribution patterns and related preferred environmental values of living planktonic Foraminifera. It should be clearly understood that the values quoted here are provisional. They will undoubtedly require re-evaluation and modification when future studies provide additional data relating to this problem. This study does, however, provide basic criteria for future studies and the information here included, while of a relatively general nature, is accurate within the limits previously defined. It is hoped that it will prove useful in future studies of foraminiferal ecology and paleoecology.

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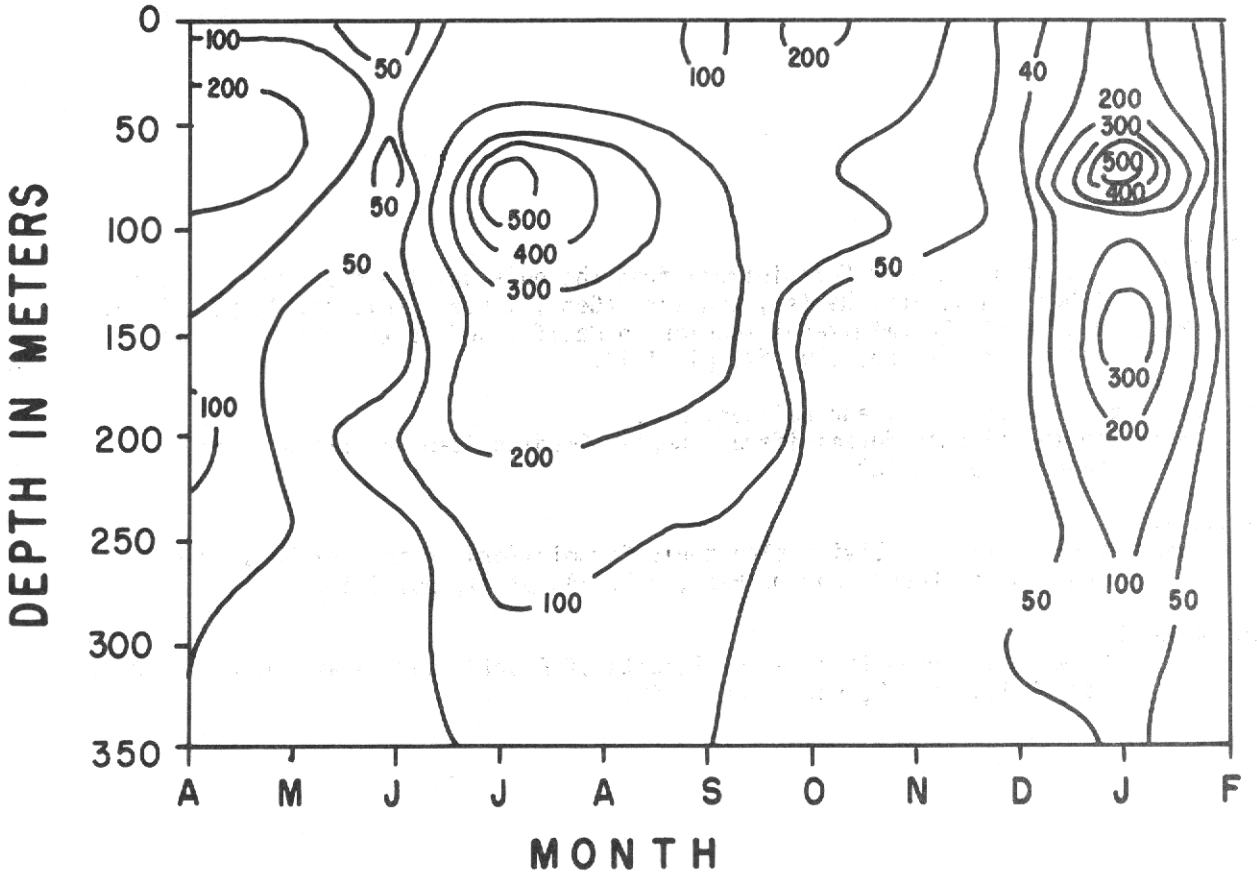

Figure 1 Average total standing crop values for the upper 350 meters at the Forty Mile Station, by month.

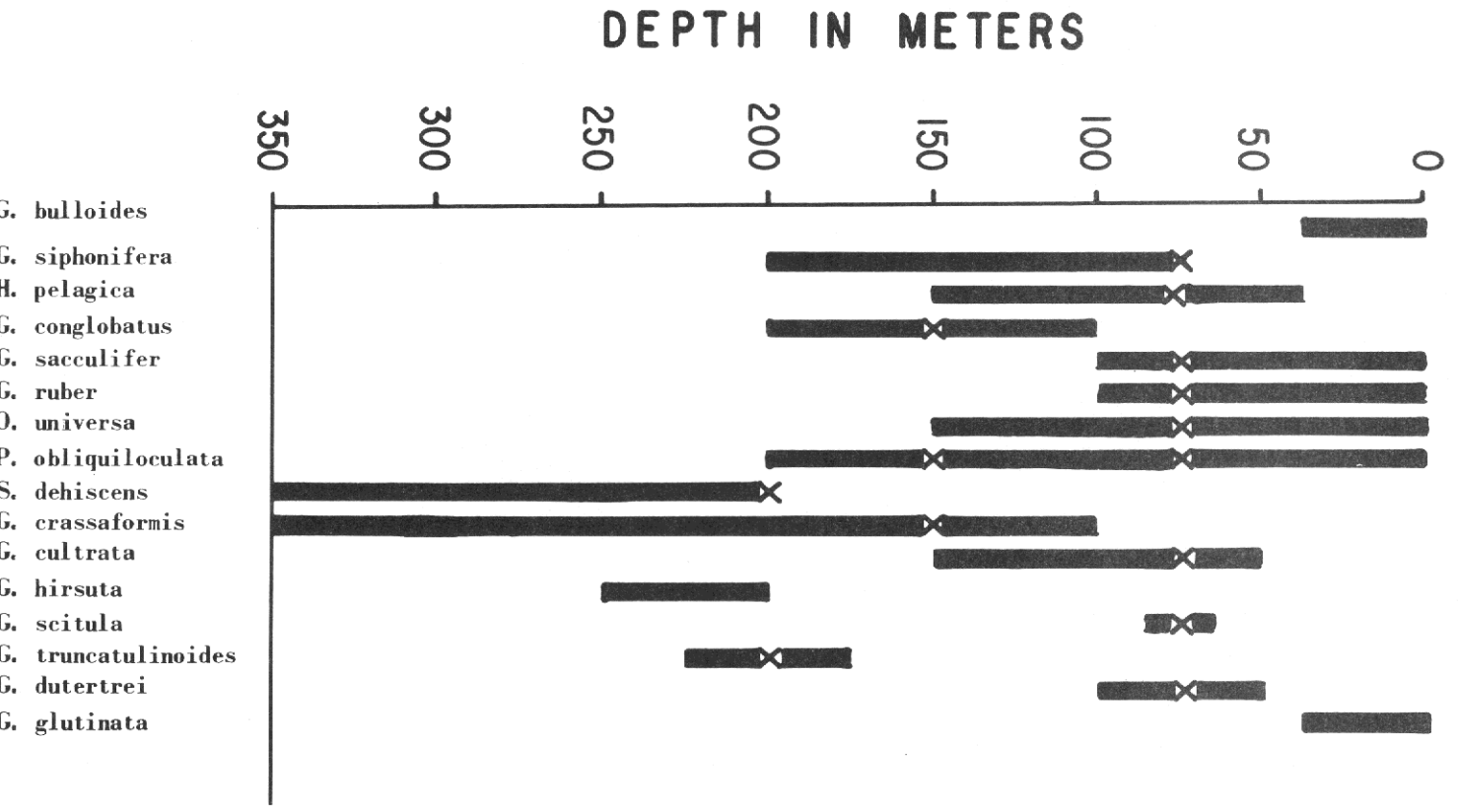

Figure 2 Preferred depth ranges and maximum foraminiferal population occurrences, (X) Forty Mile Station.

Samples no. SL52-60	Depth in Meters for A and B Series																	
	Surface		38		75		100		150		200		250		300		350	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
G. bulloides	3	1-	1			1-	1-	1-		1-	1-	1-	1-	1-	1-	1-	1-	
G. pachyderma																		
G. adamsi																		
G. siphonifera	5	4	8	2	22	16	16	10	13	16	16	18	7	5	1	7	3	7
H. pelagica	5	2	16	3	13	11	15	10	2	7	5	6	3	2	4	4	5	2
G. conglobatus	3	1	2	1	3	2	6	2	5	3	3	3	2	3	1-	2	2	1-
G. sacculifer	34	7	36	14	45	27	46	22	7	27	9	9	9	7	5	4	4	4
G. ruber	69	7	53	40	34	41	56	15	7	11	12	21	14	7	3	7	4	3
O. universa	14	11	41	16	82	64	71	53	41	46	35	33	21	11	24	12	9	7
P. obliquiloculata	5	5	7	3	12	9	6	8	16	3	9	6	5	1	5	2	3	1
S. dehiscens	1-				1-		1-	1-			1-		1-	1-	1-	1-		
G. crassaformis					1-		1-			1-	1-		1-	1-				1-
G. cultrata	6	3	6	2	8	7	8	5	6	5	3	5	5	2	5	2	2	3
G. hirsuta											1-	1-	1-	1-			1-	
G. scitula	1-				1	1-			1-		1-					1-		
G. truncatulinoides	1-	1-		1-	1-	1-	1-	1-		1-	3	2	1-	1	1	1-	1-	2
G. tumida		1-	1-			1-				1-				1-			1-	
G. dutertrei	1-	1-	1-		1	1-	1-		1-		1-	1-				1-	1-	1-
G. glutinata	1-			1-			1-					1-			1-			1-
C. nitida			1-		1-											1-		
T. atlanticus																		

Table 1 Average total standing crops, day (A) and night (B) for the Florida Straits.