

Oh Dear! Where are the Staghorn?

A survey of Acropora cervicornis after Hurricane Gilbert

A way of good  
analysis of old surveys  
and useful for  
new surveys

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1990

## Abstract

Acropora cervicornis was one of the dominant corals prior to Hurricane Allen in 1980. Surveys of the coral before Allen in 1977-1979 and after it in 1984 documented this hurricane's effect. Another survey in 1988 documented both the recovery rate (negative) and the pre-Hurricane Gilbert status of the coral. We, in 1990, resurveyed the A. cervicornis population at Mooring 1, Westfore Reef, Discovery Bay, Jamaica. We hypothesized that within the 1990 data, the coral at relatively shallow depths would be less abundant, have more bleached area, and have a higher order of branching. The data did not support these hypotheses. We hypothesized that in a comparison between the years, we would find fewer and younger coral in 1990. The data did support these hypotheses. The hurricanes have greatly affected the population and characteristics of the A. cervicornis and represent an integral part of the reef ecology dynamics.

## Introduction

*Lee  
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Acropora cervicornis, staghorn coral, was one of the dominant corals in Jamaican reefs including our study site (Moring I) at Discovery Bay. According to a survey of the coral at this site from 1977-1979, the coral was evenly distributed from 15 to 65 feet with a density up to 11 individuals/m<sup>2</sup> (Tunnicliff 1983). In 1980, Hurricane Allen flattened most of these fragile branching corals and a resurvey in 1984 ~~found~~ found a maximum coral density of 0.57 individuals/m<sup>2</sup> at 40 feet with lower densities at 20 and 60 feet. (DeVaro, 1984)

A follow up survey in 1988 found even lower coral densities, the highest being 0.15 individuals/~~m<sup>2</sup>~~ m<sup>2</sup> at 60 feet (Blechner 1988). This survey was followed by Hurricane Gilbert in August of 1988. We, in 1990, decided to survey the population once again to determine the effects of this second hurricane and to determine the state of A. cervicornis' population.

Because of the hurricanes turbulence and the tendency for turbulence to break the coral we hypothesized that within the 1990 data, there would be less coral at 20 feet than at 40 feet and less coral at 40 feet than 60 feet (Tunnicliff 1981). Because ultraviolet light may be harmful in shallow water (Jokiel 1982), we predicted an inverse relationship between depth and percent bleached area. Because shallower depths have more turbulence and branching is thought to be a strategy to counter wave action, we hypothesized that the shallower corals would have a higher level of branching (Tunnicliff 1983). And finally, for the data within the 1990 survey, we hypothesized that the coral within damselfish territories would be covered in more algae and sponges (which grow on

and common to

the base of the coral) because these corals would have less fish herbivory on the algae and sponges (Risk 1982).

We next looked at the data over the years to discern the effects of Hurricanes Gilbert and Allen. We hypothesized that there would be fewer individuals at all of the depths, both because of the effect of Gilbert and the trend found in 1988. And we also hypothesized that the individuals left would be younger, having characteristics such as being smaller and having less dead area.

## Methods

The data were collected from Discovery Bay's mooring I (Jamaica, West Indies) from 26 February to 5 March 1990 at depths of 20, 40, and 60 feet. Ten by two meter quadrats were laid out along these depths, selecting for the coral reefs instead of the sand patches. The randomization method varied between the depths. Twenty feet was on a gradual slope, so we swam towards the most distant point on the horizon, keeping the depth constant and laying the transects end on end. This depth included areas with patchy rubble and others virtually flat. At 60 feet the slope was steep, so we used the same method. At 40 feet, the coral was in large patches that were separated by sand. Here where the slope was relatively flat, we laid the transects side by side and three flipper kicks apart.<sup>We used</sup> A ten meter line that was held down by rocks and measured a meter on each side, both of us swimming the whole transects in ~~back~~ opposite directions. We measured and recorded information on each individual coral: height from the substrate, longest width, basal diameter, length of each branch~~s~~ and its branching order (see Figure 8.), total length of branches covered in algae and/or bleached, number of fractures and buds, number of branch intersection points, type of attachment (secure or loose), origin (sexual reproduction or old fractured coral), microenvironment (sheltered or not, on slope or flat), and presence of predators (damselfish, sea urchins, and snails).

We then compared the three depths in twelve aspects (see Table I). Following the 1984 survey, we defined growth rate as the sum of the lengths of the primary branches (cm) from their tip to intersection

(these have similar ages), and we likewise defined the growth index as follows:

$$\text{Growth Index} = \frac{\text{Branching Density} \times 100}{\text{Coral Size}}$$

where

and  
Branching Density =  $1 \times (\# \text{ of } 1^\circ \text{ branches}) + 2 \times (\# 2^\circ \text{ branches}) + \dots$   
Coral Size = (maximum height)  $\times$  (maximum width)  
[DeVore 1984]

We also defined one individual to be all of the coral off of one base. Two individuals could grow off of the same fragment if separated by an algae covered (dead) section of the fragment along the ground.

## Results

### Distributions

We found no significant difference in coral density based on cm of branches/m<sup>2</sup> (ANOVA, P>0.05, Table 1) or individuals/m<sup>2</sup> (ANOVA, P>0.05) (Table 1) at 20, 40, and 60 feet. 60 feet had the highest density by both standards,  $0.065 \pm 0.075$  individuals/m<sup>2</sup> and  $1.8 \pm 1.8$  cm branches/m<sup>2</sup>. The densities at all depths, measured by individuals/m<sup>2</sup>, were approximately  $\frac{1}{2}$  those from the corresponding depths of the 1988 census (Figure 1), and measured by cm branches/m<sup>2</sup> approximately  $\frac{1}{5}$  those of the 1988 census (Figure 2). These distributions represent severe declines from the pre-Hurricane Allen distribution.

### Coral Meristics

We found no significant difference between the means of the maximum heights of individuals at the three depths studied (ANOVA, P>0.05, Table 1) (Figure 4). The maximum coral heights were non-normally distributed (Figure 5), being heavily skewed towards smaller individuals. When compared with the height distribution prior to Hurricanes Allen and Gilbert (Figure 6), it is apparent that the coral height has lost a normal distribution and the corals have been severely reduced in size.

We found no significant difference in the maximum widths of individuals at different depths (ANOVA, P>0.05, Table 1). Also, there was no significant difference between the basal diameters of individuals at the three depths surveyed (ANOVA, P>0.05, Table 1), although the means themselves have the same negative relationship with

depth that was found significant in 1984 (Delaro and Rhee 1984, Table 2). There was no significant difference between the total length of branches/individual between depths ( $G$ -test,  $0.5 > P > 0.1$ , Tables 1 and 3). The means ranged from  $32.4 \pm 23.1$  cm at 40 ft to  $28.1 \pm 20.0$  cm at 60 ft.

### Growth and Branching

We found no significant difference in the highest branching order/individual, growth rate, or growth index of individuals between depths (Table 1). The growth rates at all depths have increased when compared to 1984's findings (Table 2). Both the post Hurricane Allen mean highest branching order, 2.5, and the post Hurricane Gilbert mean highest branching order, 4.2.9, were much lower than the pre-hurricanes value, 4.8 (Figure 7).

### Coral Mortality

There was not a significant difference of % dead tissue on corals between depths (ANOVA,  $P > 0.05$ , Table 1). Values ranged from  $8.4 \pm 15.5\%$  at 40 ft to  $30.7 \pm 6.1\%$  at 20 ft. The large standard deviations resulted from the fact that only 12 of <sup>at all depths</sup> 44 individuals had any sign of bleaching. This is a notable decline from the % dead tissue found in 1988 (Figure 3).

There were few occurrences of bleached coral tissues, and no difference between the % bleached tissue between depths. 20 ft had the highest mean % bleached tissue at  $17 \pm 33\%$ .

No damsel fish were found to have territories encompassing

corals in our survey, and no boring sponges were found, indicating that these were not factors contributing to *A. cervicornis* mortality. This is a notable change from the 1984 re-survey in which both sponges and damselfish were prevalent.

### Reproduction

We found only 9.6% of individuals surveyed were basally attached to a substrate, i.e. sexually reproduced. This is a large decline from 1984's 43% basally attached individuals (Table 2), indicating that as the density of *A. cervicornis* has decreased, sexual reproduction has played an ~~an~~ smaller role in recruitment. Therefore, fragmentation must still be the predominant mechanism of reproduction.

### Topographical localities

In 1990 we found 83%, 92%, and 64% of the individuals of *A. cervicornis* were located in areas offering a high degree of shelter at 20 ft, 40 ft, and 60 ft, respectively. (Table 1).

## Discussion

In 1990, we found no significant difference among the three depths between the number of individuals/m<sup>2</sup>, the growth rate, the growth index, the maximum height, the basal diameter, the # of fractures/individual, the % dead tissue, the % bleached tissue, and the maximum branching order. Although we cannot reject our null hypotheses that the number of individuals/m<sup>2</sup>, % bleached tissue, and the maximum branching order are the same at these depths, the overall homogeneity at the three depths is significant since the growth rate and growth index are known to have varied by depth prior to Hurricane Allen (Tunnicliffe 1983, Table 2), and coral density, growth index, basal diameter, number of fractures/individual, and % dead tissue are known to have varied prior to Hurricane Gilbert (DeVore and Rhee, 1984; Blechner 1988, Table 2).

Jokiel (1982) showed with other coral species that bleaching increases as depth decreases. Similarly, coral branching and coral growth rates should increase in G.A. cervicornis as depth decreases (Tunnicliffe 1983). That these factors did not vary with depth in 1990 suggests that the catastrophic factors of the hurricanes in the last decade have outweighed the other biotic and abiotic factors that normally shape morphological and reproductive characteristics of A. cervicornis. These catastrophic factors appear to have been equal at all three depths studied, as is evidenced by the current homogeneity at the three depths.

One of the key factors accounting for the homogeneity between depths could be the similarity in microhabitats in which the individuals we surveyed occurred. 83%, 92%, and 64% of the corals at 20ft, 40ft, and 60ft respectively were located either directly adjacent to a large

Were they large  
enough to move  
from sheltered sites  
to this one?

coral head or were in a crevice, crag or valley of some sort. This suggests that at 20 and 40 ft and perhaps to a lesser degree at 60 ft, corals in sheltered habitats differentially persisted during Hurricane Gilbert, having a higher chance of surviving. So, these sheltered areas may eliminate the abiotic factors that normally create differential characteristics by depth. For instance, the coral heads may shade the A. cervicornis from light and shed turbidity, making ~~and~~ light and turbidity equal for the individuals at 20, 40, and 60 ft, though the factors themselves may differ. Therefore, one would expect branching characteristics and growth rates to be similar at all depths as we found.

Our hypothesis based on damselfish territories could not be tested as we found no A. cervicornis within the boundaries of a damselfish territory. On the one hand this is surprising since the A. cervicornis tended to be found next to large coral heads, similar to those territorialized by damselfish. On the other hand, the individuals we censused were not very large and may not have presented a great enough surface area for a damselfish algal mat.

That no individuals were found with boring sponges in 1990, and that they were abundant in 1984 (Table 2) suggests that Hurricane Gilbert preferentially destroyed all individuals with boring sponges. This is not surprising since boring sponges weaken A. cervicornis and induce fragmentation (Tunnicliffe 1981).

Due to the effects of Hurricane Gilbert, we expected to find fewer individuals in 1990 than in 1988. Indeed, the coral density, # individuals/m<sup>2</sup>, decreased at all depths from 1988 by at least a factor of two

(Table 2). Although this decrease was presumably a result of Hurricane Gilbert, the coral density also decreased from 1984 to 1988 (Table 2) during which time there was not a catastrophic disturbance. Therefore, the decrease we observed may in part be residual detriment caused by the disturbance of Hurricane Allen in 1980.

We also expected Hurricane Gilbert to affect the age structure of A. cervicornis at Discovery Bay. Older individuals, being larger, would be more likely to suffer from a hurricane's force. Indeed, a number of characteristics suggest that the individuals we surveyed were younger than those prior to Hurricane Gilbert, in 1988. The maximum height of individuals decreased at 20 ft and 40 ft and remained similar at 60 ft between 1988 and 1990 (Table 2). Also, the % dead tissue dropped at all depths from 1988 to 1990. Since older individuals have been exposed to biotic and abiotic factors for longer periods of time, they are thought to have higher % dead tissue (Tunnichife 1983). Both of these factors, Max. height and % dead tissue, tell the individuals censused in 1990 were younger than those in 1988.

In order to grasp the effects of both hurricanes on the age structure of A. cervicornis at Discovery Bay, one must only look at the distribution of corals by maximum height at 1977-79 and 1990 (Figures 5 and 6). During this time, the mean maximum height dropped from 38.9 cm in 1977-79 to 7.7 cm in 1990.

Also indicating a decrease of age, during this time, the highest branching order decreased from 4.8 in 1977-79 to 2.9 in 1990, the mean basal diameter decreased from 2.04 in 1977-79 to 1.20 in 1990, and the mean % dead tissue decreased from 33% in 1977-79 to 5.4% in 1990.

Hurricanes Allen and Gilbert also appear to have altered

The reproductive rates and mechanisms of A. cervicornis. That the density of A. cervicornis declined from 1984 to 1988 suggests that Allen's effects continued to interfere with recruitment through 1988. The % basally attached individuals, sexually reproduced, declined from 43% in 1984 to 0.6% in 1990. Therefore, fragmentation appears to have become a more important mechanism of reproduction, accounting for more recruitments than sexual reproduction. However, the number of fractures / individual also decreased drastically from 1984 to 1990 (Table 2), suggesting the overall recruitment is much less in 1990 than it was in 1984. This suggests that A. cervicornis will take a long time to return to pre Hurricane Allen abundances, if indeed it does return.

( Since Hurricane Gilbert was ~17 months ago and corals branch only once/year (Tunnicliffe 1983), corals with a branching order greater than two would have to have been alive prior to the hurricane. 26 of the 42 individuals sampled had a maximum branching order greater than two, indicating that all of the coral was not decimated by the hurricane. The 16 individuals whose branching order was two or less, have grown up since the hurricane and are evidence that the coral is reproducing. )

In conclusion, it is unclear whether the decline of abundance and size of A. cervicornis recorded in 1990 is a result of Hurricane Gilbert, the continuing effects of Hurricane Allen, or a combination of the two. The 1988 data shows that at the time that Gilbert hit, the coral had not yet recovered from Allen.

The change in the A. cervicornis characteristics from 1977-79 to 1990 makes it clear that hurricanes have drastic effects on coral reef communities, and can alter single

species profoundly. In the case of A. cervicornis, morphological, distributional, reproductive, mortality, and age structure characteristics were all altered drastically. Clearly, the effects of hurricanes, and other natural catastrophes, are important factors driving evolutionary and community trends. Between 1977 and 1990, hurricanes appear to have effected A. cervicornis more than all other biotic and abiotic factors combined, indicating that in order to study a community's true dynamics, a large time scale must be used to incorporate such catastrophes.

Previous trends have made it hard to predict the future of A. cervicornis. Future studies will be needed to shed light on the ability of A. cervicornis to persist through hurricanes.

Table I. Comparison of 1990 Data by Depth.

	20 FT	40 FT	60 FT	TEST AND P-value
Maximum Height (cm)	7.8 ± 2.8	8.1 ± 3.1	7.7 ± 4.5	ANOVA $P > 0.05$
Maximum Width (cm)	10.1 ± 5.1	12.1 ± 6.7	9.7 ± 6.3	ANOVA $P > 0.05$
Basal Diameter (cm)	1.31 ± .46	1.16 ± .37	1.12 ± .29	ANOVA $P > 0.05$
* Total length of Branches (cm)	29.6 ± 20.0	32.4 ± 23.1	28.1 ± 20.0	G-test $0.5 > P > 0.1$
Highest Branching Order	3.1 ± 1.8	2.5 ± 1.1	3.0 ± 1.3	ANOVA $P > 0.05$
** Growth Rate	20.0 ± 11.6	24.2 ± 18.1	19.3 ± 13.0	ANOVA $P > 0.05$
** Growth Index	0.258 ± .142	0.173 ± .119	0.224 ± .144	ANOVA $P > 0.05$
% Dead Tissue	3.7 ± 6.1%	8.4 ± 15.5%	4.2 ± 10.8%	Arcsine transformed ANOVA $P > 0.05$
% Bleached Tissue	1.7 ± 3.3%	5.8 ± 14%	3.0 ± 8.7%	Arcsine transformed ANOVA $P > 0.05$
cm of coral per meter <sup>2</sup>	1.1 ± 2.9	1.1 ± 2.0	1.8 ± 1.8	ANOVA $P > 0.05$
Individuals/m <sup>2</sup>	0.041 ± .087	0.038 ± .069	0.065 ± .075	ANOVA $P > 0.05$
% of individuals in sheltered habitat	83%	92%	64%	—

\* See Table 3.

\*\* defined in methods

Table 2. Coral Characteristics from 1977 to 1990.

	Hurricane Allen 1977-79	1984	1988	Hurricane Gilbert 1990
Coral Density # individuals/m <sup>2</sup>	20≈40≈60 Max = 11/m <sup>2</sup>	20'<40'>60' .12 .57 .30	20'≈40'≈60' .08 .13 .15	20'≈40'≈60' .041 .038 .065
Growth Rate	20'>40'>60'	20'≈40'≈60' 11.5 15.9 12.3	—	20'≈40'≈60' 20.0 24.2 19.3
Growth Index	20>40>60	20>40≈60	—	20'≈40'≈60' .258 .173 .224
Bran Max. Branching order	4.8	20≈40≈60 ~2.5	—	20≈40≈60 3.1 2.5 3.1
Maximum Height (cm) of individuals	20≈40≈60 38.9	20≈40≈60 17	20≈40>60 15 17.6 7.1	20≈40≈60 7.4 8.1 7.9
Basal Diameter	2.04	20>40>60 1.48 1.15 1.04	—	20≈40≈60 1.31 1.16 1.12
% Individuals Basally Attached	20%	43%	—	9.6%
# Fractures/ Individual	—	20>40>60 2.42 1.56 .24	—	20≈40≈60 .13 .07 .58
% Dead Tissue	33%	20 40 60 18.4 24.5 2.1	20<40≈60 16.3% 56.6% 57.7%	20≈40≈60 3.7% 8.4% 4.2%
% Individuals w/Boring Sponges	—	20 40 60 33% 41% 0%	—	0%
% Individuals In Damsel Territories	—	20 40 60 15% 38% 93% 44% 10%	—	0%

Table 3. Frequency of heights at the different depths.

		Total cm of branches			
		0 - 20	21 - 40	41 -	
Depth	20 ft	4	8	3	$n = 15^*$
	40 ft	7	2	5	$n = 14$
	60 ft	7	6	2	$n = 15^-$
		$n = 18$	$n = 16$	$n = 10$	$N = 44$
$\left[ \text{G-test } (\text{G}_{\text{adj}} = 5.06), 0.0 > P > 0.1 \right]$					

Figure 1. Coral densities at each of the depths through the years.

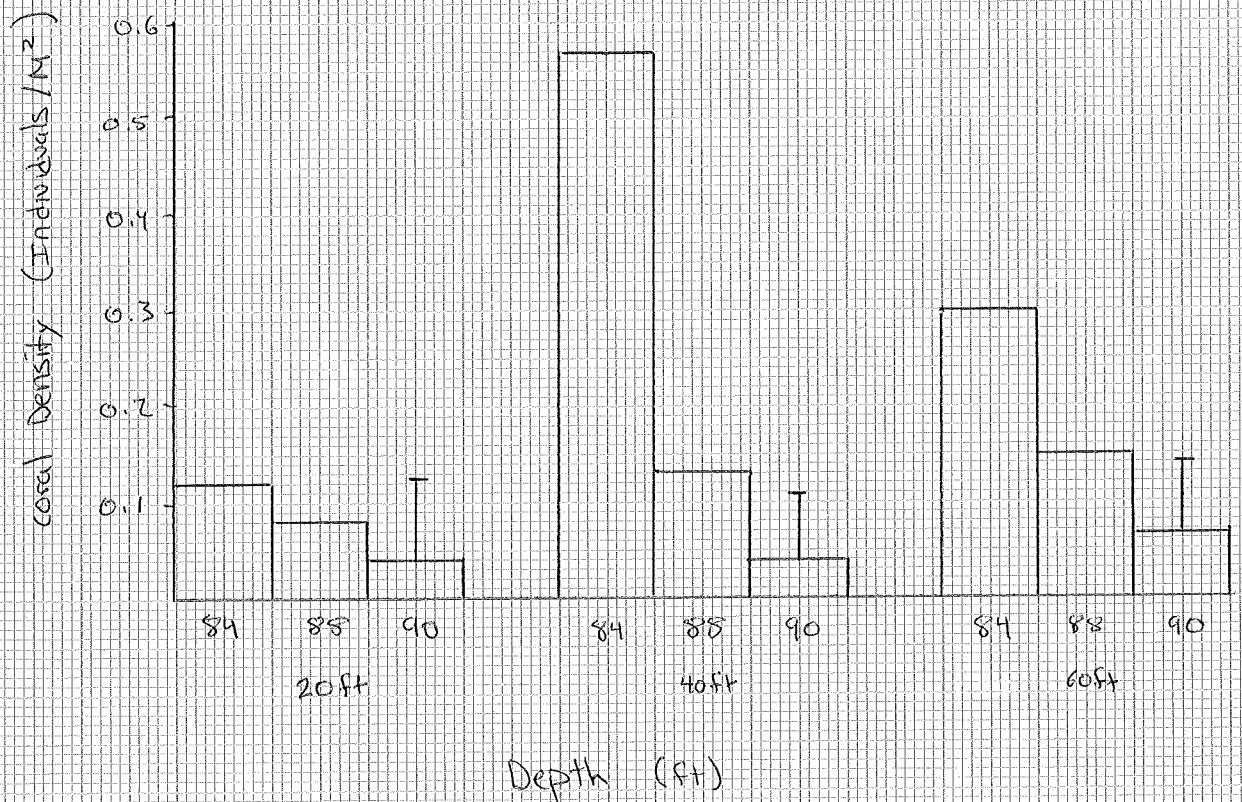


Figure 2. Coral densities (cm of branches/m<sup>2</sup>) before and after Hurricane Gilbert.

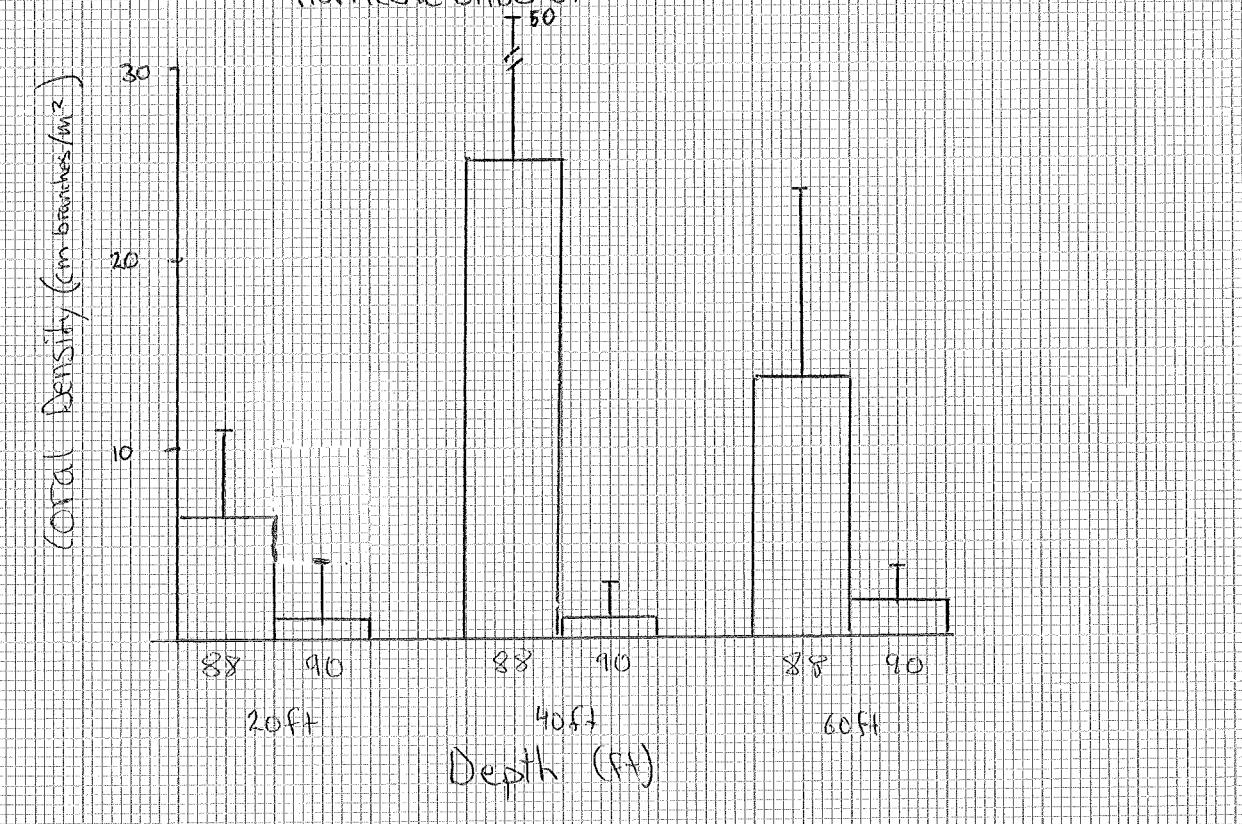


Figure 3. Percent dead tissue per individual at each depth, over the years. Standard deviations only available for the 1990 data.

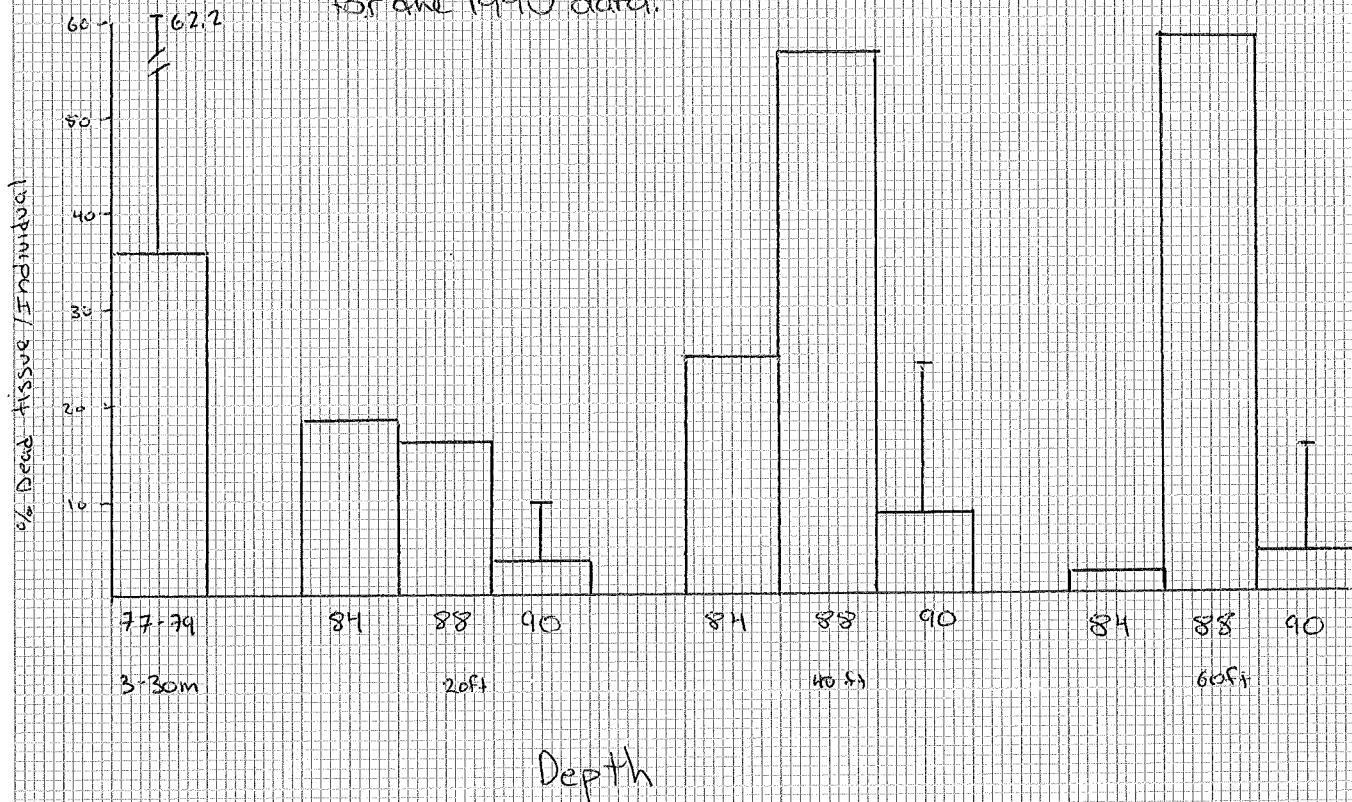


Figure 4. Mean coral height at the different depths, over the years.

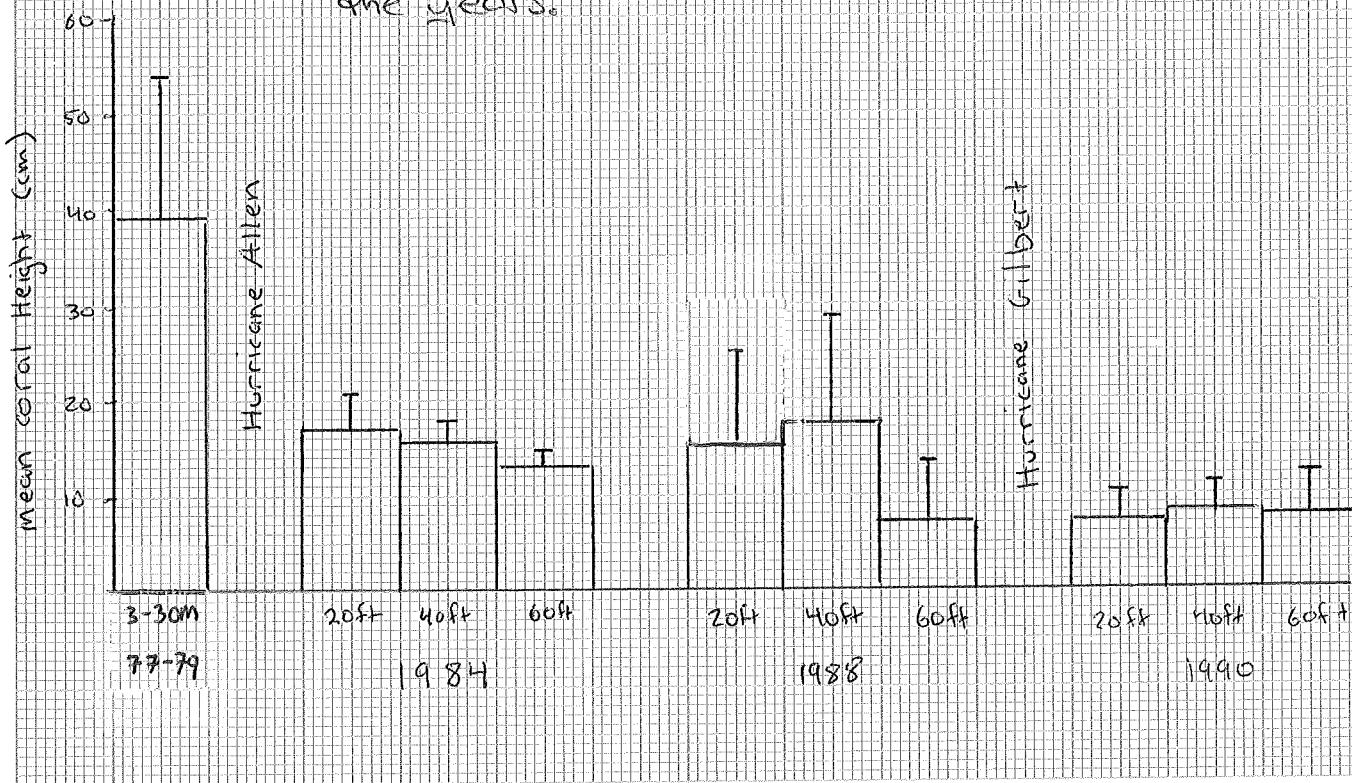


Figure 5. Frequency distribution of the coral heights in 1990.

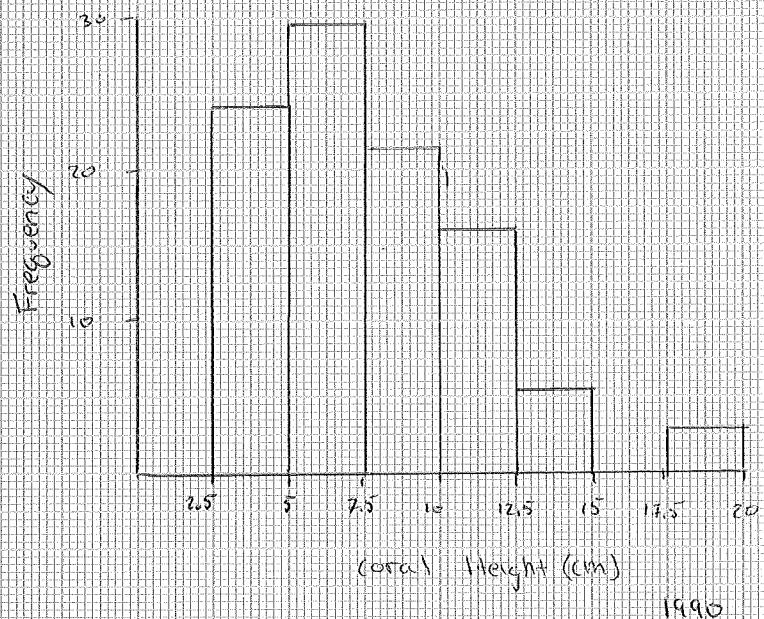


Figure 6. Frequency distribution of the coral heights in 1977-1979.  
(Tunncliffe 1981)

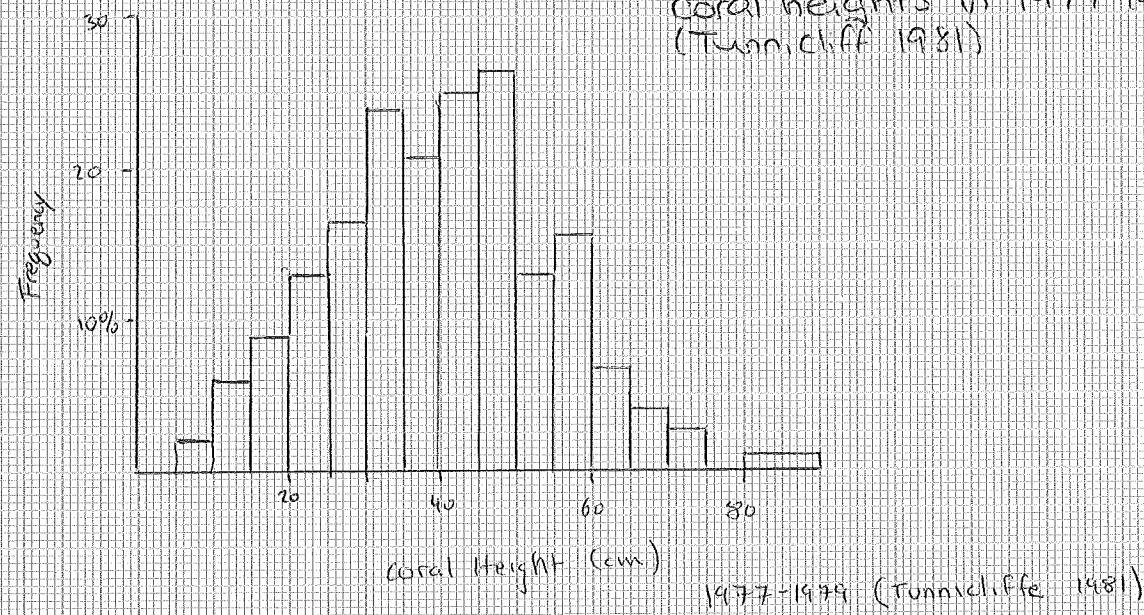


Figure 7. The <sup>mean</sup> highest branching order at the different depths, over the years

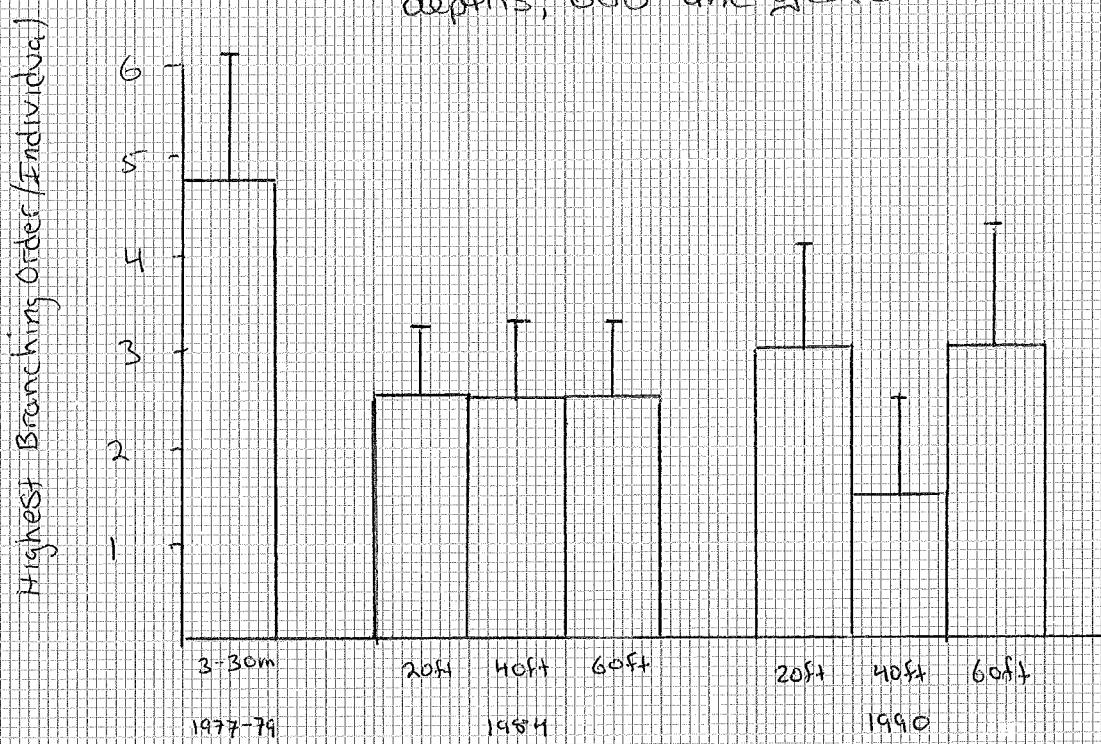


Figure 8. Branching orders demonstrated

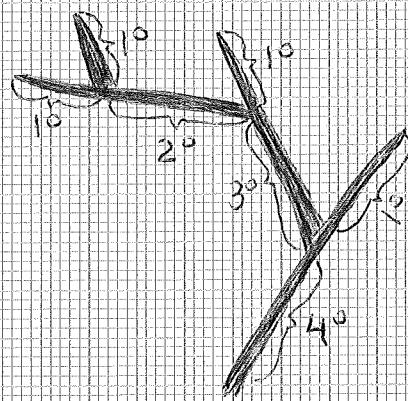
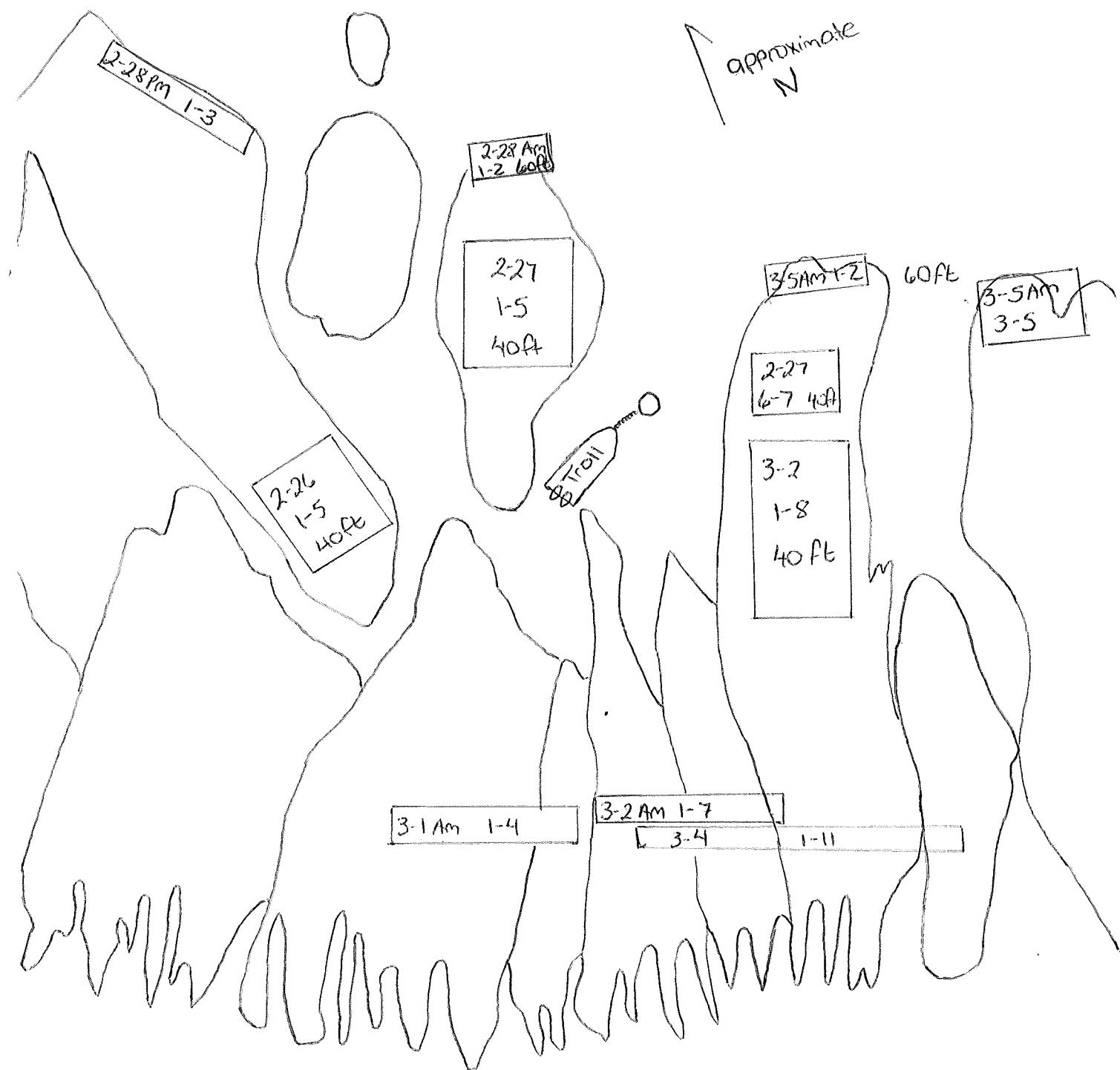


Figure 9. Map of mooring I including where we did our transects, the date, the number of transects, and the depths (to be used with the raw data, if needed).



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