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Population Density of *Octopus cyanea* in Kaneohe Bay

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Abstract:

According to fish harvest data, *Octopus cyanea* comprised 44.7% (25851.8 lbs.) of the estimated total annual harvest of fishes and invertebrate species in Kaneohe Bay during the period of March 1991 to February 1992 (Everson, 1994). Most of the *O. cyanea* catch reported was not sold for commercial use. Despite its dominance in annual fishing yield, estimates on population density and distribution across Kaneohe Bay have never been done. Results from searches of approximately 26,800 square meters of area throughout Kaneohe Bay during the months of July and August of 1998 showed patterns of distribution to be related to substratum type. Substratum was grouped into four categories: coral, loose coral rubble, sand, and pavement. The majority of active octopus dens were found in loose coral rubble. Despite lack of optimum substrate, densities on Coconut Island Refuge proved to be higher than densities found throughout Kaneohe Bay.

1. Introduction:

According to fish harvest data, *Octopus cyanea* comprised 44.7% (25851.8 lbs.) of the estimated total annual harvest of fishes and invertebrate species in Kaneohe Bay during the period of March 1991 to February 1992 (Everson, 1994). When compared to all other species, *O. cyanea* was by far the most productive fishery. The second was goatfish at just 8.6% of annual harvest. Throughout all four seasons, *O. cyanea* dominated the catch (Everson, 1994). Despite its dominance in annual fish harvest, no study has ever been done to determine the abundance and distribution of *O. cyanea* in Kaneohe Bay.

O. cyanea have a lifespan of only twelve to fifteen months (Van Heukelem, 1976). They have single matings and die soon after. In addition, reproduction is programmed. Females, upon reaching sexual maturity, if they have not found a mate, will lay an unfertilized clutch of eggs and die. A female *O. cyanea* can lay up to 700,000 eggs. *O. cyanea* are direct developers. Therefore, upon hatching, at a size of approximately only 3mm total length, they can ink, change color, and swim with a rapid forward motion at 1 to 3cm for prey. The hatchlings have a planktonic stage until they are approximately 1 cm in length.

Because they have a planktonic stage, and are well-developed motile individuals during this state, one could predict that juvenile *O. cyanea* hatched on a protected reef could easily maintain populations on nearby nonprotected reefs in the Bay. The Coconut Island Marine Laboratory Refuge has had refuge status for over 35 years. The refuge consists of the reefs and bay waters surrounding Coconut Island from the high-water mark on the island seaward to twenty-five feet beyond the outer edges of the reefs. It is unlawful to take any aquatic life from within the boundaries of the refuge (Division of Aquatic Resources, July 1997). Hawaii Institute of Marine Biology now has its own guards whose duties include the

monitoring of the refuge reefs. As a result, resources have been better protected than in the past and, therefore, may be more abundant on Coconut Island reefs than on other nearby non-protected reefs in Kaneohe Bay. A common question of fisheries managers is: Can refuges increase the stocks of fishes within refuges, and can they increase fishing yields on adjacent non-protected reefs?

A study done at Hol Chan Marine Reserve in Ambergris Cay in Belize showed a higher biomass of fishes per unit area of protected reef compared to other non-protected reefs in the area (Roberts and Polunin, 1994). Data from a marine reserve at Goat Island, northern New Zealand suggests that marine reserves may affect the local abundances of certain species of marine animals, but not others (Cole, et al., 1990).

Little is documented about the distribution and population density of *O. cyanea* throughout the reef flats and reef slopes of Kaneohe Bay. In spite of extensive literature on octopuses, reliable data concerning their behavior in nature is difficult to find (Yarnall, 1969). Studies actually performed in Kaneohe Bay are even more scarce (Forsythe, 1997).

The purposes of this study are: (1) to estimate the population density of *O. cyanea* throughout Kaneohe Bay, (2) to determine which substratum types are the optimal habitats for *O. cyanea*, (3) to determine the patterns of distribution and abundance of *O. cyanea* throughout the bay, and (4) to compare densities on the reefs within Coconut Island Refuge to densities of *O. cyanea* on other non-protected reefs in the bay to determine the effect of refuge status on this stock.

One hypothesis with regard to densities and patterns of distribution is that one should be able to find an optimal habitat. Once an optimal habitat is known, future surveys of areas of the Bay where densities have been and are currently highest, can be used to determine whether the population of *O. Cyanea* is in trouble due to factors such as overexploitation by fisherman, or changes and/or reduction of available habitat. The high fishing effort and yield shows that *O. cyanea* is an important local resource. This study will provide initial estimated densities and distribution patterns that may be used as a basis for more in-depth studies of *O. cyanea* population and potential management in the future.

2. Methods and Materials:

2.1 Development of Investigator's Search Image:

Several weeks were spent interviewing octopus fisherman about what patterns in substrate to look for in finding active octopus dens, and approximately 60 hours were spent snorkeling over reef flats of various types to develop a search image for octopus dens and the octopus itself. Approximately 9 hours were spent actually snorkeling with octopus fishermen who went out with me to show me what an active octopus den looks like on various substrata.

2.2 Selection of sampling areas:

Patch reefs were selected at random throughout Kaneohe Bay, as were sampling areas in the backreef area of the barrier reef between Kapapa Island and the sandbar, in order to get a representation of areas in the North, Mid, and South sections of the Bay (Figure 1). A reef numbering system for patch reefs in the bay is already in use (Roy, 1970). According to octopus fishermen, *O. cyanea* can be found on reef flats as well as on the reef slopes. Fishing efforts seemed to be more prevalent on the reef flats possibly because of the sparser coral cover, so it was decided that for the short duration of this study, transects on patch reefs would be done on the reef flats.

2.3 Sampling methods and materials:

Sampling of reef flats was done during the hours of 8:00am – 5:00pm, during the months of July and August of 1998. Records on prevailing winds were obtained from weather data sheets located at Coconut Island. Wind and currents may have an effect on the distribution of corals, macroalgae, and substrate types on each patch reef. Data showed prevailing winds to be out of the east and east/northeast a majority of the time so we decided to run east/west transects to ensure a representation of substratum types across each reef flat.



FIG. 1 Map of Sites searched throughout Kaneohe Bay

A temporary North to South transect was run down the center of each patch reef from the most northern point of the reef crest to the opposite reef crest using a compass heading of 180° . The position of the north/south transect was recorded using GPS coordinates for resurveying of the reefs in the future. The length of the north/south transect was then divided by 6 to calculate 5 evenly spaced points at which east/west transects would be run. Each east/west transect was run using a compass heading of 90 degrees east from the center line to the east reef crest and a compass heading of 270 degrees west from the center line to the west reef crest (Figure 2). Each east/west transect was searched by swimming the length of the transect tape and searching 2 meters on either side of the tape.

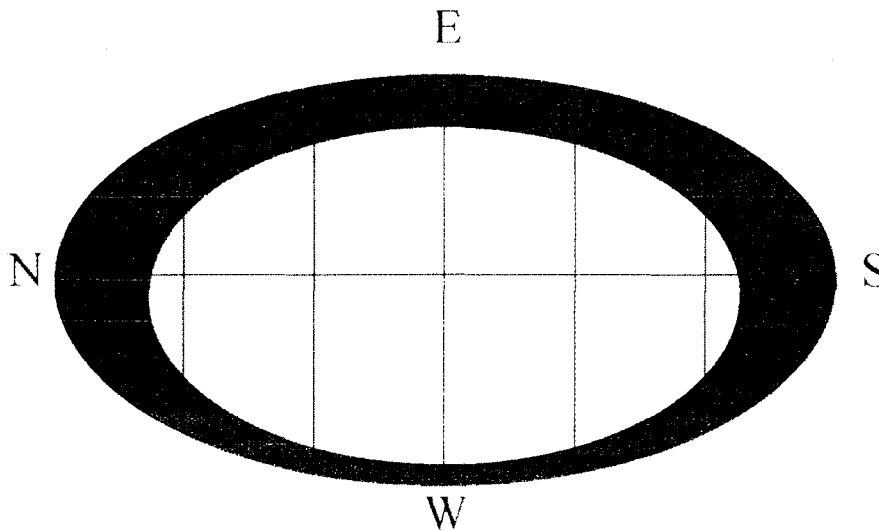


Figure 2. Patch Reef Transects

In the Backreef area and Chinaman's Hat, 100 x 100 meter grids were searched in a similar fashion as was done on the path reefs. A southern point was selected and its coordinates, determined by GPS, were recorded. A temporary North/South transect line was run using a compass heading to 360°. Five east/west transects were run using a compass heading to 90° east at 0, 25, 50, 75, and 100 meters along the north/south line (Figure 3). Each east/west transect was searched by swimming the length of the transect tape and searching 2 meters on either side of the tape.

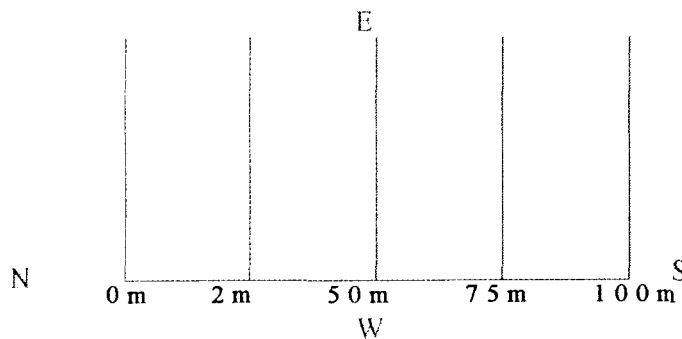


Figure 3. Transect Grids in front of Chinaman's Hat and Backreef areas

A grid to the right of the Sampan channel, which was already in place for a *Dascyllis albicella* spawning study, was also searched. A compass heading was used to determine the direction of these lines. Lines at 4-meter intervals from each other were searched by swimming along the length of the line and searching 2 meters on either side of the line.

Transects around Coconut Island were run using the 50 meter markers already in place at the reef crest around the island. Nine (9) markers were selected around the entire island and temporary 50 meter transects were run using a compass heading from each marker straight into the shoreline. Each line was searched by swimming the length of the line and was searched to 2 meters on either side of the line.

Data recorded along each east/west transect included: the total length of the transect, the number of active dens, the number of old dens, the number of octopuses and the proportion of each line in various substratum classes. The extent of each substratum class was estimated by recording the beginning and ending points of each substratum type along the transect.

The cryptic nature and camouflage capabilities of *O. cyanea* make detection of live animals along the reef difficult. For this reason, active octopus dens were used rather than live animals to estimate population density. Behavior and foraging studies done by Yarnall, Van Heukelem, Mather, and Forsythe indicated that an *O. cyanea* occupies one den for up to four weeks. None of these papers indicated that an octopus occupied more than one den and one time. In fact, video recordings of foraging efforts were done on the same animals which left and returned to the same den on foraging trips (Forsythe, 1997).

For any octopus den sighted the following data were recorded: the distance of the den from the west reef crest, the substratum type in which it was found, whether it was occupied or not, and whether the den was being actively used or was inactive. Because dens are shallow, an octopus occupying a den was easily seen by simply looking into the entrance.

Octopuses choose potential home sites and modify them rather than selecting appropriate unmodified sites for homes (Mather, 1997). Dens are excavated most often in coral rubble but may sometimes be found in living coral (Van Heukelem, 1983). We defined a den located in rubble or sand as a burrow usually no deeper than approx. 20-30 cm deep with an opening approximately 10 cm in diameter. A den in a coral area was either a round hole in which the octopus had literally broken live pieces of coral right out of the middle of the top of the coral head and burrowed inside, or an area at the base of the coral head where the octopus had broken out pieces of live coral and burrowed in the sand under the coral head. Dens in the coral heads were also fairly shallow like those found in the rubble and sand. There were loose piles of broken coral rubble in front of the dens that are used by the animals to cover themselves up when they are occupying the den. In some cases dens would have small, empty crab carapaces around the entrance, but in most cases discarded food items could not be used as indicators because there were none.

One occupied den was actually an unmodified hole in the pavement. There is a possibility that this animal may simply have been hiding from us as it saw us swim by. However, it appeared to be in a sleeping position with an arm wrapped around its head and mantle similar to Houck's observations of inactivity periods of *O. ornatus* (Houck, 1982) as well as several of our sightings of *O. cyanea* in active rubble dens. For this reason, the den found in the pavement was included in the data of active dens. Fig. 4 shows two examples of octopus dens that were found in a rubble area.

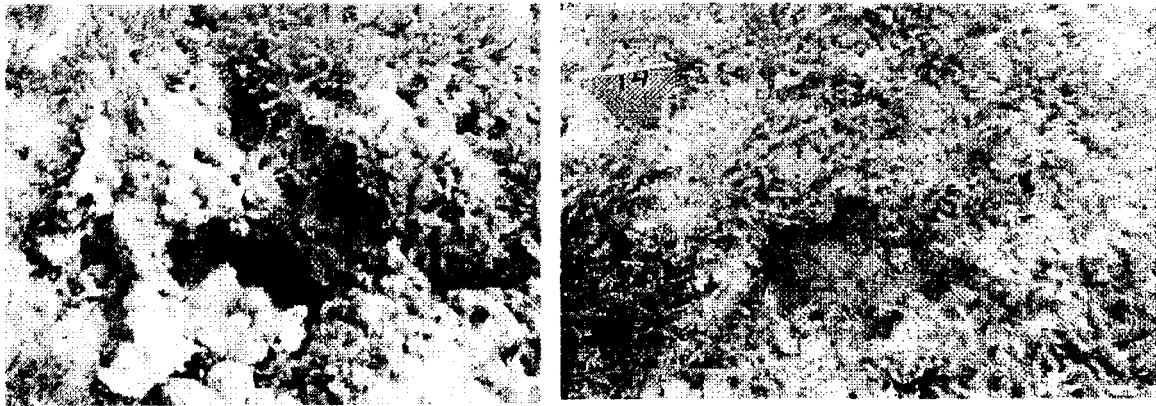


FIG. 4 Examples of octopus dens in rubble area.

Whether a den was identified as active or inactive was occasionally very subjective. Inactive dens were either filled in with sand and rubble because of heavy wave action in that area, or the loose pile of broken coral rubble in front of the den had a thick layer of algal growth indicating that the rubble had not been turned or disturbed by an octopus actively using the den. An active den's pile of broken coral rubble was free of algal growth because an octopus was regularly using the rubble. We had the opportunity to go back to some areas where we had marked active dens. Within four weeks time, the dens we had originally marked active were either completely filled in by sand and rubble or were so overgrown with algal cover that they were obviously no longer in use. For this reason, I feel comfortable that dens that were identified as active, actually were active.

Substratum types were recorded into sixteen different categories based on primary substrate and secondary substrates in the same area. For example R-C/S was an area primarily consisting of loose rubble with occasional patches of sand and/or isolated coral heads. These sixteen types were grouped into four main categories for data analysis, coral, broken coral rubble, and sand (Mather, 1997), as well as a fourth

category of pavement (solid limestone). Coral is defined as live coral cover. Rubble is defined as loose rocks and broken, dead coral covering a hard sandy bottom. Sand is defined as primarily sand cover. Pavement is defined as flat, hard, dead coral areas, which are covered with algal growth.

4. Results:

Optimal Habitat:

An analysis of substrates found in our search areas showed a large majority of the substratum found to be rubble at 47% of the total area as seen in Fig 5.

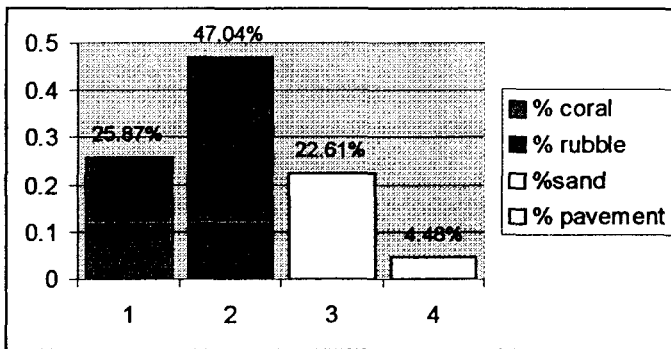


FIG 5. Percent of substratum in each category in search areas across Kaneohe Bay

Thirty active dens were found during our searches. Based on the percentage of substrate in each category, if the 30 active dens were evenly distributed across all four substratum types, one would expect to find 8 in coral, 14 in rubble, 7 in sand, and 1 in pavement. Instead, we found 2 in coral, 22 in rubble, 1 in pavement, and 5 in sand (Table 1).

Table 1. Number of active dens random expected vs. per substratum type

	# active dens per substrate				Total
	C	R	S	P	
Proportion of each substrate searched	0.26	0.47	0.23	0.04	
expected # active dens per substrate	8	14	7	1	30
observed # active dens per substrate	2	22	5	1	30

(C=coral, R=rubble, S=sand, and P=pavement)

A much higher than expected number of dens was found in rubble and much lower frequency was found in coral (Goodness of fit test, $G=10.98$, $p<0.025$). This is probably due to the fact that the rubble

areas are easily excavated and there is lots of loose broken coral which can be used around the outside of the den.

An analysis of each individual search area shows the distribution of substratum types (Fig 6).

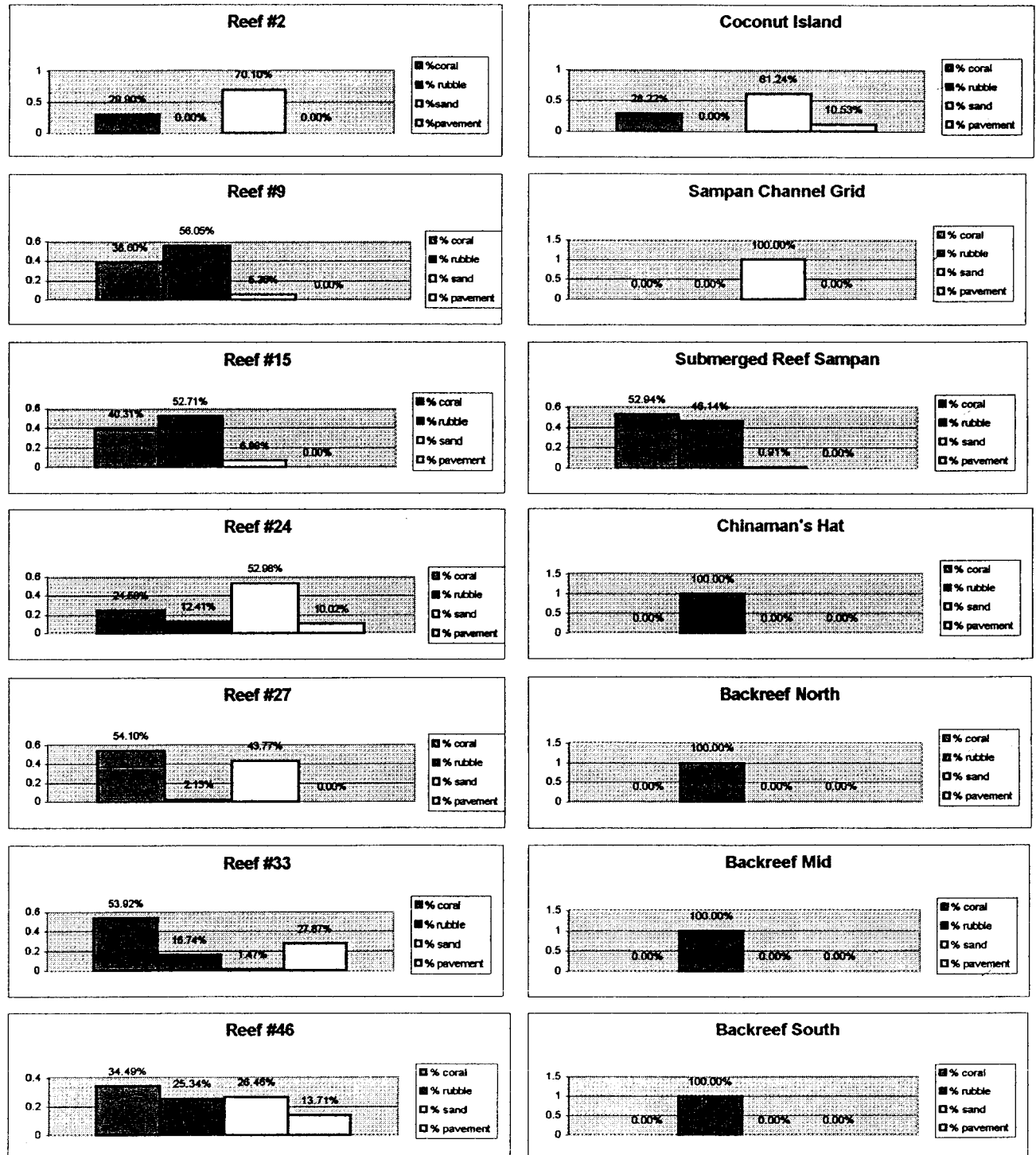


Fig. 6 Comparison of percentage of substratum types in each search area.

Patterns of density & distribution:

Chinaman's Hat, Sampan Channel, the Backreef and one submerged reef area near Sampan channel were all primarily rubble in the outer part of the Bay. For comparisons, these outer bay areas were grouped together and patch reefs in the inner part of the Bay were categorized as another group. The patch reefs were oval in shape with the longest length being oriented North to South. These usually had a ring of live coral growth around the perimeter of the oval and a mix of rubble, sand, and pavement inside the ring. The flats of patch reefs in the north part of the bay had more relief than those of patch reefs in the mid or south parts of the Bay. They were also covered by deeper water and were subject to heavier wave action than other patch reefs in the Bay. This was probably due to their proximity to the large boat channel at the north end of the bay.

The average density of active dens throughout Kaneohe Bay was 0.12 per 100 m² of search area. A comparison of dens per 100 m² per search area did not indicate any pattern of distribution from north to south in the bay (Fig. 7). Outer bay sites had higher densities than most patch reefs (Figure 7). This may be due to the higher percentage of loose coral rubble at the outer bay sites as seen in figure 6. Also, densities at Coconut Island Refuge were higher than all but one of the patch reefs, reef #15 (Figure 7).

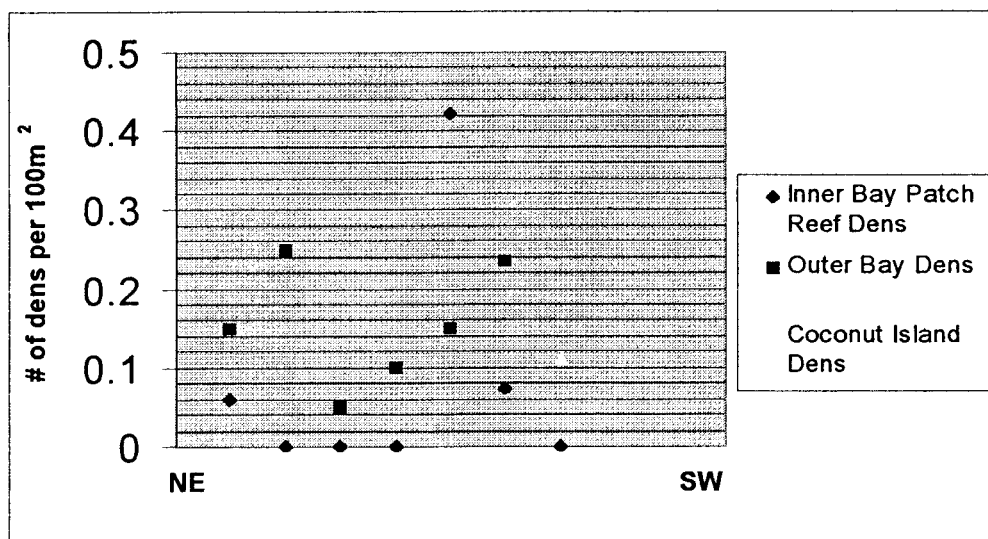


FIG 7. Number of active dens per 100m² per search area with areas sequenced from Northwest to Southeast in the Bay. (Inner Bay Patch reefs from left to right: #46, #33, #27, #24, #15, #9, and #2. Outer Bay areas from left to right: Chinaman's Hat, Backreef North, Backreef Mid, Backreef South, Submerged reef near Sampan Channel, Grid in Sampan Channel.)

If distance from the reef crest were a function of predator avoidance, one would expect octopus dens to be found as far in from the reef crest as possible. Our data shows ten out of fourteen dens on patch reefs were between 25% and 50% in from nearest reef crest (Fig 8). This distance appears to be more a function of substratum type than of predator avoidance since most dens were found in rubble areas and patch reefs had a perimeter ring of dense coral cover. This perimeter ring of live coral could account for the lack of dens in the first 25% of area from the reef crest, thus supporting the hypothesis that *O. cyanea* prefer loose coral rubble for den locations.

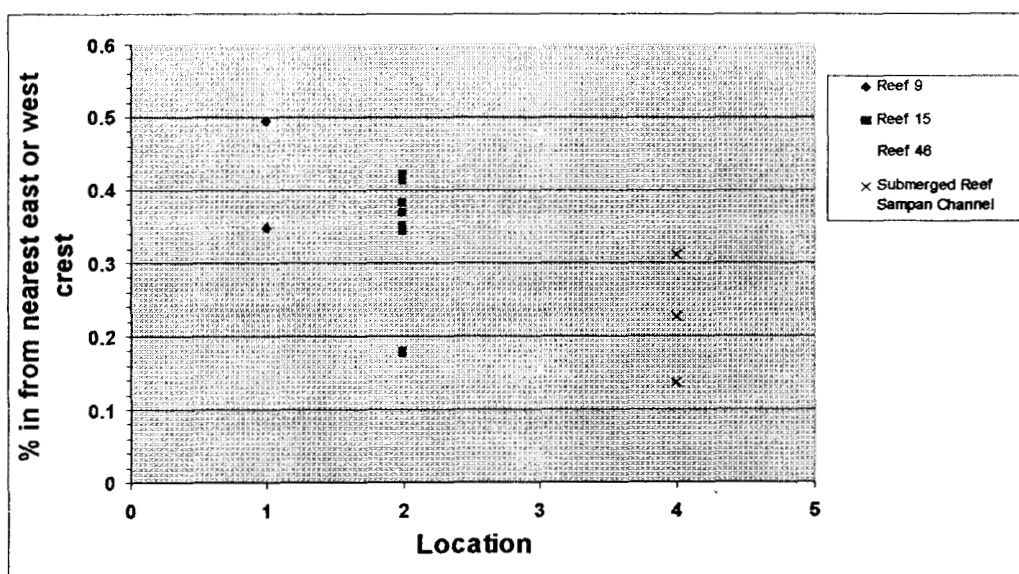


FIG 7. Percent distance of active dens from nearest east or west reef crest as a function of transect length.

Discussion:

A total of 26,800 square meters were recorded and only 30 active dens and 5 live octopuses occupying dens were identified. The densities acquired from this study were obtained during what is regarded as a season of low density. Although, throughout all four seasons, *O. cyanea* dominates the fishing catch in Kaneohe Bay there is seasonality to the number of *O. cyanea* caught. According to catch data in 1994, there were 2,266 lbs. of *O. cyanea* caught in the spring, 6,107 lbs. in the summer, 11,027 lbs. in the fall, and 6452 lbs. in the winter (Everson, 1994). Also, conversations with several octopus fishermen indicated, this has been a relatively low year for *O. cyanea* in Kaneohe Bay. Personal observation of the octopus fishing effort while we were out in the bay also confirms this. We saw very few fishermen looking for octopus while doing censuses in the Bay. The low densities we obtained may have

been in part, due to the season considering our searches extended from July to August. The densities may also be due, in part, to the fact that we had to develop a search image for identifying dens and animals. However, although our search image improved over the course of this study, we did spend approximately five weeks developing our search image. We are, therefore confident that our searches were consistent enough to provide accurate data throughout the study.

The high frequency of searched areas with 0 dens makes it difficult to detect and support patterns of distribution and abundance. However, some patterns can be suggested. Certainly, density of dens was greatest on rubble areas. Densities appear to be higher in outer bay areas, even after correcting for gross differences in substratum classes.

Coconut Island had a higher density of inner bay patch reefs despite its composition of mostly sand and live coral. Therefore, as a protected area, Coconut Island may very well be contributing to the success of the octopus population in Kaneohe Bay. A more in-depth study of Coconut Island and its surrounding reefs would have to be done to determine conclusively if this is true.

O. cyanea seems most common in the shallow reefs in the autumn and winter months (Van Heukelem, 1976 & Everson, 1994). However a systematic study of changes in distribution with season has never been conducted. This census should be repeated during the fall, winter, and spring to obtain an accurate picture of the population density of *O. cyanea* throughout the year. A multi-year monitoring program would be needed to produce accurate population data.

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