CORAL VARIATION WITH DEPTH ON THE EAST FORE REEF AT DISCOVERY BAY

-OR-

AROUND THE REEF IN TWENTY DIVES

Randy, Jesse, Aron:

A very thorough study containing lots of information. Your results are well and concisely presented. Your discussion is excellent.

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March 3, 1980

INTRODUCTION

This study examines variations in distribution, diversity and spatial heterogeneity of corals and other sessile invertebrates with depth. Also investigated are were depth-related variation in wave surge and morphology of Montastrea cavernosa and ~~Meandrina cerebriformis~~ Agaricia agaricites.

This is basically a descriptive work which seeks to characterize a system that is so poorly understood that most recent literature concerning it is also on the descriptive level.

We have compared our results with those of other studies (Goreau and Goreau 1973, Loya 1976) in an attempt to see if some general principles can be drawn concerning species distribution on coral reefs. In so doing it became apparent that the literature requires many more descriptive studies before ~~solid empir~~ species distribution on coral reefs is well enough understood to allow solid empirical work to be done on the general level.

Methods and Materials:

This study was done at five locations on the East Fore Reef of Discovery Bay, Jamaica. The approximate locations are marked on the map located on the following page. Data were collected by SCUBA diving techniques between the dates of Feb. 23 and March 1, 1980. The depths studied were 20, 40 and 60 feet.

The first portion of the project concerned coral diversity over depth. To study this, transects were placed at 20, 40, and 60 feet, with replicates at 20 and 40 feet. Transect location was determined by beginning at a mooring and following a predetermined compass heading until the desired depth was reached, as measured on depth guage. At this point a 5m transect line, weighted at both ends, with a marker bottle attached to one end, and marked into 1m segments with surveyors tape, was placed at each site. The 20 foot transects were established by heading due South from the shallow mooring. The 40 foot transects were North-Northwest of the medium mooring, and the 60 foot was Northwest of the medium mooring.

After placing the transect line, a 2m x 2m quad was placed on the line such that half of the quad was on each side of the line. By moving the quad over the length of the line, a transect of 5m x 2m was covered. The quad

itself was divided into sixteen 0.25 m^2 segments. In dealing with the coral, each 0.25 m^2 segment was considered separately. For each segment, all of the coral species were identified, either *in situ* if possible or in the lab if the underwater guide did not contain that coral, and then percent cover for each was estimated. Sponges, gorgonians, sand, anemones, zoanthus, palythoa, and dead coral (hard substrate) percent covers were also estimated.

The area around the transect was further studied in terms of coral depth. The height of the coral in the area surrounding the transect was measured by randomly selecting areas and determining the height using a meter stick divided into 10cm units. Random selection was done by throwing the stick and using the spot which the front of the stick hits.

The same area was used to determine polyp density and polyp length for *M. cavernosa* and *A. agaricites*. For *M. cavernosa* a wire mesh with a 25 cm^2 area cut out of it was placed over a colony and all of the polyps within were counted. For polyp diameter the elevated calices were measured. The density of *A. agaricites* polyps was determined using one square of the wire mesh. This was $\frac{5}{6}$ cm x $\frac{5}{6}$ cm, or .69 cm^2, and will hereafter be called one unit. Polyp length was measured by using the length of each depression as the polyp size. An additional study was done on *A. agaricites*, which that was

to compare the number of polyps in each groove. In all polyp studies, no more than five measurements were ever taken from a single colony and three was the normal number. For polyp density of M. cavernosa only one count per colony was taken.

The last set of measurements taken was a series of wave surge measurements. These were taken at 20 and 40 feet on both the East and West Fore Reefs. On the East fore Reef measurements were taken by the shallow and middle moorings. For the West Fore Reef the measurements were both done near mooring number one. The study was done on March 1 between 15:30 and 17:00 hours. At each site the frequency of the wave surges was measured by two methods. The first was by observing the pattern of a neutrally buoyant bottle and the second by observing seafans waving. All timing was done using the sweep second hand of a Heuer diving watch. The amplitude of the wave surge was measured by allowing a neutrally buoyant bottle to oscillate in the water and holding a meter stick alongside of it. Divers were careful to keep from blocking the surge. They also held on to coral to keep from oscillating themselves. The bottle was kept between one and two meters off the bottom.

The last part of the project concerned

developing a heterogeneity and complexity (HAC) variable for each transect. The method of calculating it is discussed in the Results section. It included a measure of the macroscopic diversity which each coral species creates. This measure was determined subjectively based on the personal qualitative observations of the authors. Also considered was the fate of dead coral and how it contributed to environmental diversity.

RESULTS

Percent cover of substrates, corals and other sessile invertebrates for each of the five 10 m^2 transects may be found in TABLE 1. The standard deviations were calculated from differences among ~~each~~ the ten 1 m^2 sections of each transect.

GRAPH 1 presents the % cover data in bar graph form. Note that % cover of substrates are shown at 1/10 scale for ease of presentation.

Trends ~~of~~ in changes of % cover ~~for substrates~~ with depth for substrates and groups of organisms (live coral, sponges, gorgonians, anemones, and zoanthids) may be found in GRAPH 2. More specific information concerning % cover vs. depth for each species of coral and Millepora are given in GRAPH 3.

Two approaches were used to gain some insights into differences in ~~species~~ coral species distribution between transects at equal and different depths. The calculations and results for these approaches are shown in TABLE 2

In TABLE 3 may be found the results of amplitude and period measurements on wave surge at 20' and 40' on the east and west fore-reefs (TABLE 3B), as well as ~~measurements~~ calculations of coral species diversity (TABLE 3A), and measurements of coral depth ~~(TABLE 3C)~~, and spatial heterogeneity and complexity ~~(otherwise (heretofore known~~ (the HAC variable) (TABLES 3A & 3C).

Data concerning variations in polyp density and polyp morphology of Montastrea annularis and Agaricia agaricites with depth are presented in GRAPHS 4 through 8.

Note that the raw data for % cover of substrates, corals, and other sessile invertebrates for each 0.25 m^2 section can be found in the ~~app~~ APPENDIX ~~in~~ TABLES 4, 5, and 6. The subject rankings used for the HAC variable are located on Table #6

DISCUSSION.

1) Diversity. Diversity is something of a nebulous term, and has been defined in a number of ways. One of the simplest approximations to diversity is a simple species count. The results of such a count at each of the three depths sampled appear in Table 3A. The fact that, for both the 20' transects and the 40' transects, the total number of species sampled is greater than either of the individual transects indicates that some species were found in each that ~~were~~ were absent in the other. This seems to indicate the patchiness of some rare corals and the need for larger transects or more replicates. In any case, it seems likely that had a replicate been done at 60 feet, more species would have been found. Since this is unknowable, it seems necessary to compare results from individual transects to get the most realistic relationships. The result is that there appears to be very limited variation with depth, with perhaps a few more species at 40 feet than at 20 feet, and no great difference from either at 60 feet. ~~There are too few data to perform any statistical tests on this or the other diversity measures.~~

Another, more comprehensive measure of diversity is the Shannon-Weaver index, more commonly used where numbers of individuals are readily accessible. There numbers are turned into a proportion of the total community to yield a measure of importance; we used percent of total cover made up by each species of coral as a measure of importance, as in Loya (1972, 1976). The results are again in Table 3A. Ignoring the absence of a duplicate 60 foot transect, there is apparently a decrease in diversity as depth increases. When the lack of a duplicate is taken into account and the individual transects compared, however, the difference does not seem as pronounced. This is largely due to the patchiness in the corals at 20 feet, which leads to the observed increase in species number when both transects are looked at, which in turn

increases the diversity of the two transects together considerably above either one alone. If it should turn out that diversities do decrease with depth, this could perhaps be explained by a decrease in light intensity, which would limit the number of species which could grow, and their quantity. This would also agree with Loya's (1976) results for a Puerto Rican reef between the upper and lower fore-reefs, in which the diversity decreased from the upper (11-17 m - about equivalent to our 40 foot sites) to the lower (18-20 m - our 60 foot site). Our data disagrees with Loya's, however, on the difference between the 40 foot and 20 foot sites: our diversity is higher at the 20 foot sites, where his were lower. This is in spite of the fact that our species number trends agree fairly well with his, which indicates that the distribution (ie, percent covers) of our corals were of 20' were of higher ranks more less even than his. This agrees with his interpretation that the decreased diversity on the reef flat was due to dominance of a few species: we had many species of various importances. He ascribes this to decreased turbidity and a self-cleaning action on the steep slope which tends to rid it of sediments, which presumably provides the most favorable environment for growth, since % ~~cover~~ living coral cover is highest here. This, he seems to imply, has allowed a few species to outcompete the others and decrease diversity. Given the relatively low percent cover at our 20 foot sites, it would seem that they are not as favorable environments as Loya's reef-flat. Possible reasons will be discussed later. Hence the lack of competition allows for various colony sizes and increased diversity.

In order to obtain a measure of diversity relevant to the provision of living space for other species (stretching our data to the breaking point), we compounded a new variable entitled the Heterogeneity and Complexity (HAC) variable, explained below Table 3A. It consists of a subjective structured diversity ranking

for each coral, percent covers of each coral in a transect, and average height of the coral in that transect, in order to give a relative number of spatially different microhabitats available. This in turn should reflect the possible diversity of life each area can support, assuming space is a limiting resource. Our HAC values appear in Table 3A. They are greatest at 40 feet, somewhat less at 60 feet, perhaps reflecting our lack of a duplicate transect, or more likely, an increase in the percentage of structurally uniform corals such as Siderastrea siderea and Montastrea cavernosa exceeding the decrease in other such corals (e.g. Montastrea annularis) (see Graphs #3). The HAC variable also decreases from 40 feet to 20 feet, largely due to a decrease in mean coral height (see Table 3C). Hence, one expects an increase in hiding and various attaching spots at 40 feet, and thus a total community structure which is more diverse, relative to 60 feet, with 20 feet being less diverse than either. The only ~~species~~ groups for which we have data are sponges, which are more numerous, though not necessarily more diverse, at 40 feet than at 60 feet, and at 60 feet than at 20 feet; gorgonians, which show just the opposite trend, perhaps because structural diversity increases the ~~difficulty~~ probability of colonizing a poor site (ie likely to break) (for the sorts of problems gorgonians have with substrate, see Kinzie (1973)); anemones, which show a trend similar to that for sponges; and zoanthids, which decrease with depth, perhaps due to decreased light, increased competition, or increased predation (R. Lathrop, pers. comm.). Whether the diversity of these groups follow the expected trends, or if other groups, such as vertebrates, invertebrates, and algae, follow our predictions is beyond the scope of this study but would be useful to know.

Our wave data (Table 3B) may help explain the high diversity with relatively low species number at 20 feet in a way quite different from Loya (1976). While we were able only to get data

from 20' and 40', there was a definite increase in the surge at 20 feet, with "gusts" up to ~~[illegible]~~ three times the amplitude found at 40 feet. This may be due to the fact that waves "feel bottom" at depth equal to half their wavelength. Hence no surge would be felt at 40 feet from waves with wavelengths between 20 and 40 feet, while these would be felt at 20 feet. There would, however, be some waves of sufficiently long wavelength to be felt at 40 feet, and some even at 60 feet, but these become increasingly rare. Net result is that the 20 foot sites are subject to a great deal of surge, which would eliminate some of the more fragile species, and perhaps provide sufficient disturbance for the remainder of the system to be maintained in a nonequilibrium, and therefore potentially more diverse than expected, state.

Interestingly, the total percent of the transects covered by dead matter (ie dead coral and sand) is more or less constant over depth (~~Table~~ Graph 2). This would seem to indicate that space is not limiting, since about 60% of the substrate is generally bare, but there may be some other resource being competed for, or a process of extinction and ~~equilibration~~ recolonization (perhaps caused by predation) which has reached equilibrium with less than the whole surface of substrate colonized. This may explain why our diversities on the whole were ~~[illegible]~~ somewhat higher than in Loya (1976), since no species is ever allowed to competitively exclude another here, where such may be happening in Puerto Rico where percent covers are much higher.

All of the above discussion on diversities should be regarded as speculation on possibilities, since the data producing the trends in diversity are scarce and the differences at various depths appear to overlap to some degree, ie there may not be any real differences.

2) Species distribution. Graphs 3 is ~~are~~ a summary of all the species of coral we found and their average percentages at each depth.

Dominant at all depths are Montastrea annularis and M. cavernosa, which ~~make up 12%~~ have together a cover of 17% at 20 feet, 16% at 40 feet, and 21% at 60 feet, although they individually vary, apparently without pattern. The importance of these two together agrees qualitatively with Loya (1976) and Goreau and Goreau (1973) for the depth range studied. The next most common species overall was Agaricia agaricites, which again is consistent with these authors. All three of these species have wide variations with depth which are apparently without pattern, which may be an artifact of our small sample size. General observations indicate that at shallow depths on the reef crest, Acropora palmata is dominant (R. Lathrop, pers. comm.), consistent with Goreau & Goreau (1973), but it is absent from all our transects. This is one of only a few corals showing definite trends with depth. Siderastrea siderea increases from about 1% to about 6% from 20 feet to 60 feet, while Porites astreoides drops from about 5% to about 2%. Millepora complanata drops from a little over 1% at 20 feet to zero at 60 feet, and Madracis decactis drops from about 1% to almost nothing. The Millepora and Madracis agree fairly well with Goreau and Goreau (1973), as does the Siderastrea, but the Porites varied in a manner ~~would be expected to do the opposite of what it did~~ opposite to that described in Goreau & Goreau. Other species with more than 1 percent of total cover at some depth are Diploria labyrinthiformis (1.6% at 60 feet), Siderastrea radians (1.1% at 60 feet), Porites porites (at least 1% at all depths), and Acropora cervicornis (1.5% at 40 feet). These and all the other corals found except those noted above showed no definite trends with depth, consistent with Goreau & Goreau (1973), where a bell-curve with depths above which and below which a given species would not grow were rare.

also

This also agrees with Loya (1976), which states that ~~below~~ above 30 meters, coral diversity is not likely to be limited by light attenuation. This then eliminates the possibility that light attenuation is responsible for the decrease in species diversity at 60 feet, as proposed in the previous section. Comparison of species present at various depths

~~Comparison of the species distribution with the general zonation described for the west fore-reef at Discovery Bay, shows remain Woodley and Robinson (1977) shows some major differences. The reef flats are the same, with large quantities of Acropora palmata~~ and across transects at the same depth (Table 2) indicate that ~~species percent~~ species differences between depths were about the same as ~~species percent~~ species differences between transects. This again seems to indicate that the species found are not strongly zoned with depth, and that more species would be found at each depth if more transects were done.

This contrasts strongly with the situation for the west fore-reef at Discovery Bay, as described in Woodley and Robinson (1977). Our 20 foot site is included in the depth range of their barren zone, which includes low density corals and has a low diversity, in marked contrast to the high diversity and 33 percent live coral cover found. The mixed zone is more comparable, with its high abundance and diversity, although relatively little Acropora cervicornis was found. This zone was at 8 to 15 m, about equivalent to our 40 foot sites. From 15 to 25 m, which includes our 60 foot site, is the Acropora cervicornis zone, similar to the mixed zone, but A. cervicornis is dominant. This is very dissimilar to our results, at least in regard to the quantity of A. cervicornis ~~the~~ found, which was virtually nil. Otherwise, the corals present and their abundance and diversity is similar to a very extended mixed zone. A possible reason for this lack of A. cervicornis relative to the west fore-

reef is wave action. As mentioned earlier, the surge on the east fore-reef was very strong at 20 feet relative to 40 feet (Table 3B); the surge at 20 feet on the west fore-reef, however, is about half that at 40 feet on the east fore-reef, and surge at 40 feet on the west was less than half of that. Even with that relatively moderate surge, there were large quantities of broken cervicornis to be seen on the west reef. It may be that the surge on the east reef is simply too strong for the fragile staghorn coral to establish itself. The reason for the difference in surge, has its cause, in turn: ~~the~~ topography and climate. The tradewinds blow from the northeast, which is the direction the east fore-reef faces, while the west fore-reef is sheltered by the east. Thus the daily surge pounds much harder on the east reef, and storms probably do the same. An interesting question is just why the east reef extends so much further out into the ocean if it gets broken down so much more by waves. It may be a simple matter of underlying formations, or some quirk in the reef development.

3) Polyp Morphology

In discussing polyp morphology over depth, the two coral species will be considered separately. M. cavernosa has well developed tentacles and does significant feeding via them. A. agaricites has primitive tentacles and feeds mainly with mucus (Kinzie, lecture). This difference will be important in considering the different polyp morphologies.

Lasker (1977) says that it has been proposed to distinguish two morphs for M. cavernosa. These are large and small or nocturnal and diurnal morphs. "The diurnal morph colonies have small polyps...

and the nocturnal polyps have large polyps" (Lasker 1977). The diurnal polyps are expanded during the day due to energetic benefits from photosynthesis by zooxanthellae. The nocturnal polyps have less zooxanthellae and would derive less photosynthetic benefit by expansion during the day and hence are expanded only at night. Below 20m one rarely finds diurnal morphs (Lasker 1977). Thus all makes sense. As depth increases, light intensity decreases, and hence one would expect more nocturnal morphs with depth. One would also expect intermediate morphs or at least mixed colonies at intermediate depths. Lasker (1979) says that intermediate morphs as far as expansion is concerned do exist; hence it seems logical that they would be intermediate in size as well. The picture #3 on page 198 of Lasker 1979 shows an example of mixed morphs in a colony. Another point to note is the difference in the tightness with which the polyps are packed in the five pictures. The nocturnal polyps are farther apart while the fully expanded diurnals are closer together. This too would make intuitive sense. At shallow depth diurnally expanded polyps are more photosynthetically effecient than the interpolyp spaces. The interpolyp spaces meanwhile are more photosynthetically effecient than nocturnal polyps which are contracted during the day. Hence at shallow depth dense polyps would be expected. At increased depth, the expanded polyps are no longer energetically effecient and hence the colony turns to more interpolyp space. This is supported by the fact that that at depth there is a greater percentage of the total zooxanthellae in the interpoly space.

How does this relate to our data? To begin with, we found a significant increase in polyp size as depth increased

from 20 to 60 feet. This is what is expected. Looking at graph #5, one sees a wide range of polyp size. As from 20 to 60 feet is an intermediate depth, one would expect a wide range of polyp sizes. The results definately show this wide range.

Graph #4 shows that there is also a significant decrease in polyp density with depth. Part of this is due to larger polyps. They are also farther apart. This enables the coral to maximize net photosynthesis by decreasing polyp area, increasing coenosarc area, and zooxanthellae density in the coenosarc (Lasker 1977). Another possible explanation, or actually another way of looking at it, is presented in Goreau 1963. He explains that $CaCO_3$ production is a function of photosynthetic activity while tissue growth is a function of how well fed the coral is. He uses this as an explanation of growth form, but it could help explain polyp morphology and density as well. Larger polyps are also deeper and hence have a smaller surface area to volume ratio than smaller polyps. Presumably a fairly large amount of $CaCO_3$ is needed to produce a chalice compared to interpolyp space. Hence, larger less dense polyps might be the result.

It is interesting to note that different coral species react differently to increased depth. M. annularis also decreases polyps/cm^2. The chalice size remains unchanged but the polyps are farther apart (Dustan 1979). O. agaricites has significantly more polyps/cm^2 at 60 feet than at 20 feet. The explanation for this can be seen by looking at graphs #7 and 8. Graph #7 shows that polyp size remains unchanged with depth. Graph #8 reveals an insignificant trend. Much of the reason for the insignificance is the large standard deviation. However, the trend appears to hold, the trend being

more polyps per groove with increased depth. At 20 feet there are few polyps per groove and hence a lot of area is taken up by the ridges. At 60 feet there are less ridges and hence there is more room left for polyps. Of course it is possible that the polyps within a given groove are closer together (i.e. had less interpolyp space) at increased depth, but this does not appear to be the case as within grooves there appears to be no difference in interpolyp distance. This can not be stated definitively however as no measurements were taken.

The authors can only speculate as to why polyp density increases with depth. One possible explanation would deal with light intensity difference and the resulting difference in photosynthetic efficiency. Because the tentacular development of *A. agaricites* is so low, it would seem as if whether or not the tentacles are extended would make little difference photosynthetically. However the amount of surface area of the coral would be a significant factor. The ridges on the side of these grooves would add to the useable surface. At increased depth, there is less need for increased surface area. At the same time available $CaCO_3$, which is a function of photosynthesis, becomes less (Goreau 1963). Hence it no longer becomes energetically worthwhile to build these ridges.

The groove and the number of polyps in it are a result of a certain type of reproduction which supposedly differs from creating new grooves. Hence the two reproductive modes would have to be regulated in some way by the $CaCO_3$: tissue ratio or photosynthetic levels in the zooxanthellae. This would have interesting possibilities.

CONCLUSIONS

Not surprisingly for such a time-limited study, there are but a few solid conclusions which can be drawn. First is that coral species diversity seems to vary only slightly between 20 feet and 60 feet on the East fore-reef, when measured either as species number or by the Shannon-Weaver index. In spite of this, there seems to be much ~~so~~ more spatial heterogeneity at 40 feet and at 60 feet than at 20 feet, which should provide more microhabitats and thus support a greater array of inhabitants. This is largely due to a decrease in ~~height~~ coral height at 20 feet. This difference is exceeded by the difference between the zonation described by Woodley and Robinson (1977) for the west fore-reef and our results for the east. This is largely due to the absence of *Acropora cervicornis*, which is likely because of the ~~difference~~ increase in wave action at the east reef. In general, our findings are consistent with Loya (1976) and Goreau and Goreau (1973) for Puerto Rican and Jamaican reefs. Together, these may indicate that the situation on the east fore-reef is the norm, and the situation on the west fore-reef a special case for decreased wave action.

As regards polyp morphology, several conclusions can be reached. As expected the number of polyps / 25 cm^2 decreases with depth for *M. cavernosa*. Polyp size increases with depth. These results are consistent with Lasker (1977) and Lasker (1979). The wide variation is due primarily to a mixture of the large and small morphs on the same colony. For *A. agaricites* the number of polyps per unit area increased with depth. There was no cause which could be shown to be significant in causing this; although polyp

Size was shown not to be a factor.

% COVER OF SUBSTRATES, CORALS, AND OTHER SESSILE INVERTEBRATES ON 10 m² TRANSECTS AT 20', 40', AND 60' ON THE EAST FORE REEF OF DISCOVERY BAY

TABLE #1

TRANSECT / SPECIES		20 ft #1 MEAN	20 ft #1 ST. D	20 ft #2 MEAN	20 ft #2 ST. D	40 ft #1 MEAN	40 ft #1 ST. D	40 ft #2 MEAN	40 ft #2 ST. D	60 ft MEAN	60 ft ST. D
SAND		34.0	11.7	16.4	6.7	31.2	27.8	11.5	7.3	28.4	10.3
DEAD CORAL		40.0	12.8	40.2	18.0	25.1	18.3	49.2	19.7	22.1	17.1
Stephanocoenia	michelini	1.7	1.0	1.3	2.8	0.2	0.8	0.5	0.4	0.06	0.1
S.	intersepta	0.1	0.2	0.2	0.4	0.9	1.5	0.2	0.3	0.1	0.2
Acropora	cervicornis	0.1	0.3	0.03	0.1	1.1	0.8	1.9	1.2	0.4	0.4
Madracis	decactis	0.00	0.0	0.25	2.3	0.9	1.7	0.1	0.3	0.2	0.5
M.	mirabilis	0.06	0.1	1.4	3.2	0.3	0.8	0	0	0.1	0.3
Agaricia	agaricities	7.5	3.6	17.7	24.4	3.4	2.5	3.7	2.1	7.0	2.5
A.	fragilis	0	0	0.06	0.1	0.7	0.6	0.5	0.4	0.1	0.3
A.	grahamae	0	0	0	0	0.3	0.4	0.4	0.4	0.1	0.3
Siderastrea	siderea	1.6	3.5	0.2	0.4	0.8	1.5	2.9	5.1	5.8	3.2
S.	radians	0.7	1.5	0.1	0.2	0.2	0.2	0.06	0.3	1.1	2.4
Porites	astreoides	3.9	5.5	4.9	4.2	2.3	2.6	2.7	4.8	1.9	1.6
P.	furcata	0.2	0.4	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.3
P.	porites	1.0	2.8	1.8	1.0	0.6	0.8	1.1	1.3	1.2	1.4
Favia	fragum	0.03	0.1	0	0	0	0	0	0	0	0
Diploria	strigosa	0.2	0.3	0.25	2.3	0	0	0.4	1.2	0.3	0.5
D.	labyrinthiformis	0.6	1.6	0.45	1.7	0.2	0.6	0.3	0.6	1.6	2.4
Colpophyllia	natans	0	0	0.03	0.1	0.1	0.3	0	0	1.6	2.4
Montastrea	annularis	5.1	4.4	6.9	4.3	16.8	6.3	9.0	4.2	8.4	14.5
M.	cavernosa	2.0	2.8	8.1	8.0	0.9	1.3	3.1	4.7	11.3	6.5
Solenastrea	hyades	0.5	1.6	0	0	0.2	0.3	1.3	2.3	0	0
S.	bournoni	0	0	0	0	0	0	0.3	0.6	0.3	0.9
Oculina	diffusa	0	0	0	0	0.8	1.7	0	0	0	0
Meandrina	meandrites	1.1	2.4	0.1	0.3	0.05	0.2	0.1	0.2	0.6	1.0
Dichocoenia	stokesii	0	0	0.9	1.1	0.2	0.6	0.4	0.7	0.6	1.0
Isophyllastrea	rigidia	0.03	0.1	0	0	0	0	0	0	0	0
Mycetophyllia	danaana	0	0	0	0	0	0	0.3	0.8	0	0
Mussa	angulosa	0	0	0	0	0.06	0.1	0.04	0.1	0	0
Eusmilia	fastigiata	0	0	0	0	0.05	0.2	0.3	0.6	0.3	0.8
Millepora	alcicornis	0.2	0.4	0.4	0.6	0.4	0.4	0.8	0.7	0.2	0.2
M.	complanata	1.4	1.2	1.3	1.9	0.3	0.8	0	0	0	0
Anemones		0.1	0.2	0.5	1.0	0.6	0.6	0.7	1.1	0.1	0.3
Gorgonians		2.0	2.1	4.0	3.6	2.6	2.6	0.7	0.7	1.8	1.3
Sponges		0.3	0.5	1.9	2.4	2.0	1.2	5.2	4.7	1.9	1.1
Palythoa	spp.	0.4	1.0	0.7	1.2	0.4	0.5	0.4	0.8	0	0
Zoanthus	spp.	0	0	0.9	1.6	0.06	0.1	0.03	0.1	0	0

TABLE #2

COMPARISONS OF CORAL SPECIES DISTRIBUTIONS AMONG TRANSECTS

PAIR BEING COMPARED	AVG. % DIFF.	STANDARD DEVIATION	N	# spp. in one member of the pair but not in the other
20'. #1 vs. 20' #2	67%	36%	22	7
40'. #1 vs. 40' #2	62%	31%	28	7
all 20' vs. all 40'	69%	26%	28	8
all 20' vs. 60'	61%	38%	25	6
all 40' vs. 60'	68%	27%	28	4

Two avenues were used to compare coral species distribution among transects. The first involved calculating the average % difference in % cover for each coral that was present in at least one member of the pair being compared. In other words,

$$\text{AVG. \% DIFF.} = \frac{\sum_{i=1}^{N} \frac{a_i - b_i}{a_i} \cdot 100}{N},$$

where:

N = total # of spp.

a_i = % cover of species i in one member of the pair

b_i = % cover of species i in the other member of the pair

and where $a_i > b_i$ (always).

The second avenue examined coral species distribution in terms of presence and absence. In this case we calculated the number of coral species present in one member of the pair but not in the other.

These rankings
should be
presented somewhere.

TABLE #3

Three diversity measures with depth.

	20'			40'			60'
	1	2	total	1	2	total	
number of spp.	21	20	24	26	23	28	23
diversity (H')	2.07	2.25	2.37	1.87	2.41	2.25	2.17
HAC	266	195	231	348	336	356	328

TABLE 3A

1) number of species determined by counting
2) diversity obtained from the Shannon-Weaver index $H' = -\Sigma p_i \log p_i$, where p_i is the proportion of the total community ~~cove~~ of the i^{th} species, determined in this case by comparing a species' % cover to the total % cover of living coral
3) HAC variable (Heterogeneity and Complexity) - a variable designed to give an approximation to the structural complexity of the environment, or the ~~number~~ of possible habitats available.
   Computed by:
   1) ranking all coral species for complexity of growth form on a scale from 1 to 10, 1 being least diverse (such as a brain coral), 10 being most diverse (Acropora cervicornis was arbitrarily assigned a 10 as the most complex coral we found).
   2) % cover for each species is multiplied by its ranking,
   3) the results summed,
   4) the sum multiplied by the average coral height to take into account the differences in available space possible with a given species composition.

WAVE DATA

TABLE 3B

	EAST FORE-REEF		WEST FORE-REEF	
	20'	40'	20'	40'
Amplitude (cm)	30-60	20	10	~~15~~ 5
Period (sec)	4 3/4 - 7	5.5	6	~~8~~ 6

VALUES USED IN CALCULATING HAC

TABLE 3C

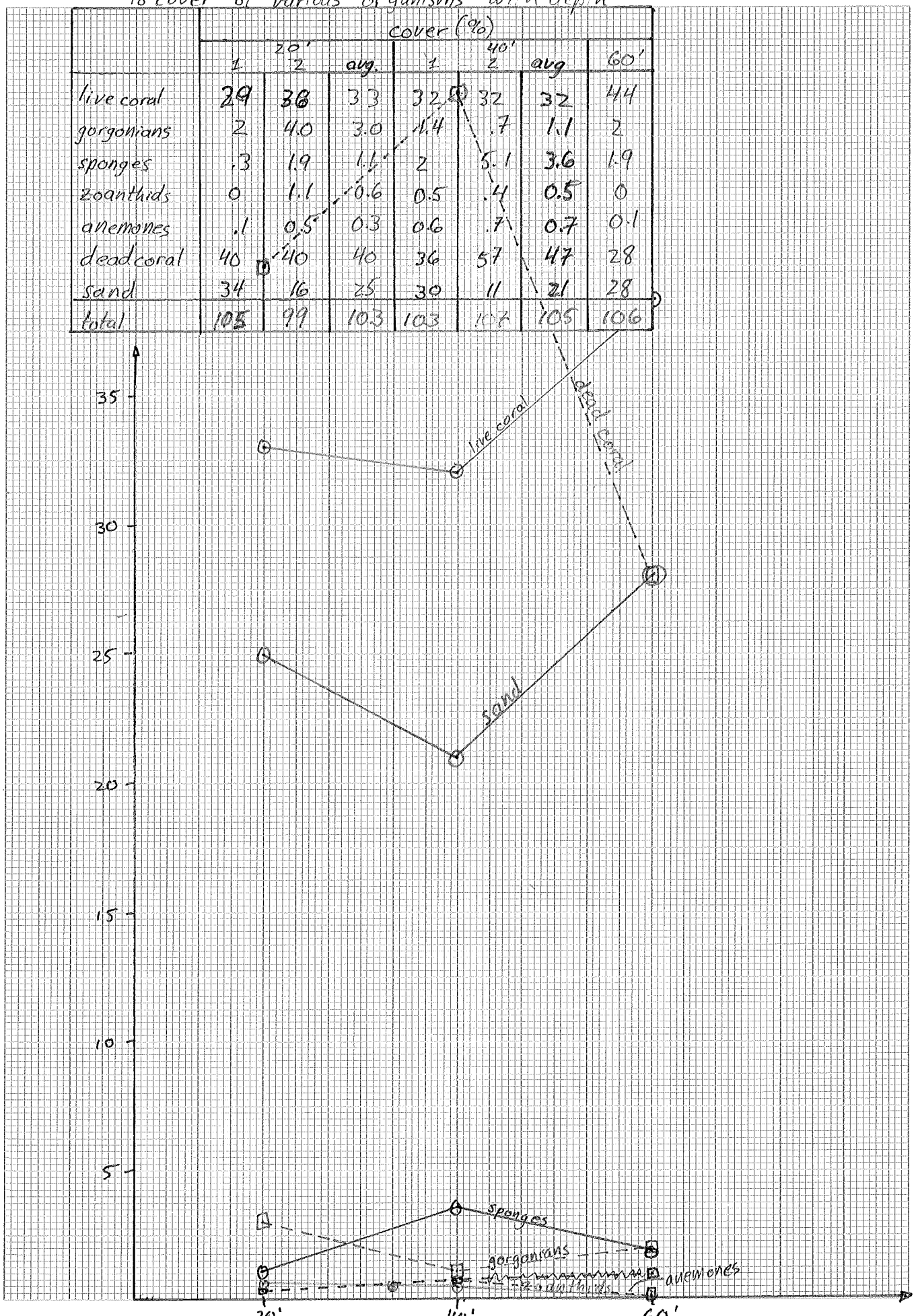
TRANSECT		20', #1	20' #2	40' #1	40' #2	60'
CORAL DEPTH	# measurements	0	25	16	10	10
	avg. depth	—	36.6 cm	43.8 cm	45.8 cm	44 cm
	std. dev	—	16.3	20.9	17.4	13.5
Σ % cover · ranking		72.7	53.4	79.6	73.5	74.6

20 Squares to the Inch

GRAPH #2

% cover of various organisms with depth

	cover (%)						
	20'			40'			60'
	1	2	avg.	1	2	avg	
live coral	29	36	33	32	32	32	44
gorgonians	2	4.0	3.0	1.4	.7	1.1	2
sponges	.3	1.9	1.1	2	5.1	3.6	1.9
zoanthids	0	1.1	0.6	0.5	.4	0.5	0
anemones	.1	0.5	0.3	0.6	.7	0.7	0.1
dead coral	40	40	40	36	57	47	28
sand	34	16	25	30	11	21	28
total	105	99	103	103	107	105	106



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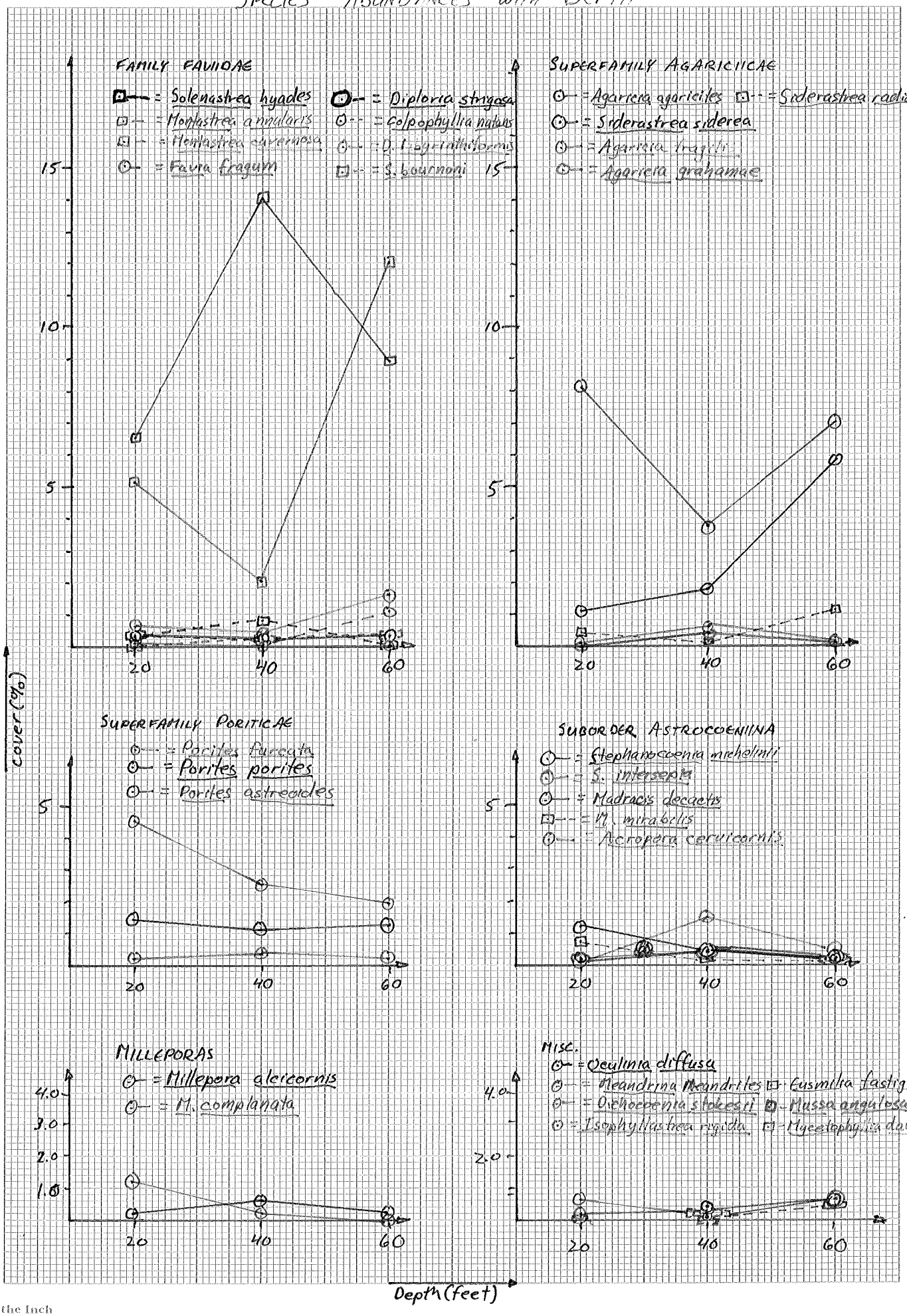
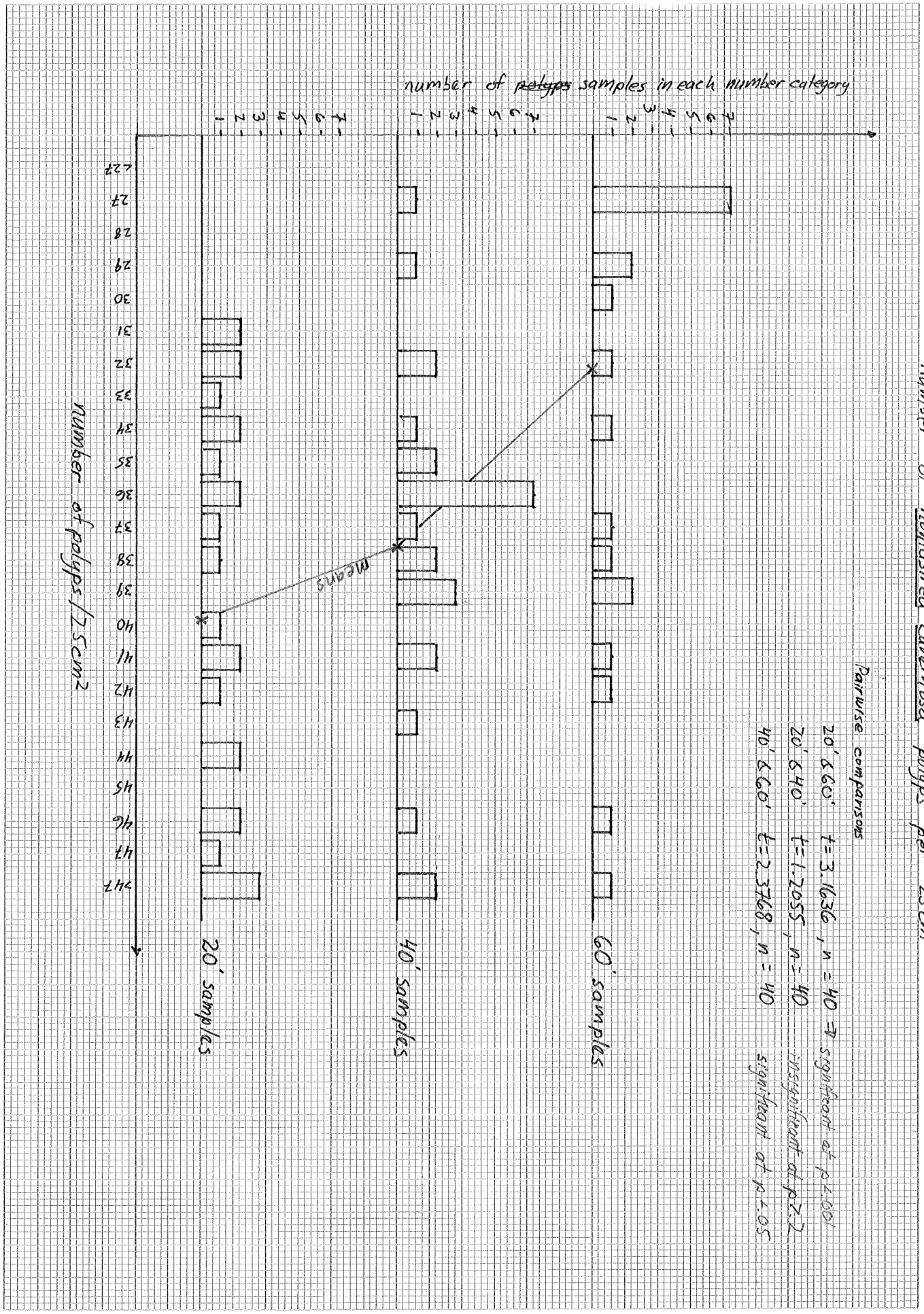
GRAPH # 3

SPECIES ABUNDANCES WITH DEPTH



20 Squares to the Inch

GRAPH #4



20 Squares to the Inch

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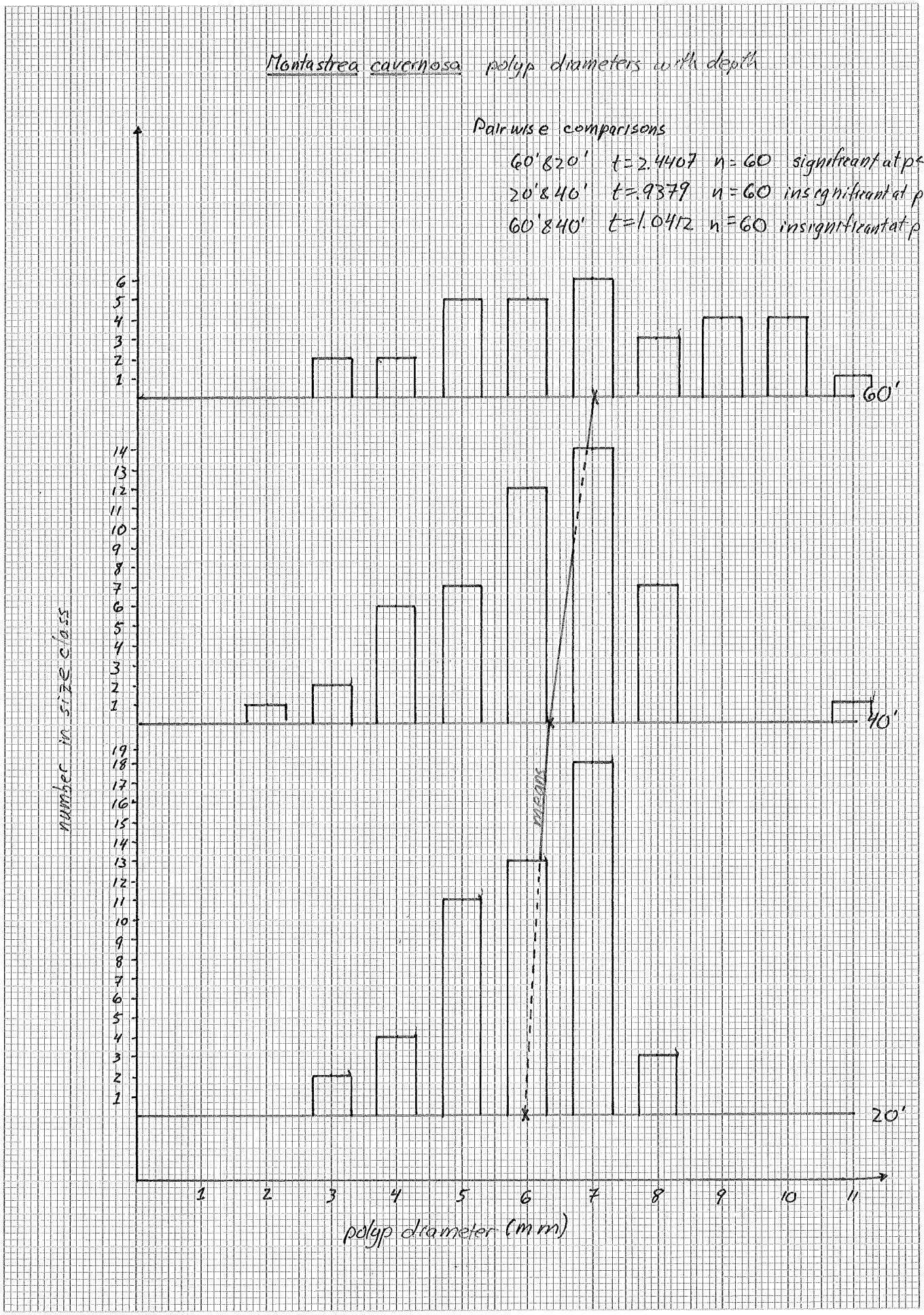
GRAPH #5



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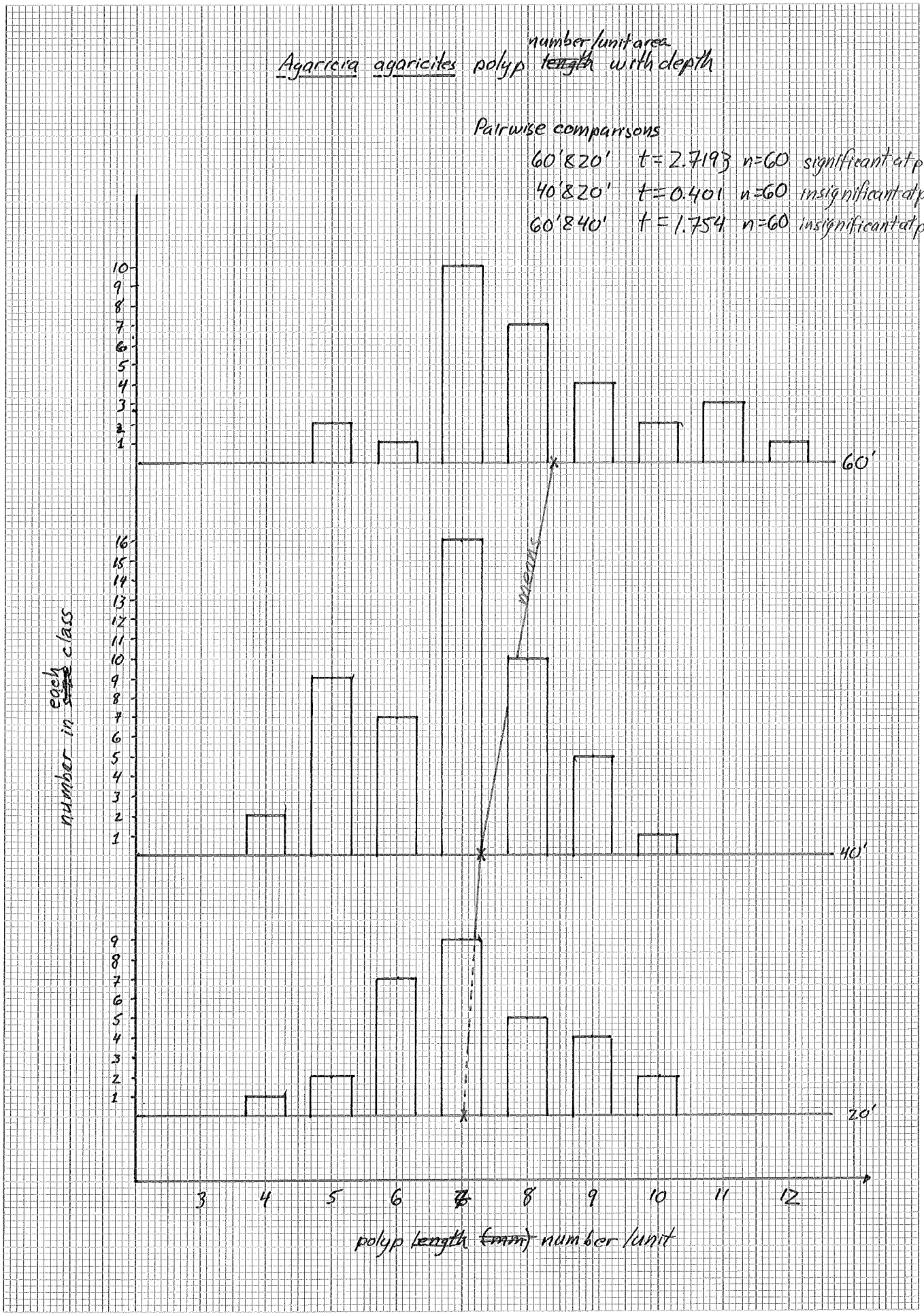

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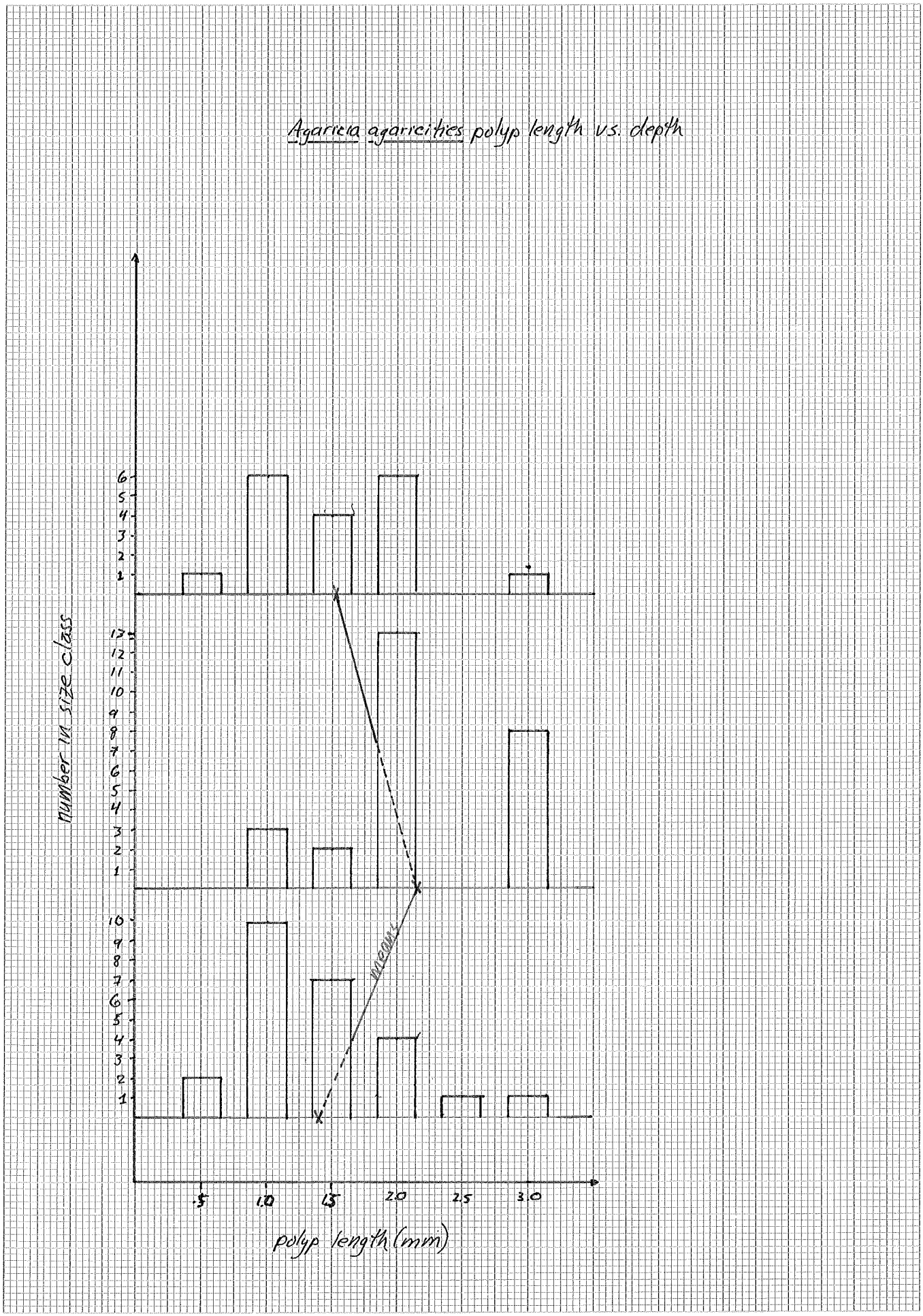

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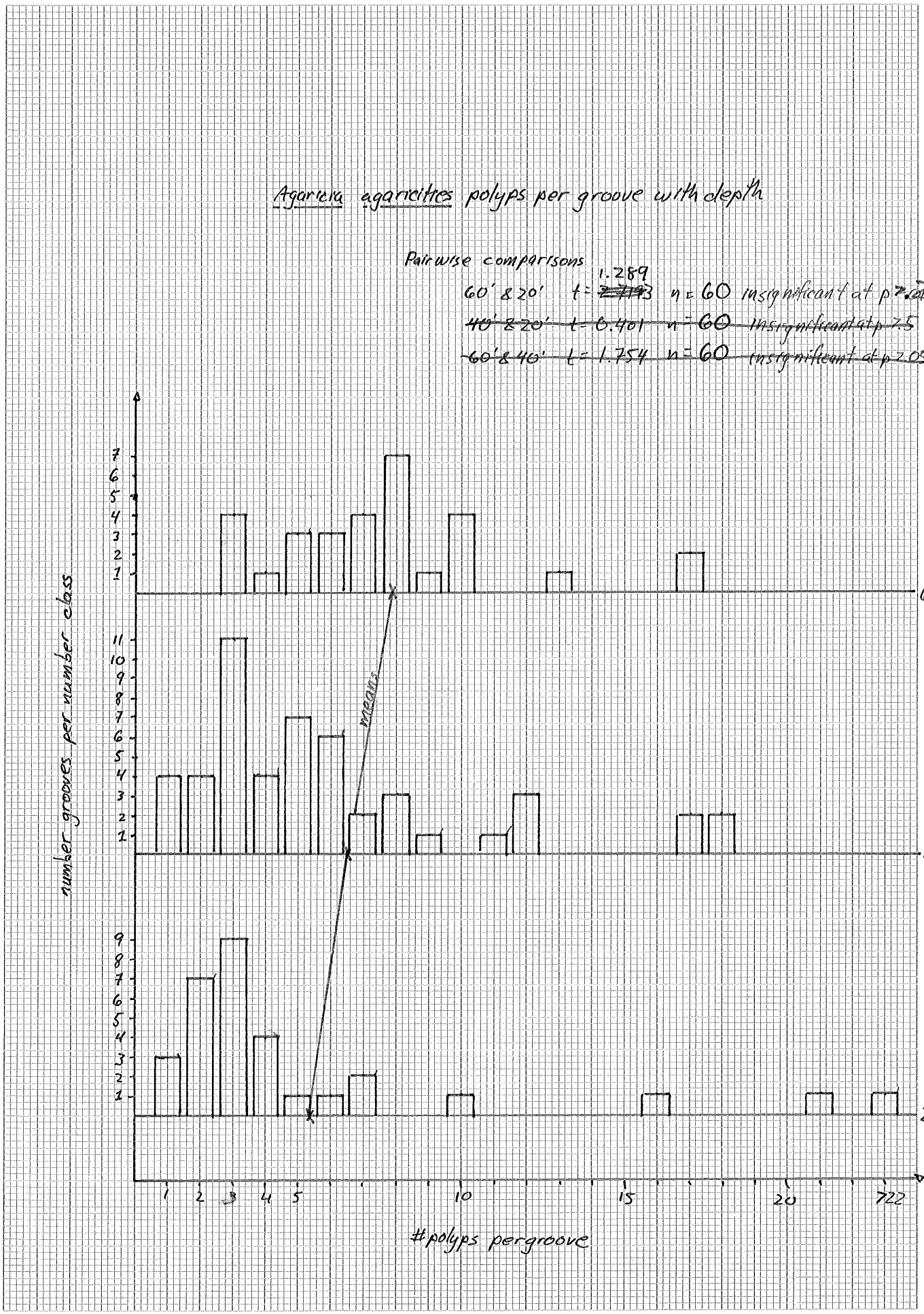
GRAPH #8



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APPENDIX

TABLE #4

transect / species		20 ft #1 side 1					20 ft #1 side 2					20 ft #2 side 1					20 ft #2 side 2				
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SAND		44	41	25	29	30	50	24	3.5	54	35	15.0	20	21	14	19	13	3.8	26	23	9.0
Dead coral		31	36	51	35	46	30	43	70	28	33	33	23	13	36	21	60	68	53	48	47
Stephanocoenia	michelini	1.3	0.8	1	2	2.5	3	3	2.8	2.5	0.8	2.5	0.3	0.5	0.3	0	0	0	0	0	0
S.	intersepta	0	0.5	0	0.5	0	0	0	0	0	0	0	0	0	0	0	1.0	1.0	0	0	0
Acropora	cervicornis	0	0	0	0.3	0	0	0	0	0	1	0	0	0	0	0	0	0	0.3	0	0
Madracis	decactis	0	0	0	0	0	0	0.3	0	0.3	0	0	0	2.5	0	0	0	0	0	0	0
M.	mirabilis	0	0	0	0	0	0	0.3	0	0.3	0	0	0	0.3	0	0	0	0	0.3	3.8	10.0
Agaricia	agaricites	9.3	9.0	7.5	7.0	12.	4.3	0	6.3	8.8	11.0	10.0	2.0	1.2	4.8	2.0	8.0	5.3	2	8.5	7.5
A.	fragilis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.3	0	0	.8	0
A.	grahamae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Siderastrea	siderea	0	0	0	0	0	0.3	1.3	11.0	3.8	0	0	0	0	0	0	1	0	.3	1	0
S.	radians	0	0	0	0	0	0	4.8	1.0	0	1.0	0	0.5	0	0	0	0	0	0.8	0	.5
Porites	astreoides	0.5	2.5	1.5	6.3	6.3	2.5	18.0	0	3.8	0	14	7.5	5.3	9.3	2.5	.3	2	2	2.5	3.8
P.	furcata	0	0.8	0	0.5	0	0	0	0	0	1.0	0	0	0	0	0	.3	.5	0	0	.8
P.	porites	9.0	0	1.3	0	0	0	0	0	0	0	2.5	0	1	2	.5	3	2.5	2	2	2
Favia	fragum	0	3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diploria	strigosa	0	0.5	0.5	0	0	0	0	0	0	to	0	0	2.5	0	0	0	0	0	0	0
D.	labyrinthiformis	0	0	5.0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	4.5	0	0
Colpophylia	natans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.3	0
Montastrea	annularis	0.8	4.3	9.0	12.0	8.8	10.0	3.0	0.8	0	2.5	8.8	2	8.0	13	5.5	5.0	15	2	5	5
M.	cavernosa	1.3	2.5	0	0	0	2.5	7.5	0	0	6.3	5.5	21	24	10.0	5	4.8	1	1	5	3.8
Solenastrea	hyades	0	0	0	0	0	0	0	5.0	0	0	0	0	0	0	0	0	0	0	0	0
S.	bournoni	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oculina	diffusa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meandrina	meandrites	0	0	0	6.3	0	0	0	5.0	0	0	0	0	0	0	0	0	0	0	0	1
Dichocoenia	stokesii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.5	1	.3	.3	2
Isophyllastrea	rigida	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mycetophyllia	danaana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mussa	angulosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ecsimilia	costigata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Millepora	alcicornis	1.0	0	0	0	0	0	0.5	0	0.8	0	0	1	0	0	0	.3	.3	0	.3	2
M.	complanata	0	3.0	0.5	1.0	0.8	1.0	3.0	0.3	0.3	1.0	1	1	4.5	5	.3	0	0	.3	0	.8
Anemones		0.3	0.5	0.3	0	0	0	0	0	0	0	0	0	0.1	2.5	2.5	0	0	0	0	0
Gorgonians		5.3	0.8	3.5	3.3	0.5	2.5	0	0	0	5.5	5.0	0.3	5.5	2.0	0.1	2.5	2.3	2.8	1.2	7.5
Sponges		0.5	0	0	0	1.5	0	0	0.3	0	1	1.0	7.8	2.0	2.0	0.8	0.5	0.3	4.5	0.5	0
Palythoa	spp	3.3	0	0.5	0	0	0	0	0	0	0	3.8	0	0.5	0	0.8	1.0	0	0.8	0	0
Zoanthis	spp.	0	0	0	0	0	0	0	0	0	0	2.5	1.0	0	0	0.5	0	0	0	0	0

APPENDIX

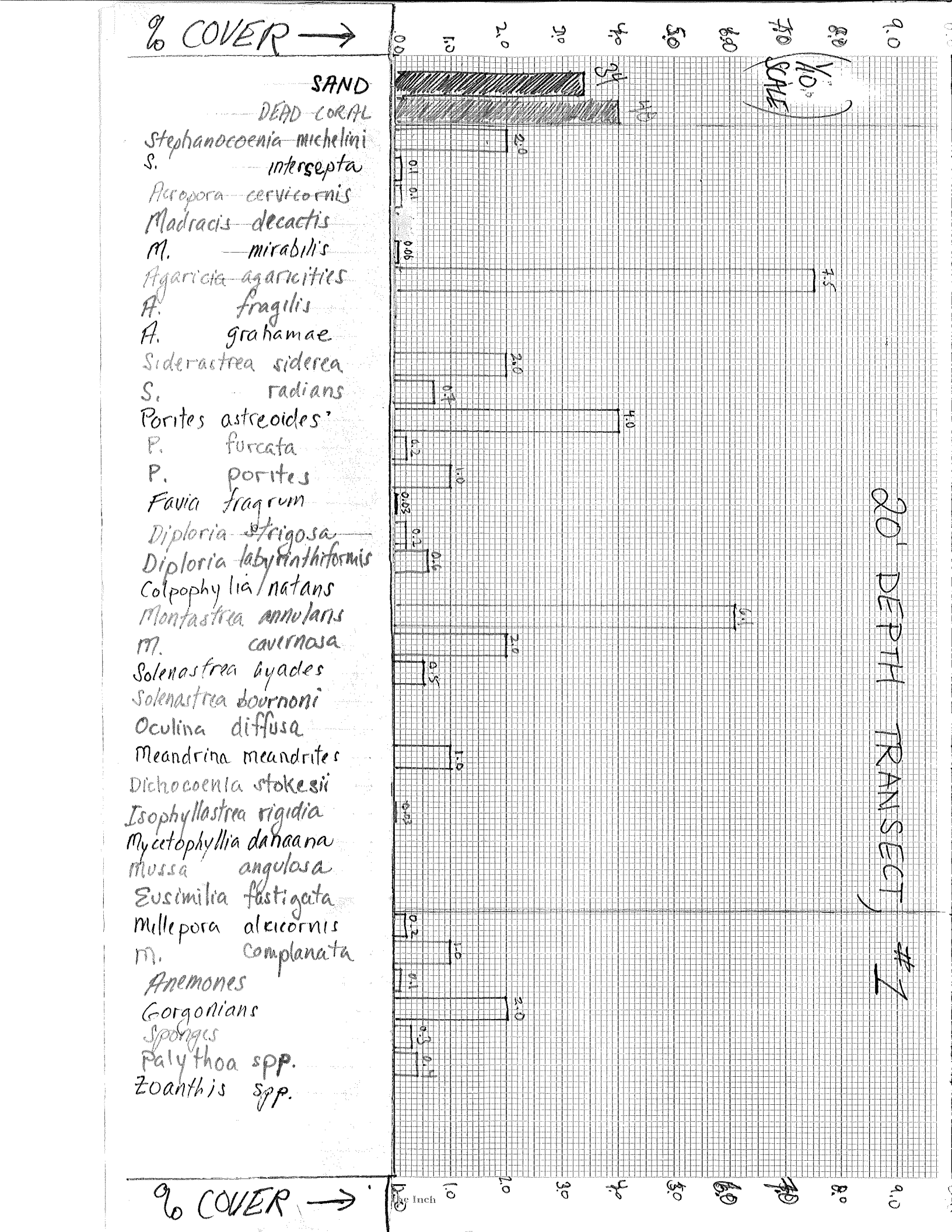
TABLE #5

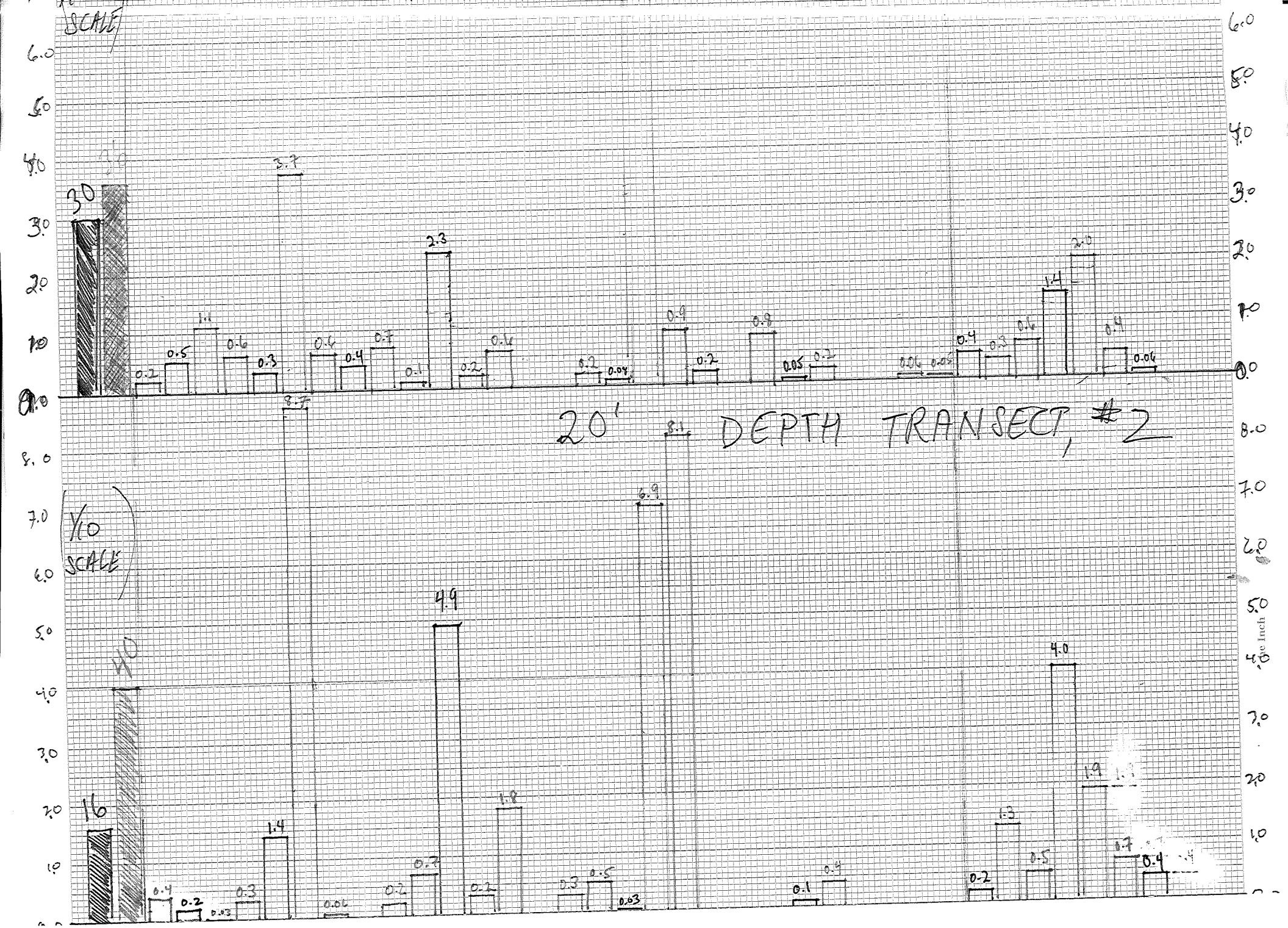
Species \ Transect	40 ft #1 side 1					40 ft #1 side 2					40 ft #2 side 1					40 ft #2 side 2				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
SAND	41	69	66	63	0	16	10	7.8	21	38	19	16	7.5	25	0	13	25	8.3	13	5.3
DEAD CORAL	33	16	16	4.8	6.5	16	23	49	50	47	43	38	38	34	60	21	78	73	36	71
Stephanocoenia michelini	0	0	0	0	0	.8	.3	0	.5	0	1	0	.5	.3	0	1	1	.3	1	.3
S. intersepta	1	.5	.5	.5	.8	.5	0	0	.5	.3	.8	.5	0	0	.3	0	0	0	0	0
A. cervicornis	.3	2	2	.8	.5	1	.5	2	2	.3	4.3	2	2	2.5	.8	.8	.8	.5	2.8	2
M. decactis	0	0	0	.5	.3	0	0	0	.5	0	0	0	0	0	0	.8	0	.5	0	0
M. mirabilis	0	.3	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. agaricites	3.5	3.3	.9	2	.8	3.8	7	7.5	4	3.8	6.3	4.8	4.3	2.5	7.5	2	3	.6	3.5	2
A. fragilis	2	0	.8	1	.8	0	.5	1	1	.3	.3	1	0	.3	.5	.4	0	.3	.9	.8
A. grahamae	0	0	0	1	.5	0	0	0	1	.5	1	0	.5	1	0	.4	.4	.5	0	0
S. siderea	0	0	0	0	0	2	.3	.3	4.3	0	0	0	.5	4.5	6.5	0	0	1	16	0
S. radians	0	.3	.1	0	0	.5	.5	0	0	0	0	0	0	0	0	0	0	.6	0	0
P. astreoides	4	3.8	0	.6	.5	8.3	3.5	.8	1	.5	2.5	.3	3.5	2.5	6.3	2	2	1	5	2
P. furcata	0	0	0	0	0	.5	.8	0	0	.3	.5	0	.3	1	.5	0	0	0	.3	0
P. porites	.8	1	0	0	0	0	2	0	2	0	3.8	0	5	2.5	2	1	.3	0	.5	.3
F. fragrum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D. strigosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.3	0	.3	0	0	3.8
D. labyrinthiformis	0	2	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0
C. natans	0	0	0	0	0	0	0	0	0	.8	0	0	0	0	0	0	0	0	0	0
M. annularis	21	18	20	9.3	3	21	20	21	13	21	8	4.8	11	11	11	10	3	3	13	15
M. cavernosa	0	0	0	3.8	0	.5	1	0	2.5	.8	.8	0	7	0	2	0	0	8.3	13	0
S. hyades	0	0	0	0	0	0	0	1	.5	0	5.8	5	0	0	2	0	0	0	0	0
S. bournoni	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0
O. diffusa	0	0	0	0	0	2.5	5	0	0	0	0	0	0	0	0	0	0	0	0	0
M. meandrites	0	0	0	0	0	0	0	0	.5	0	0	0	0	0	.5	0	.3	0	0	0
D. stokesii	0	0	0	0	0	0	0	0	2	0	.5	1	0	2	0	0	0	0	0	0
I. nigida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M. alawaana	0	0	0	0	0	0	0	0	0	0	0	2.5	.5	.3	0	0	0	0	0	0
M. angulosa	0	0	.3	0	.3	0	0	0	0	0	0	0	0	0	0	0	0	.4	0	0
E. fastigiata	0	0	0	0	.5	0	0	0	0	0	2	0	.5	0	0	.3	0	0	0	0
M. alcicornis	.8	.3	1	.3	.3	.8	0	0	.8	0	2	1	.3	.5	1	.8	.1	.4	2	.1
M. complanata	0	0	0	0	0	0	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0
Anemones	.3	.3	.3	.8	0	.5	2	1	.5	0	0	3	0	0	0	2.5	.3	0	.8	.6
Gorgonians	.5	2	0	1	1	3.3	2.5	.5	.3	3	1	1	0	1	2.5	.4	.3	.5	.3	0
Sponges	3.3	2	2	.8	0	2	4.3	2	2	2	2	4.3	8.3	12.3	1	.5	12	9	.8	2
Palythoa spp	.8	1	0	1	1	0	0	0	0	0	0	1	0	0	0	.5	.3	0	2.5	0
Zoanthis spp	0	0	.3	0	.3	0	0	0	0	0	0	0	0	0	0	.3	0	0	0	0

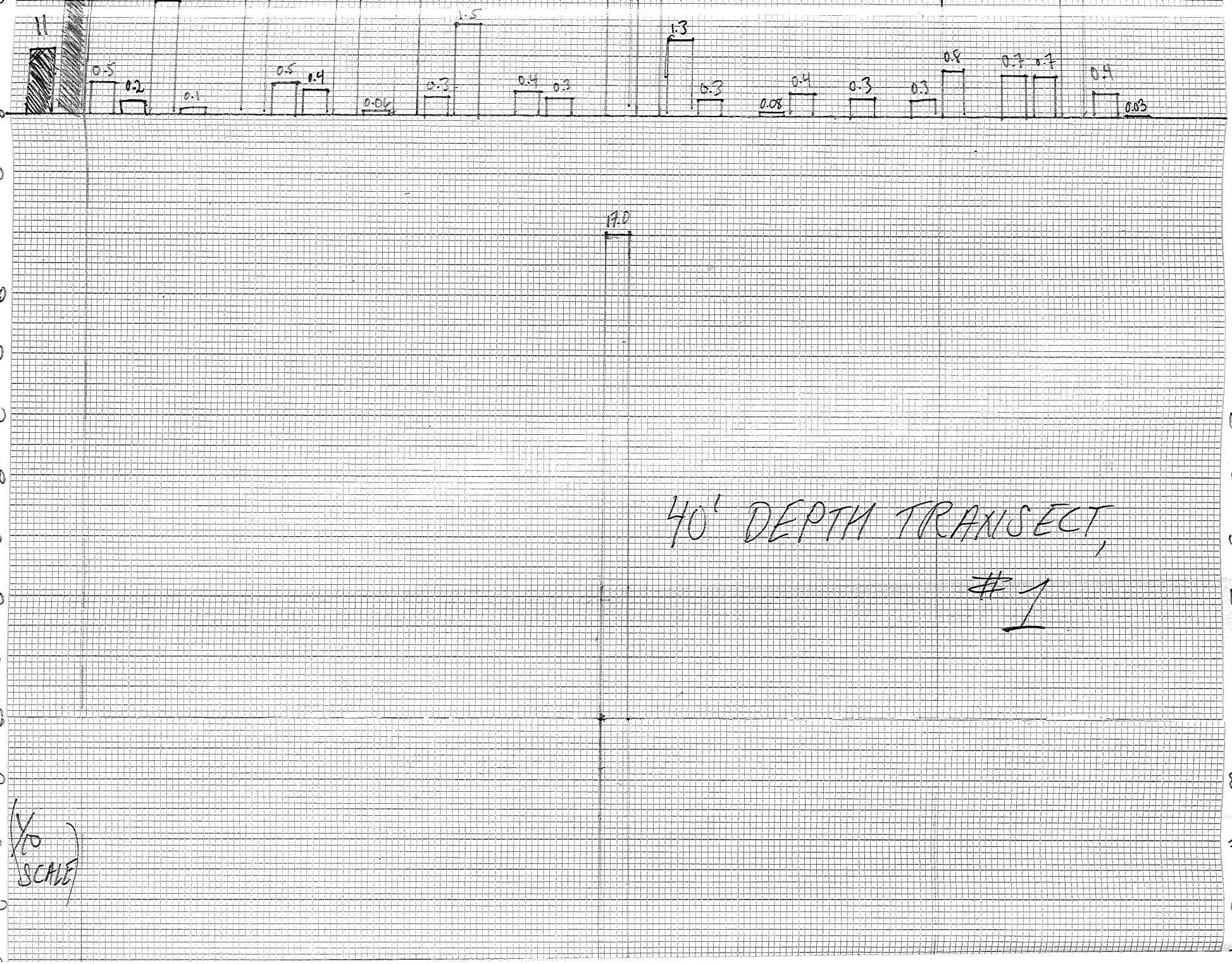
APPENDIX

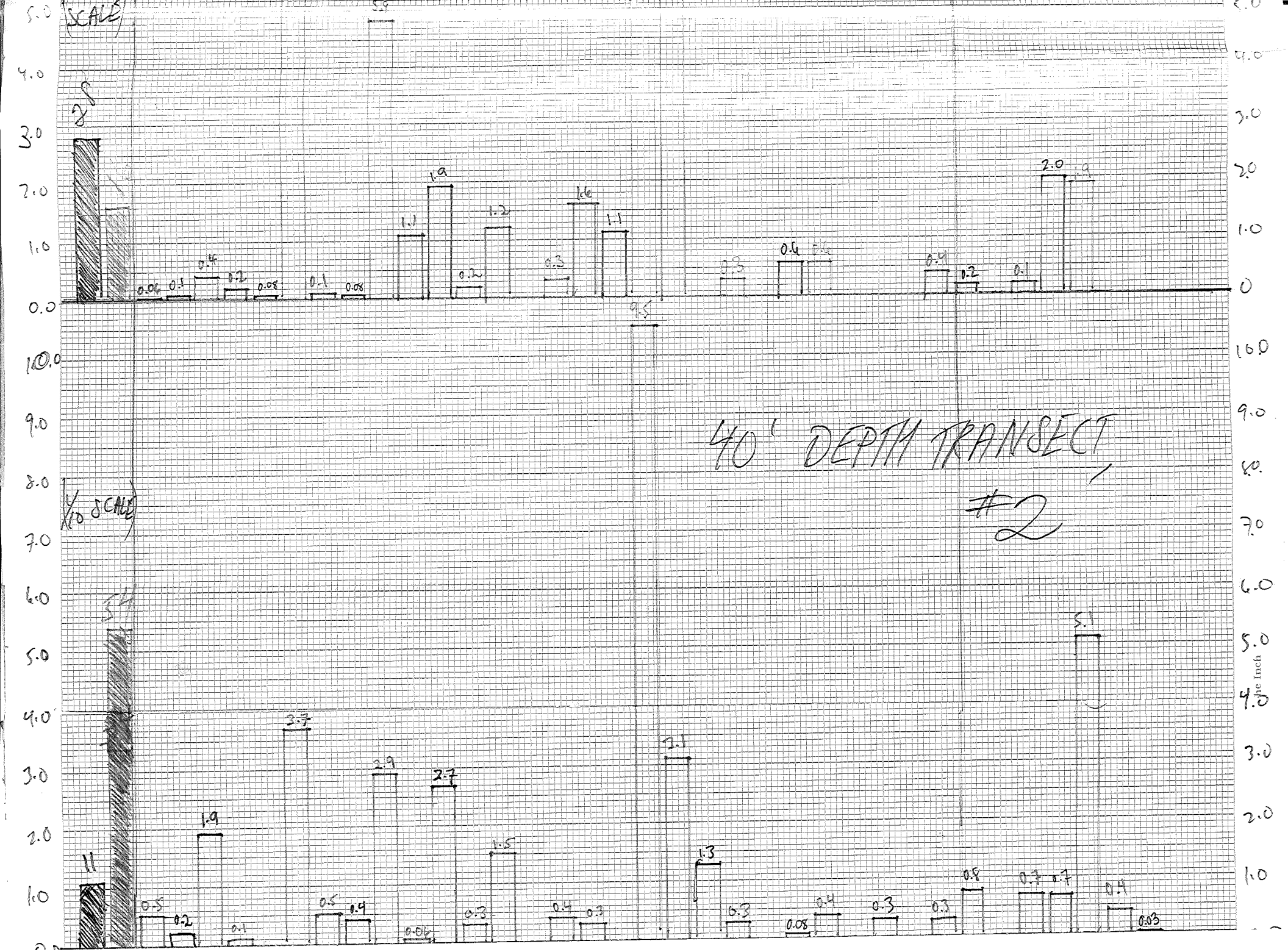
TABLE #6

species \ transect	side 1					6M ft	side 2				Subjective ranking for use in HAC
	1	2	3	4	5	1	2	3	4	5	
SAND	30	30	36	28	34	35	31	39	16	5	
DEAD CORAL	70	15	63	1	14	33	27	21	63	24	
S. michelini	0	.3	0	0	.3	0	0	0	0	0	1
S. intersepta	.5	0	0	.5	0	0	0	0	0	0	1
A cervicornis	0	0	.8	.8	.3	1	0	.3	.3	.3	10
M. decactis	0	0	0	0	0	0	.8	0	0	1.3	5
M. mirabilis	0	0	0	0	.8	0	0	0	0	0	7
A. agaricites	5.8	5.5	4	8.9	6.3	6	10.	11.	3.8	8.8	2
A. fragilis	.3	0	0	.8	0	0	0	.1	0	0	2
A. granamae	.8	0	0	0	0	0	0	0	0	0	2
S. siderea	25	3.5	7.5	11	2	6.3	2.5	10	5	7.3	1
S. radians	0	0	6.3	5	0	0	0	0	0	0	1
P. astreoides	3	2	0	2	.5	2.8	4.8	0	.3	3.9	2
P. furcata	0	.5	.8	.5	.3	0	0	0	0	0	5
P. porites	3.3	0	0	0	1	3	1.3	.5	0	2.8	3
F. fragrum	0	0	0	0	0	0	0	0	0	0	1
D. stringosa	0	.5	.5	0	1	0	0	0	0	1.3	1
D. labyrinthiformis	2	2.5	0	0	0	0	5	6.3	0	0	1
C. natans	0	0	0	.3	0	0	0	0	3	7.5	1
M. annularis	0	0	0	6.3	13	6.3	1.3	9.5	22	1	2
M. cavernosa	7.8	13	21	16	19	25	14	8.8	10	1.3	1
S. hyades	0	0	0	0	0	0	0	0	0	0	1
S. bournoni	0	0	0	0	0	0	0	2.8	0	0	1
O. diffusa	0	0	0	0	0	0	0	0	0	0	9
M. meandrites	2.5	0	0	0	0	0	1.3	2.3	0	0	2
O. stokesii	.3	0	0	.3	.5	2.5	0	2.5	.3	0	1
I. rigidia	0	0	0	0	0	0	0	0	0	0	2
M. dianana	0	0	0	0	0	0	0	0	0	0	1
M. angulosa	0	0	0	0	0	0	0	0	0	0	2
E. fastigata	0	0	0	0	0	0	0	2.5	0	.1	7
M. alcicornis	0	0	.3	.5	0	.3	.6	0	.1	.3	3
M. complanata	0	0	0	0	0	0	0	0	0	0	2
Anemones	0	1	0	0	0	0	0	0	0	0	
Gorgonians	2.5	.3	2.8	2.8	2	1.3	0	4.1	1.5	.05	
Sponges	3.5	1	2.5	2	2	0	.8	3.3	2.8	1.5	
Palythoa spp.	0	0	0	0	0	0	0	0	0	0	
Zoanthus spp.	0	0	0	0	0	0	0	0	0	0	


% COVER →
SAND
DEAD CORAL
Stephanocoenia michelini
S. intersepta
Acropora cervicornis
Madracis decactis
M. mirabilis
Agaricia agaricities
A. fragilis
A. grahamae
Siderastrea siderea
S. radians
Porites astreoides
P. furcata
P. porites
Favia fragrum
Diploria strigosa
Diploria labyrinthiformis
Colpophyllia natans
Montastrea annularis
M. cavernosa
Solenastrea hyades
Solenastrea bournoni
Oculina diffusa
Meandrina meandrites
Dichocoenia stokesii
Isophyllastrea rigidia
Mycetophyllia danaana
Mussa angulosa
Eusimilia fastigata
Millepora alcicornis
M. complanata
Anemones
Gorgonians
Sponges
Palythoa spp.
Zoanthis spp.
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
NO SCALE
20' DEPTH TRANSECT #7
% COVER →
The Inch


1/10 SCALE
30
0.2
0.5
1.1
0.6
0.3
3.7
0.6
0.4
0.7
0.1
2.3
0.2
0.6
0.2
0.04
0.9
0.2
0.9
0.05
0.2
0.06
0.05
0.4
0.2
0.6
1.4
2.0
0.9
0.06
20'
DEPTH TRANSECT, #2
1/10 SCALE
40
16
0.4
0.2
0.03
0.3
1.4
8.7
0.06
0.2
0.7
4.9
0.2
1.8
0.3
0.5
0.03
8.1
6.9
0.1
0.4
0.2
1.3
0.5
4.0
1.9
0.7
0.4
6.0
5.0
4.0
3.0
2.0
1.0
0.0
7.0
8.0
per inch

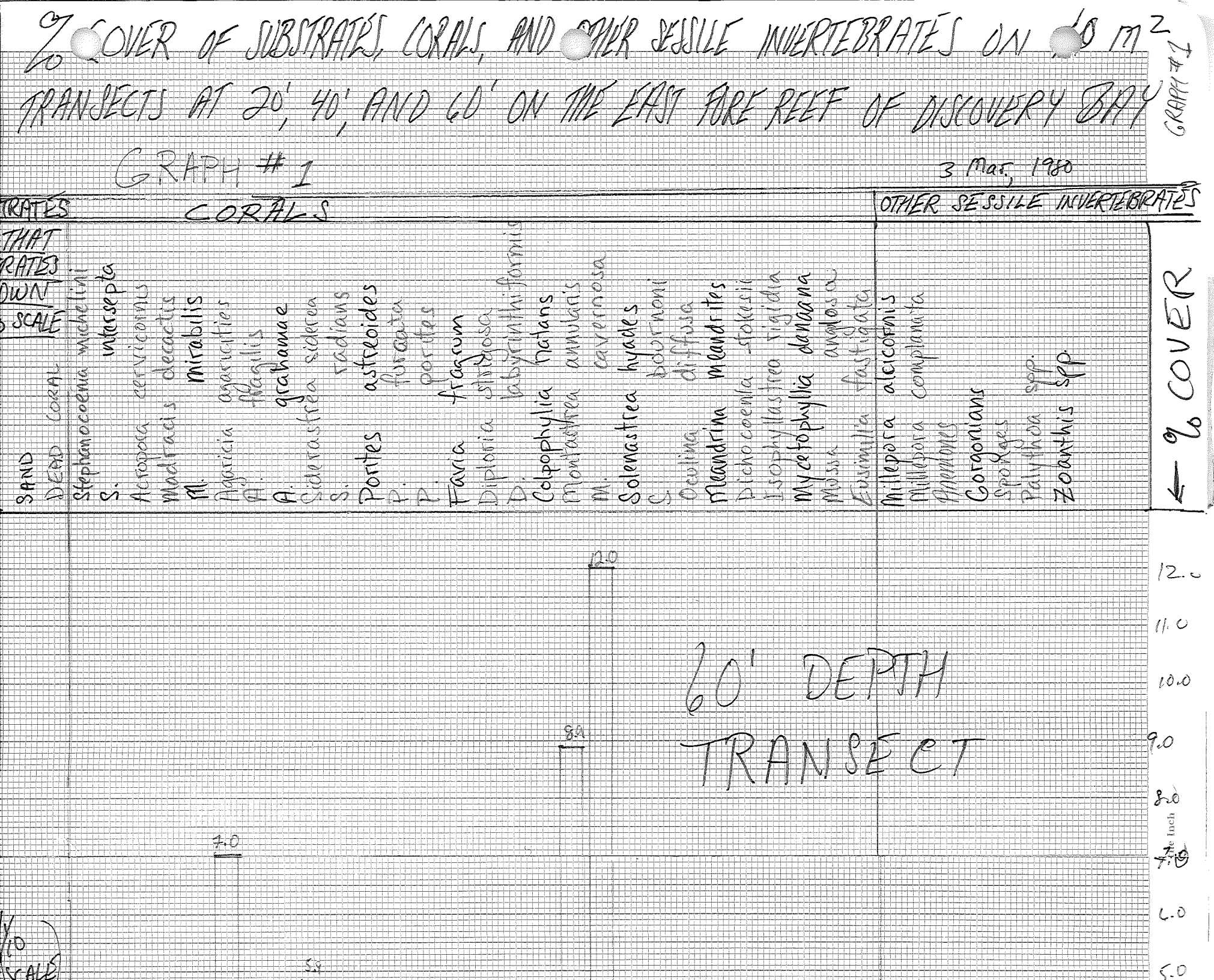

11
0.5
0.2
0.1
0.5
0.4
0.06
0.3
1.5
0.4
0.3
1.3
0.3
0.08
0.4
0.3
0.3
0.8
0.7
0.7
0.4
0.03
17.0
40' DEPTH TRANSECT,
#1
1/10 SCALE
1.0
0.0
18.0
17.0
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
one inch


SCALE
1/10 SCALE
40' DEPTH TRANSECT
#2
One Inch

% COVER OF SUBSTRATES, CORALS, AND OTHER SESSILE INVERTEBRATES ON 10 M² TRANSECTS AT 20', 40', AND 60' ON THE EAST FORE REEF OF DISCOVERY BAY

GRAPH #1

3 Mar, 1980



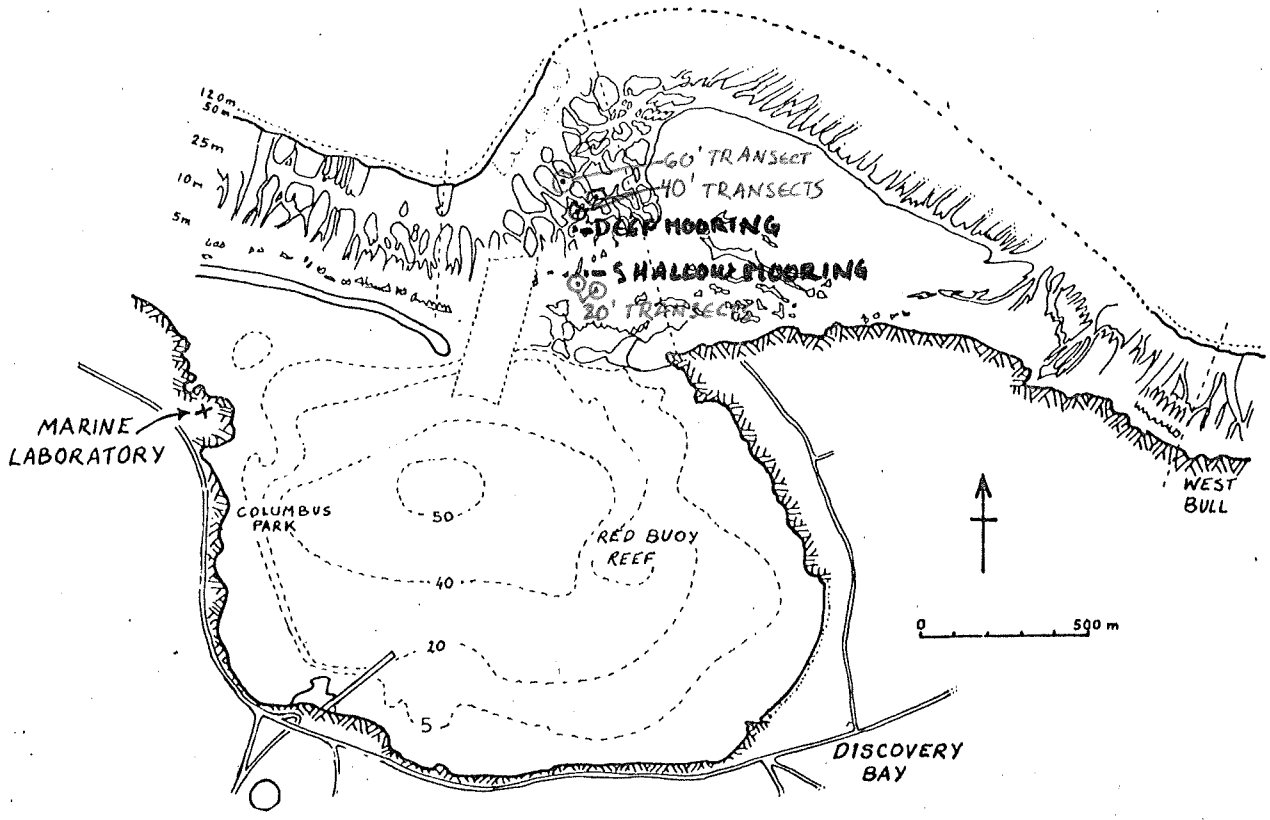


Figure 8. Discovery Bay, traced from an aerial photograph. Depth contours within the Bay in metres. Notice the differing extent of the submarine terraces on the western and the eastern fore-reef. From Woodley & Robinson 1977.