The effect of quartz versus calcareous sand on the densities of living foraminifera

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ABSTRACT: To evaluate the effect of quartz versus calcareous sand on foraminiferal densities, the genera *Quinqueloculina, Ammonia, Elphidium* and *Ammobaculites* were monitored at Link Port, Florida. Observations were made over four to seven months in each of 1984, 1985, 1986 and 1987.

Densities were analyzed for each year by two-way ANOVA's. Each year there was a significant periodicity, approximately synchronous across genera, in both substrates. Out of 16 trials only four indicated a significant difference between sediment type. The results lead to the conclusion that the mineralogy of the sediment is not important in regulating foraminiferal densities at Link Port.

INTRODUCTION

The availability of $CaCO_3$ increases with increasing water temperature and salinity. Greiner (1974) reasoned that arenaceous species occupied low salinity areas in the Gulf of Mexico because of the lack of availability of $CaCO_3$ for the secretion of calcareous tests. He believed hyaline tests need less availability of $CaCO_3$ than porcelaneous ones due to the construction of their wall types. He envisioned a gradient from low availability of $CaCO_3$ (arenaceous), intermediate availability (hyaline) to high availability (porcelaneous).

The large size and thick walls of foraminifera in shallow tropical waters has also been attributed to $CaCO_3$ availability (Boltovskoy and Wright 1976). The substantial contribution foraminifera make to carbonate production has received considerable attention (e.g. Hallock et al. 1986). No one, however, has tried to evaluate the significance of the carbonate substrate itself. Is the distinct Florida-Bahamas faunal province due in part to the calcareous sediment?

The purpose of this study is to compare foraminiferal densities in quartz versus calcareous sand to find out if the mineralogy of the sand has an effect on benthic foraminiferal densities. Genera from porcelaneous, hyaline, and arenaceous foraminifera are used for the evaluation. They are *Quinqueloculina* (porcelaneous), *Ammonia* (hyaline), *Elphidium* (hyaline) and *Ammobaculites* (arenaceous). The genus *Quinqueloculina* is represented by the species *Q. impressa* and *Q. seminula.* The genus *Ammonia* is represented by the species *A. beccarii.* The genus *Elphidium* is represented by the species *E. gunteri* and *E. mexicanum.* The genus *Ammobaculites* is represented by the species *A. exiguus.*

METHODS

Quartz sand was obtained from a mud-free sand deposit near Link Port, Florida, and mud-free calcareous sand was obtained from a beach on San Salvador Island, Bahamas. Four windows (35 cm on a side) were cut into each of two large (166 liter) PVC trash cans. The windows were cut so that sediment could be added to the can to a depth of 15 cm. About 30 liters of sand was added to each can and the cans were placed in 15 cm deep holes dug on the bottom (1 m water depth) so that the sediment in the cans was approximately level with the natural sediment, which is 98% quartz sand and 2% mud.

The water temperature at Link Port varies from 12°–32°C and the salinity from 20–38‰ (Nelson et al. 1982).

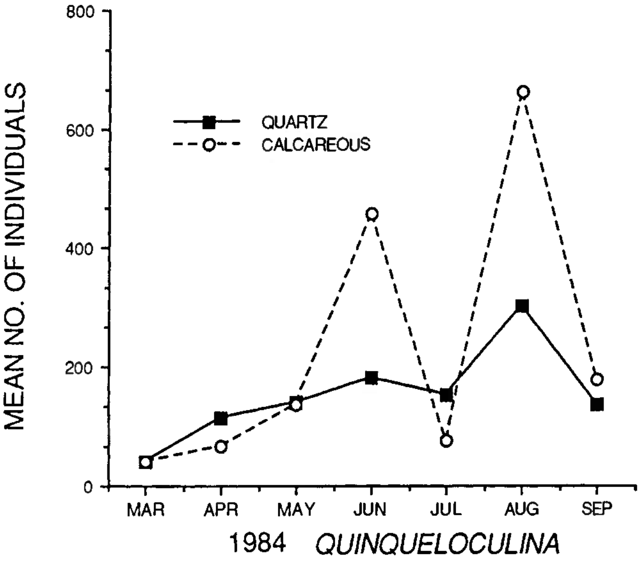
After one month, four replicate samples of 5 ml each were taken by inserting core liners into the sediment of each can. After washing over a 63 μ sieve to remove any mud which might lower the pH or act as a chelating substance, samples were stored in 95% EtOH. Rose Bengal was added the day before enumeration so that the stain would have sufficient time to penetrate the protoplasm. The cans were sampled monthly during the duration of each experiment. The experiments ranged in duration from four to seven months per year (text-figs. 1–16), and were conducted in the years 1984, 1985, 1986 and 1987.

The experiments were designed for analysis by two-way ANOVA's with interaction. Differences in observed densities are tested for by the hypotheses: time, sediment type and interaction (sediment types behave differently with time). The original counts were transformed to $\ln(x + 1)$ to make the data more normal and alleviate the problem of a zero count.

RESULTS

The mean number of individuals per 5 ml for the four taxa are shown in table 1. Sixteen two-way ANOVA's were calculated to analyze the data. Rather than presenting the traditional 16 ANOVA tables, the results are summarized by listing the probability of the F-ratios, p(F), for each hypothesis (table 2).

In 1984 samples were taken each month from March through September. The time hypothesis was significant for all taxa (table 2). Text-figures 1–4 show why this is so. All the taxa had maximum densities in the warmer months. Note the scale on the ordinate is not the same for the taxa so that the maxima achieved by *Ammobaculites* in August and September only amounts to a few individuals, while the maxima for *Quinqueloculina* amount to changes in hundreds. The hy-



TEXT-FIGURE 1
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

TABLE 2
Probabilities of F-ratios, p(F); significant values (< .05) are underlined.

	Quinque-loculina	*Ammonia*	*Elphidium*	*Ammo-baculites*
1984				
Time	$\underline{.00}$	$\underline{.00}$	$\underline{.00}$	$\underline{.00}$
Sediment	.37	.39	.70	.14
Interaction	.45	.49	.57	.06
1985				
Time	$\underline{.00}$	$\underline{.02}$	$\underline{.00}$	.47
Sediment	$\underline{.01}$	.10	$\underline{.04}$	.82
Interaction	.12	.07	.13	.55
1986				
Time	.70	$\underline{.02}$	$\underline{.00}$	$\underline{.02}$
Sediment	$\underline{.00}$	$\underline{.00}$	.22	.96
Interaction	$\underline{.00}$	.06	$\underline{.00}$	$\underline{.02}$
1987				
Time	$\underline{.00}$	$\underline{.03}$	$\underline{.00}$	.19
Sediment	.30	.95	.42	.50
Interaction	.06	$\underline{.04}$	.15	.27

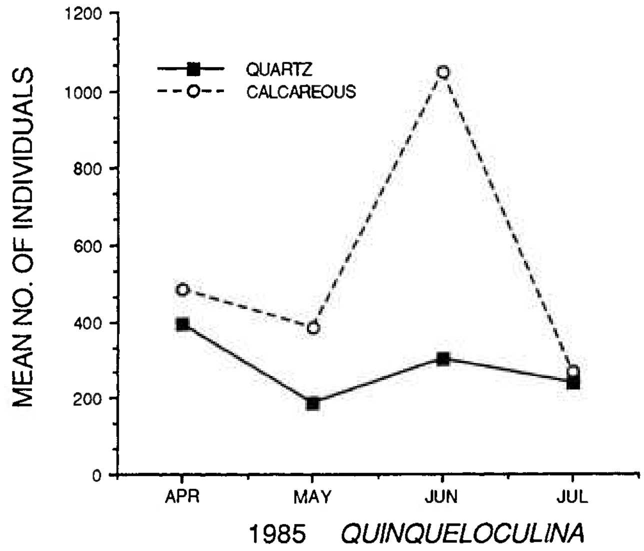
potheses for sediment and sediment-time interaction were not significant (table 2).

In 1985 the experiment was conducted from April through July. Table 1 shows that the highest densities during the four years of experimentation were recorded in 1985. Table 2 indicates the time hypothesis was significant for all taxa except *Ammobaculites.* Text-figures 5–8 plot the mean densities. Text-figures 5–7 show the maximum density for these three taxa is again in the summer. Unlike 1984, the hypothesis for sediment (calcareous vs. quartz) was significant for *Quinqueloculina* and *Elphidium.* Text-figure 5 shows the significant difference for *Quinqueloculina* is due to the very high mean density (1045) in the calcareous sediment during the month of June. For *Elphidium,* June was also the time of maximum density in the calcareous sediment. There were no significant differences for *Ammobaculites,* and text-figure 8 is a good example of why statistical analyses are helpful in making decisions about hypotheses. None of the sediment-time interaction hypotheses were significant.

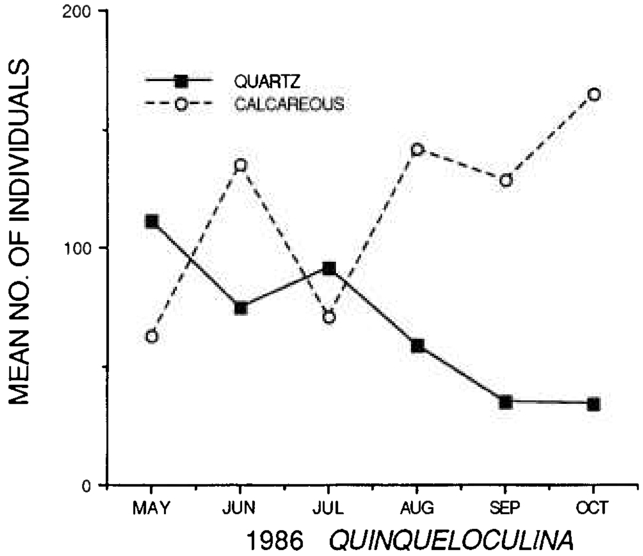
In 1986 the experiment was conducted from May through October. This year had, by far, the lowest mean densities recorded (table 1). The time hypothesis was significant for all taxa except *Quinqueloculina* (table 2). Maximum densities for calcareous sediment were in September and October (text-figures 9–12). Maximum densities for the quartz sediment

TABLE 1
Mean densities of foraminiferal genera in quartz and calcareous sand at Link Port, Florida.

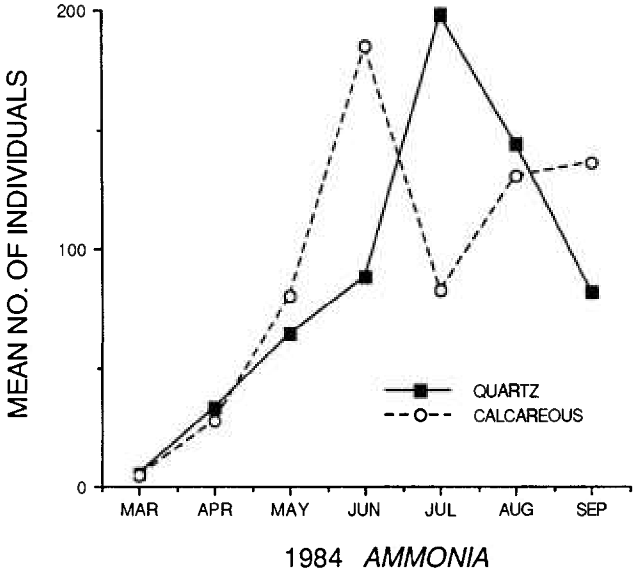
	1984	1985	1986	1987
Quinqueloculina				
Quartz	151.68	280.06	67.50	423.19
Calcareous	232.18	546.06	116.79	336.25
Ammonia				
Quartz	78.79	157.75	32.58	112.25
Calcareous	92.77	201.38	51.83	102.25
Elphidium				
Quartz	24.39	62.88	6.0	27.56
Calcareous	21.32	73.31	10.00	20.44
Ammobaculites				
Quartz	8.29	16.19	5.83	8.93
Calcareous	3.21	14.13	6.62	12.00



TEXT-FIGURE 2
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



TEXT-FIGURE 3
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



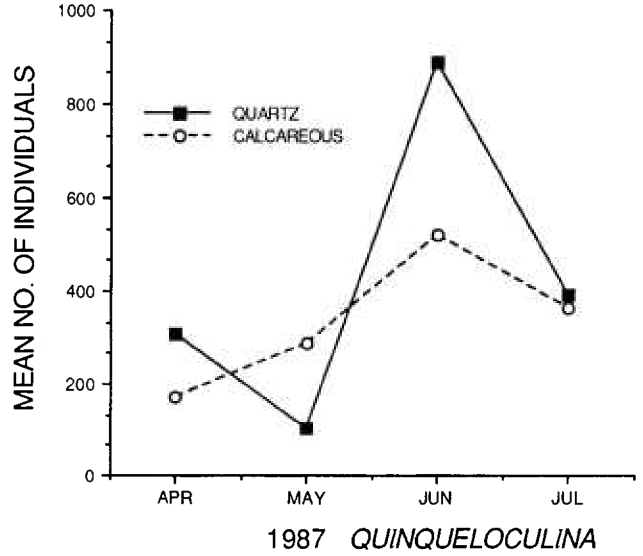
TEXT-FIGURE 5
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

were in July and August except for *Quinqueloculina* which peaked in May. The sediment hypothesis was significant for *Quinqueloculina* and *Ammonia*. In both cases the calcareous sediment had higher mean densities (table 1). Unlike other years, the interaction hypothesis was significant for all taxa except *Ammonia*, and it was almost significant for this species. The reason for this is because in the fall the density in the calcareous sediment was rising while the density in the quartz sediment was falling (text-figs. 9–12).

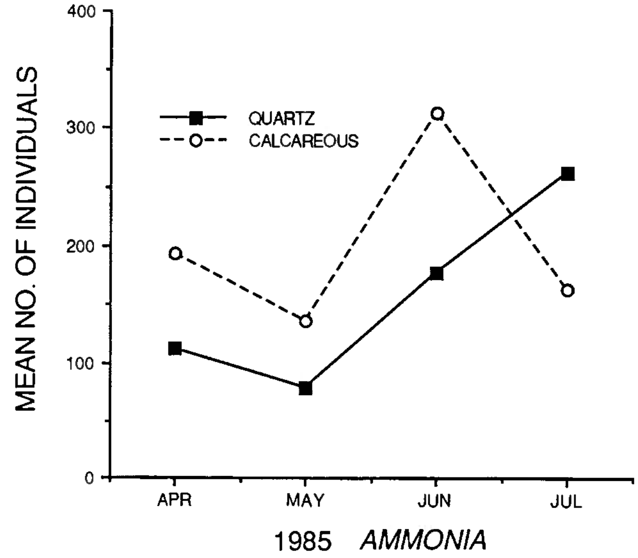
In 1987 the experiment was conducted from April through July. The time hypothesis was significant for all taxa except *Ammobaculites* (table 2). The highest densities were in the summer for all genera and both sediments, except for an *Ammobaculites* calcareous peak in May (text-figs. 13–16). Like 1984, there were no significant differences with sediment type. The interaction hypothesis for *Ammonia* was significant, probably because the densities in the calcareous sediment remained relatively constant in May, June and July while the densities in the quartz sediment fluctuated.

DISCUSSION

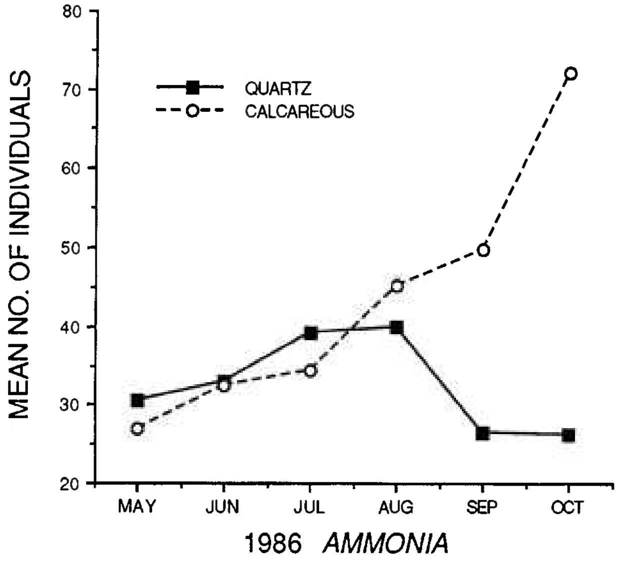
In all but two cases, the time hypothesis is significant (table 1). This is not surprising because in 1976, 1977, 1978 and



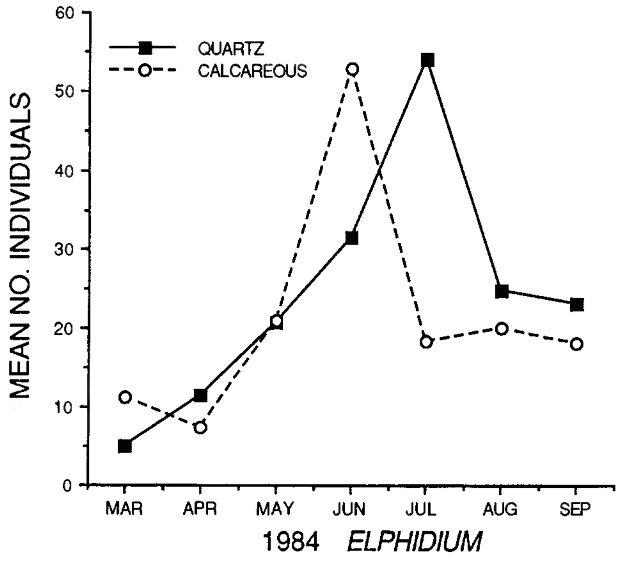
TEXT-FIGURE 4
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



TEXT-FIGURE 6
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



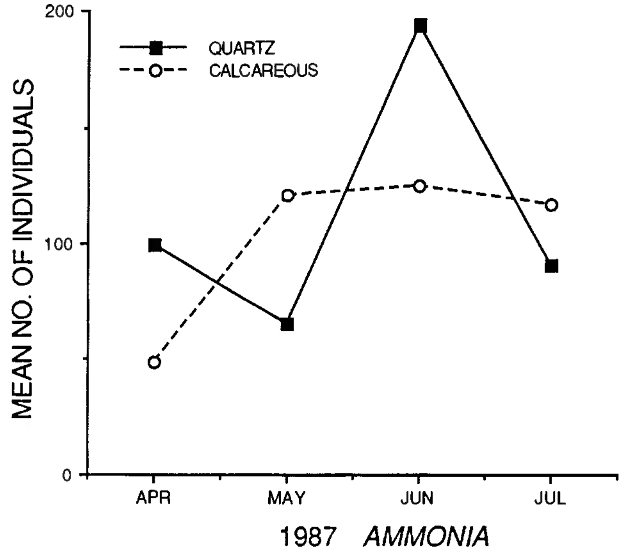
TEXT-FIGURE 7
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



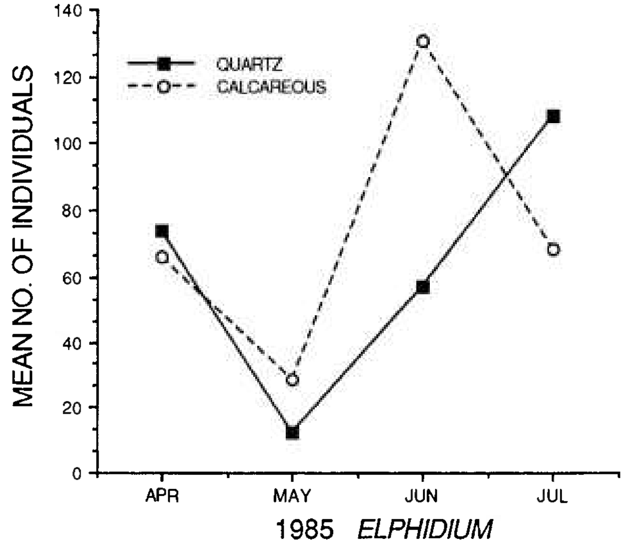
TEXT-FIGURE 9
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

1979, while conducting predation experiments at the same location, Buzas (1978a, 1982) observed that the foraminiferal species always exhibited periodicity. Indeed, seasonal periodicity has been demonstrated for benthic foraminifera from all over the world (Boltovskoy and Lena 1969; Buzas 1969; Buzas et al. 1977; Daniels 1970). Moreover, most species exhibit similar periodicities, although there are some exceptions (Boltovskoy and Lena 1969; Buzas et al. 1977; Daniels 1970). Apparently, when times are good for one species they are good for most. Therefore, relative abundances or species proportions remain fairly constant. In this study, the taxa maintained fairly constant species proportions from year to year in both experimental sediments and in the natural environment (table 3). In 1986 all taxa had relatively low densities while in 1985 and 1987 all had relatively high mean densities (table 1), but species proportions remained relatively constant (table 3). This orderly ranking of taxa is not exhibited by the benthic macrofauna in the same area (Young et al. 1976; Buzas 1978b). It is also not exhibited by planktic foraminifera (Cifelli and Smith 1970).

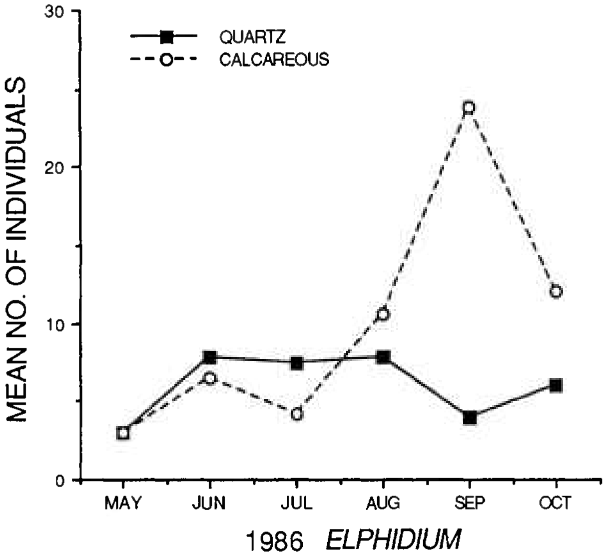
Previous work (Buzas 1978a, 1982) indicates predation greatly depletes benthic foraminiferal densities. Consequently, the benthic foraminifera may be continually below the carrying



TEXT-FIGURE 8
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

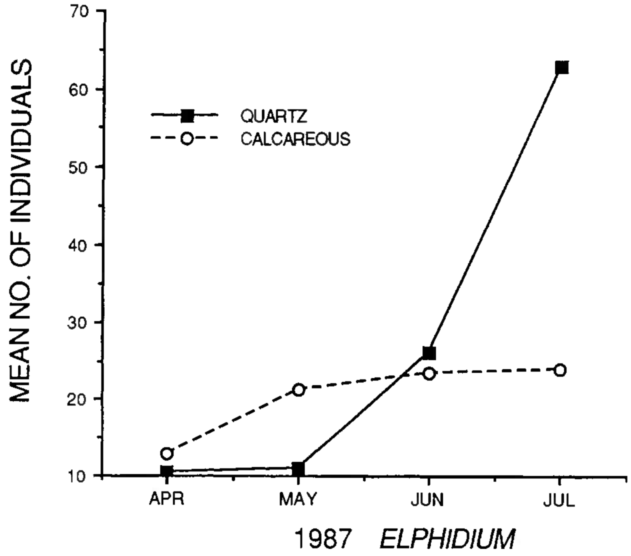


TEXT-FIGURE 10
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

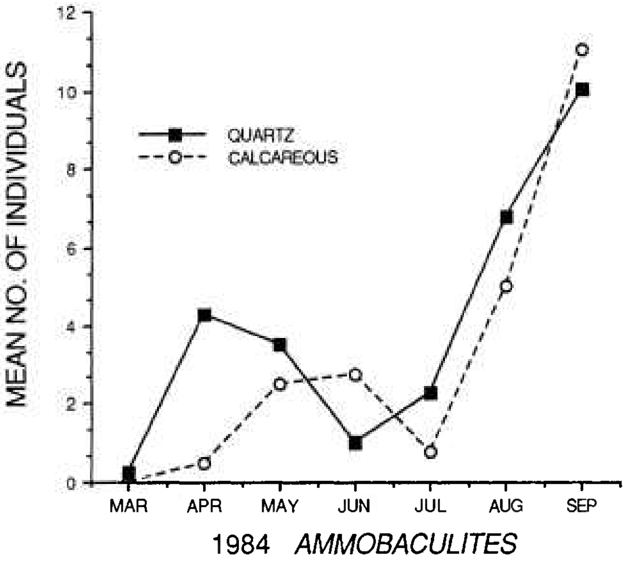


TEXT-FIGURE 11
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

capacity of the environment and are, therefore, subject to the exponential Malthusian reproduction equation which is $N_0e^{rt} = N_t$, where N_0 is the number of foraminifera at some arbitrary intial time, N_t the number t time units later, e the base of the natural logarithms, and r the intrinsic rate of natural increase. If so, then the maintenance of the rank order of species density might be due to a constant r among species. In this case, all species would be cropped in proportion to their densities. On the other hand, if some species are selectively preyed upon, to maintain constant species proportions will require differences in the value of r. Unfortunately, no data exist for the species in the Indian River.



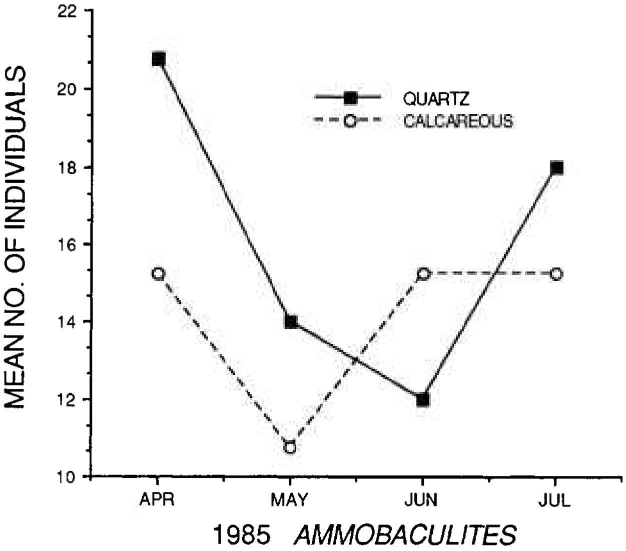
TEXT-FIGURE 12
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



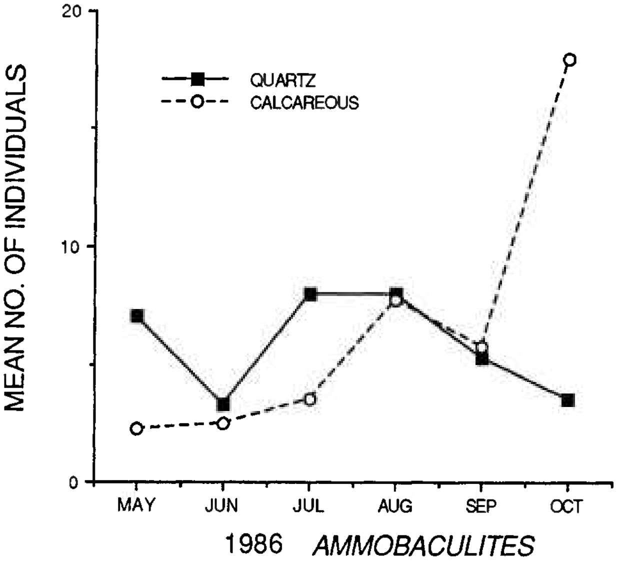
TEXT-FIGURE 13
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

The value of r must vary for foraminiferal species in different environments because some species are dominant in a particular environment and rare in another. For example, *Elphidium excavatum* is dominant in Long Island Sound (Buzas 1965), but rare in the Indian River, Florida (Buzas and Severin 1982).

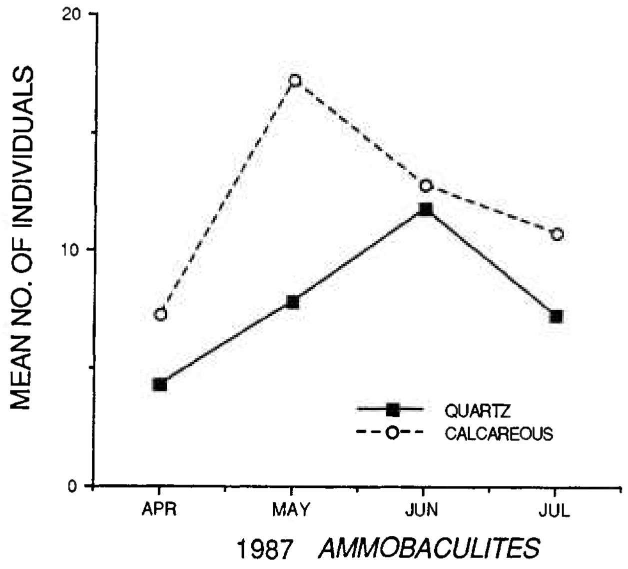
The hypothesis testing for differences in density between quartz and calcareous sand was significant four times out of 16 trials (table 2). These were for *Quinqueloculina* in 1985 and 1986, *Ammonia* in 1986 and *Elphidium* in 1985. In all these cases the calcareous sediment had the highest densities. In general, the results (12 non-significant trials) do not war-



TEXT-FIGURE 14
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



TEXT-FIGURE 15
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.



TEXT-FIGURE 16
Mean number of individuals per 5 ml in trash cans at Link Port, Florida.

rant any belief that the taxa involved prefer either calcareous or quartz sand. It is significant for the structuring of ecological studies to note that, had the experiment been performed only in 1985 and 1986, I probably would have attached some significance to the mineralogy of the sand.

Three of the four significant interaction hypotheses occurred in 1986. For some unknown reason, in the fall of 1986 densities were dropping in the quartz sand while they were on the rise in the calcareous sand (text-figs. 9, 11, 12). Most likely, this was a coincidence, because for most cases the interaction hypothesis is not significant, and I conclude that foraminiferal densities in the calcareous and quartz sands behave similarly with time.

TABLE 3
Percentage of taxa in quartz sand, calcareous sand, and the natural environment (quartz sand) at Link Port, Florida.

	1984	1985	1986	1987
Quartz				
Quinqueloculina	58	54	60	74
Ammonia	30	31	29	20
Elphidium	9	12	5	5
Ammobaculites	3	3	5	2
Calcareous				
Quinqueloculina	66	65	63	71
Ammonia	27	24	28	22
Elphidium	6	9	5	4
Ammobaculites	1	2	4	5
Natural environment				
Quinqueloculina	65	50	56	62
Ammonia	24	36	29	28
Elphidium	9	8	8	5
Ammobaculites	2	5	7	4

The genus *Ammobaculites* has low densities in both sediments. The taxa in this study makes its test out of quartz grains. In both the calcareous and quartz sands individuals had tests made of quartz. It is unclear whether or not the individuals in the calcareous can were washed in from the natural environment or if they utilized quartz grains which were washed into the calcareous can. Perhaps, both phenomena occurred.

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