Distribution, abundance, growth and recruitment of the black-lip pearl oyster, *Pinctada margaritifera* in Kāne'ohe Bay, O'ahu, Hawai'i

S. Ku'ulei Rodgers

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Advisors
Dr. Paul Jokiel and Dr. Evelyn Cox
Hawai'i Institute of Marine Biology
P.O. Box 1346
Kāne'ohe, Hawai'i

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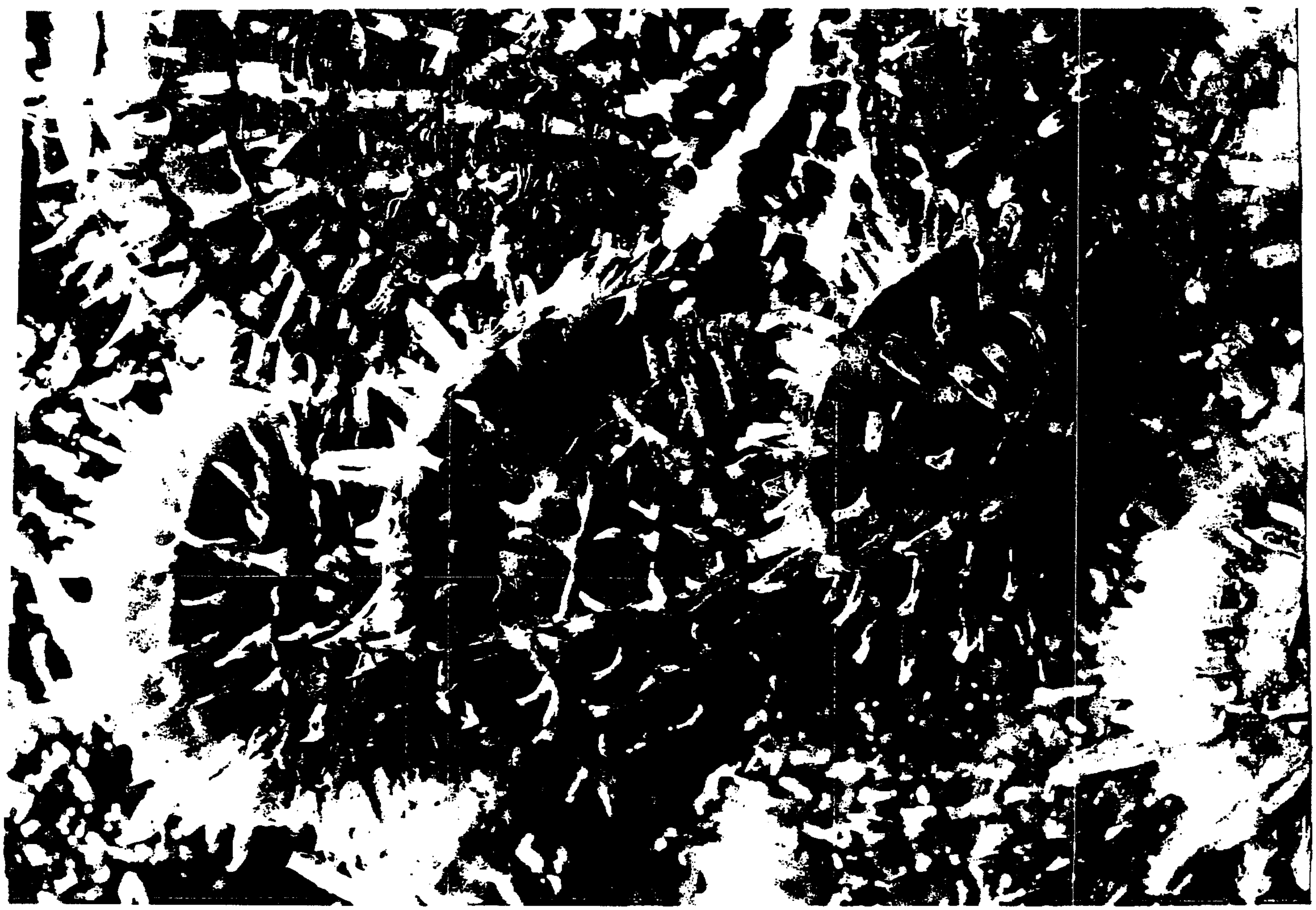

Abstract

The distribution, abundance, growth and recruitment of *Pinctada margaritifera* in Kāne'ohe Bay, O'ahu, Hawai'i was studied. Standing stock in Kāne'ohe Bay is estimated at 769 oysters with a density of 0.00001 oysters per m^2. Highest density was found in the Central Basin at depths between 2 and 6 meters. Failure of recruitment onto standard collection bags indicates a population with a low effective population size, limited by recruitment.

Growth and mortality rates indicate sufficient availability of resources and limited predation to support restocking of depleted populations. This study provides a baseline to monitor population stability and effects of supplemental recruitment for artificial enhancement of natural stocks. Continued legal protection is essential to conservation efforts.

Introduction

The black-lip pearl oyster *Pinctada margaritifera*, is a bivalve belonging to the family Pteriidae. It is widely distributed in tropical and sub-tropical seas throughout the Indo-Pacific region. Distribution is associated with coral reefs surrounding scattered tropical islands. The greatest abundance of this species is found in atolls and lagoons of French Polynesia and the Cook Islands in the South Pacific. In Hawai'i, *P. margaritifera* are usually found in shallow inshore areas, in waters from 1 to 5 meters deep.

The shell is oval to quadrate in shape, thick, compressed and dense. The exterior is laminated while the interior is silver gray and iridescent, bordered by a dark or smoky band, leading to the name black-lip pearl oyster (Kay 1979). The dorsal margin is straight while the anterior, posterior and ventral margins are curved (Summers 1990). Maximum sizes of 30 cm in diameter and shell weights of 9 kg have been documented. *P. margaritifera* has a lifespan of up to 30 yrs (Fassler 1992).

Several subspecies have been distinguished on the basis of origin. *Pinctada margaritifera* var. *cumingi* is found in French Polynesia. The Hawaiian variety described as *Pinctada margaritifera* var. *galtsoffi* is an endemic subspecies.

Historical Background

Historical accounts of usage of pearls as ornamentation and for religious purposes extends as far back as the civilizations of the Greeks, Romans, Assyrians, Babylonians, Egyptians, Chinese and Indians, 3,000 years ago (Reed 1973).

During the Industrial Revolution in the early 1800's, a large-scale use of pearl oysters for making buttons began. When synthetic products were developed in 1955, predictions that the button industry would collapse were unfounded. Synthetic materials could not rival genuine mother-of-pearl, and fine garments producers continue to utilize this diminishing resource (Reed 1973).

Natural pearls are rare in *Pinctada margaritifera*, thus early fisheries targeted the pearl shell. Mother-of-pearl currently sells for $8,000 a ton.

Modern large-scale exploitation of *P. margaritifera* began in 1802 in the Gambier Islands, located in the South Pacific. The industry was based on collection of native stock by local people. The black pearl was exported for jewelry. The shell of the oyster was used for buttons. The natural populations declined rapidly due to overfishing, and by 1940 the oysters stocks had become too depleted to sustain the industry (Sims 1992a).

The native oyster (pā) was vitally important to the Hawaiian culture and traditions. Artisans used the shell in creating jewelry, weapons, images and other arts and crafts that were an integral part of the culture.

In Hawai'i in the early 1800s, King Kamehameha I developed a fishery for pearl oysters in Pearl Harbor in response to increasing Western demands. This industry was short lived due to increased siltation from runoff caused by introduced cattle grazing. By 1940, most of the colonies of pearl oysters had smothered from the unprecedented sedimentation (Reed 1973).

At the turn of the century a new supply was discovered at Pearl and Hermes reef, an atoll situated 1,100 miles northwest of O'ahu. Hawaiian Sea Products harvested over 100,000 oysters between 1927 and 1930 (Galtsoff 1933).

In response to declining populations throughout the Hawaiian chain, *Pinctada margaritifera* were resown from Pearl and Hermes Reef to Kāne'ohe Bay, on the island of O'ahu. In 1930, 310 oysters were placed in the site selected for transplantation, located near the southern end of Moku o Lo'e along the slope of the coral reef at 5 to 12 m depth. They were later dug up from thriving beds in Kāne'ohe Bay and transplanted to different islands in 1938 (Devaney *et al.* 1976).

Once abundant throughout the Hawaiian archipelago, populations have been reduced due to over-harvesting for pearl shells (Kay 1979).

In Hawai'i, only remnant populations remain of once thriving colonies. The Kona coastline of the Island of Hawai'i and Pearl and Hermes Reef have only vestigial populations left, representing a fraction of original colonies. No other surveyed area in the Hawaiian archipelago presently supports substantial adult *P. margaritifera* colonies. Surveys report complete extirpation from Midway. Following an eight month survey of Pearl Harbor, only two black-lip pearl oysters were found. Individuals have been sighted in low densities at several locations throughout the State. (Jokiel pers. comm. 1997).

Hawai'i Revised Statutes has listed *P. margaritifera* as a protected species, and legal protection is provided against harvest (§-13,83,1,2).

The first experiments with pearl culture began in 1963 in French Polynesia. The industry was based on collections of wild oysters.

Numerous attempts were made to produce and raise larvae in 1976 and 1977. Larval rearing was undertaken to produce the quantity of pearl oyster larvae necessary to fulfill the increasing requirements of the industry for young implantable oysters. Wild stock had become so depleted from overfishing that the industry could no longer rely on the previously utilized resource of natural populations. Failure of these trials to produce viable larvae for culture renewed harvest from local lagoons. The poor results from hatchery trials also led to development of larval collection from the lagoons (Coeroli *et al.* 1984). A method of natural collection of larvae, called spat, was developed on Takapoto Atoll. This relied on catching spat on collectors in natural growing areas (Sims 1992c).

Early experiments submerged branches of u'u (*Phemphis acidula*), a native plant which is widespread on nearby atolls. Spat would settle on the branches, attach and begin to filter feed. They would then be transferred to sheltered areas.

As the spat collection technique developed, materials diversified. Today, shade cloth, polyethylene film and mesh, in addition to native plants, are protected within a polyethylene mesh bag. Veligers can propel themselves, unlike adults of the species which remain sessile. Spat settlement is selective. Natural collectors have proven more efficient than artificial ones (Coeroli et al. 1984).

Study Site

Kāne'ohe Bay is located on the Northeast coast of the island of O'ahu, in the Hawaiian Archipelago (Fig.1). It is the largest embayment in the State of Hawai'i and the most extensively studied. It extends approximately 13 km in length and 4.5 km in width. Two navigable channels penetrate the outer barrier reef, at the northern and southern ends of the bay. The inshore, inner bay and outer bay comprise the major physiographic zones. The inshore zone is composed of the shoreline intertidal zone and the fringing reef. The lagoon and the patch reefs comprise the inner bay. The lagoon is divided into three sectors: Southeast, Central Basin and Northwest. The outer bay zone contains the barrier reef. (Smith et al. 1973).

Anthropogenic influences include erosional runoff of terrigenous sediments, dredging, diversion and channelization of streams, changes in the watershed and riparian environment, 25 years of sewage effluent discharge and invasive introductions. Despite a population increase in the surrounding watershed, the water quality of Kāne'ohe Bay improved following sewage diversion from highly eutrophic to relatively oligotrophic conditions (Laws and Allen 1996).

Seawater is driven shoreward across the barrier reef by wave action. Prevailing tradewinds blow from the NE and E approximately 70% of the time. Circulation in the inner bay is determined by bathymetry and driven by tides and wind and the inflow across the barrier reef. The southeast sector has more restricted circulation.

Kāne'ohe Bay is an ideal location for the survey of *P. margaritifera* distribution and recruitment. It is one of the few areas in the state where a population remains. There is an extensive history of flourishing populations as well as rapid declines. Environmental records exist for physical parameters, topography and bathymetry within the bay and the surrounding watershed due to extensive scientific research of the ecosystem.

Methodology

Transect surveys of representative reef types

In 1989, Sims (unpublished) assessed adult populations of *Pinctada margaritifera* in Kāne'ohe Bay and established reproducible transects. The 1989 survey focused on patch reef slopes, where the highest density of *P. margaritifera* was expected. Standard line transects were used to resurvey the 21 sites, located in all three sectors of the bay: South bay, Central basin and North bay. Area surveyed at each site ranged from 200 to 1,000 m^2 (Table 1).

Three reef types typify Kāne'ohe Bay's physical environment : fringing, patch and barrier reefs. To assess the current population and establish a baseline for future research, additional sites were surveyed and include fringing reef and barrier reef habitats. Sites were selected as representative of these reef types in the three main sectors of the bay.

At each site, a standard line transect of 100 m length was located between 4 and 6 m depth. Three sites in each bay sector were selected to represent the fringing reef. Six barrier reef sites were located on the reef flat and back reef. Each transect encompassed an area of 1,000 m^2, surveyed by observers covering 5 m on each side of the 100-m line (Table 2). Number, shell diameter and location on transects of pearl oysters were recorded along with depth, substrate type and transect length.

Density was extrapolated using estimates of total area of reef types from (Hunter 1993). Density within the three sectors was calculated separately for each reef type (Table 3). Standard statistical analysis was used to determine change in dorsoventral measurements.

Recruitment

Recruitment was determined with the use of "spat collectors", 50 x 20 cm bags of 2 mm mesh, loosely filled with 70% shade cloth measuring one m^2 . At each sampling station, 10 bags were placed at a depth of 8 m, anchored to the substrate and suspended in the water column by internal flotation. Bags were deployed for three months. To allow for seasonal variation, two collection periods were sampled: April through June 1997 and June through August 1997. Four sites were selected to represent the three major physiographic zones of the bay and proximity to navigable channels that penetrate the outer barrier reef at the northern and southern ends of the bay.

Growth

Dorsoventral measurements were used to estimate growth. Individuals were growing in natural conditions. Individuals were not identified, so growth estimates were based on the mean size of 5 measurements per group of individuals. The external shell diameter from the umbo to the outermost continuous edge of the non-nacreous border, excluding the digitate growth processes, was measured with calipers. Measurements were obtained from two age groups. Growth was monitored monthly from three groups of adult pearl oysters totaling 15 individuals for a period of 18 months (Fig. 2). Shell diameter was also recorded from two sets of juvenile oysters, totaling 15 individuals for a period of 6 months (Fig. 3).

Results

Distribution and Abundance

The population increased by 29% between surveys. Density of oysters on 21 transects measured in 1989 (n=17) and 1997 (n=22) are not significantly different (Kruskal-Wallis one-way analysis of variance p= 0.68).

Shell diameters ranged from 80 to 215mm in 1989 and 35 to 230mm in 1997, with an increase in mean shell diameter of 20.1mm. The mean dorso-ventral measurements increased between surveys from 148.4 mm in 1989 to 174.5 mm in 1997 (Fig. 4). Size distributions for the two years were not significantly different (Kolmogorov-Smirnov test p= 0.46).

Twenty-two pearl oysters were found at seven sites. Mean density in the south bay was 0 per $1000m^2$, central basin 0.23 per $1000m^2$, and north bay 0.07 per $1000m^2$. Patch reef slope area (Hunter 1993) was used to estimate total density for patch reef habitats. The three sectors of the bay were calculated separately since density was highly variable between sectors. Overall abundance on the patch reefs is estimated at 698 individuals (Table 3). 91% of the population occurs on the patch reefs. 83% of the population occurs in the Central Basin, 17% in the North Bay and 0% in the South Bay.

Nine permanent transect sites were established on the fringing reef and 12 sites on the barrier reef to better monitor stocks and to avoid variability in estimates due to spatially patchy distributions (Fig. 1). Calculations for density were made using fringing reef slope area estimates and barrier reef flat and back reef estimates (Hunter 1993). Calculations were made separately for each sector. Total density on the fringing reef is estimated at 41 individuals, barrier reef density is estimated at 30 individuals (Table 3). Highest density occurs in the Central Basin on both the fringing and barrier reefs. Standing stocks, estimated from calculation of all suitable substrate totaled 769 pearl oysters within the 56,700,225 m^2 of Kāne'ohe Bay. Using the estimated confidence limits for the mean density overall, it is estimated that the density in the bay can be as low as 384 or as high as 1,538 pearl oysters. Highest density was concentrated in the Central Basin in close proximity to the Sampan channel (Fig. 1). Some shifting of patterns of distribution on patch reefs occurred between surveys, yet the majority of the population remains in the Central Basin.

Recruitment

Pinctada margaritifera was absent from all spat collection sites on the collection date of 19 June, 1997. Four recruitment bags were retrieved from site #1 in the North Bay, 7 bags from site #2 in the Central Basin, 10 bags from site #3 located in the Central Basin and 10 bags from site #4 in the South

Bay. Settlement of other species of bivalves occurred. The North Bay site recruited an average density of 3.3 bivalves per collection bag. The Central basin sites recruited an average density of 0.6 bivalves per collection bag. The site located in the South Bay recruited an average density of 1.7 bivalves per collection bag (Fig. 5).

Growth

Growth rates varied widely between individual adult *P. margaritifera*. Monthly average growth rates ranged from -0.11mm to 0.40mm per day (Fig. 2). Growth estimates were based on means from 5 individuals in 3 groups. The adult size class ranged from 84mm to 121mm at the start of the trials. Average dorso-ventral measurement increase was 0.12mm per day or 4.4cm per year.

Growth varied widely between age groups under identical culture conditions. The largest growth increments occurred in the smaller size class. The juvenile size class ranged from 11mm to 64mm at the start of trials. Growth measurements were based on the mean size of 7 and 8 measurements in 2 groups. Growth averaged 0.32mm per day or 11.7cm per year (Fig. 3). Regression of annual increment against dorsoventral measurements was used to compare growth between size classes.

Mortality rates of 6.7% occurred in each size class.

Discussion

Distribution and Abundance

The population of *P. margaritifera* is restricted in size and distribution in Kāne'ohe Bay. They are concentrated in the Central Basin in close proximity to the Sampan channel. Limited circulation and heavy sedimentation may limit settlement in the South Bay. Oceanic conditions of the North Basin may also limit settlement.

Pearl oysters were most abundant between 2m and 6m depth. Below 6m, calcareous and terriginous sediment exclude populations by preventing larval settlement and impeding filter feeding. High mortality may occur in waters shallower than 2m due to high water motion and periodic runoff of fresh water, which can inundate patch reef flats at low tides.

The black-lip pearl oyster is typically found in large aggregations in the Indo-Pacific region. It does not appear to be found in large aggregations in Hawai'i. Patchy distribution occurred in all three sectors of the bay on all reef types. This species appears to be sparsely populated throughout the Hawaiian archipelago occurring in low numbers over wide areas.

Density estimates from the robust colony of pearl oysters prior to 1927 at Pearl and Hermes reef were compared to current populations at Kāne'ohe Bay. Based on area estimates, Pearl and Hermes reef had a total density of 0.0003 oysters per m^2 and Kāne'ohe Bay has a density of 0.00001 oysters per m^2, an equivalent of 30 times higher density at Pearl and Hermes Reef.

Water circulation patterns can limit recruitment. Although high levels of within population variation occur, low genetic distance has been observed among widely separated populations in the Pacific (Benzie and Ballment 1994). This implies high gene flow among widely dispersed populations and restrictions in gene flow on a local scale. It takes 16 to 30 days for the planktonic veligers to metamorphose and "set", forming shells. This long planktonic early life stage is responsible for gene flow in widely dispersed populations.

By calculating juvenile growth for the first two years and adult growth rates for the next six years, based on growth rates in this survey, approximately half of the oysters found in the current survey have recruited since the original 1989 survey. Based on these growth estimates, all oysters on the baseline survey would be greater than 230mm. No oyster in growth trials exceeded 160 mm. in 18 months of monitoring. Growth rates appear to slow further at larger sizes. Lifespan can exceed 30 years (Reed 1973). Some mortality has occurred between surveys including individuals in the maximum size class. Although transects indicate some recruitment, the low density suggests low recruitment has occurred since 1989.

Absence of recruitment of *P. margaritifera* onto larval collection bags further supports the suggestion of limited recruitment. Other bivalves recruited to collection bags yet were not found on any of the transects.

Pearl oysters are excellent indicators of heavy metals and can be useful to environmental monitoring (Shiber 1980, Jacob et al. 1980). Kāne'ohe Bay's limited population decreases its usefulness as an indicator of environmental change.

Recruitment

Absence of *P. margaritifera* on collection bags may be due to seasonality, low sample size and number of sites, a limited breeding population or larval transport out of the bay. Recruitment of *P. margaritifera* for the period from Jan. 1996 to Jan. 1997 at Moku o Lo'e has also been monitored (Rodgers unpublished). No recruits have been found during this time period. A reproductively active population of between 30 and 60 individuals was maintained during this period of spat collection.

Temperature is the main factor initiating spawning in *P. margaritifera.* Spawning in tropical pearl oysters occurs throughout the year and is not limited by seasonality. Maximum spawning intensity usually occurs in summer or winter months but may vary between years and locations. Spawning peaks may correlate with increases and decreases in water temperature. Other local stimuli may include changes in salinity, currents or stress related situations (Reed 1973).

Veligers are positively phototaxic, remaining near the surface. Larvae remain planktonic for 16-30 days. Suitable settlement substrate, food resources and temperature contribute to the length of the larval stage. Settlement location can be controlled by temporary mobility. High predation rates during the veliger stage increase upon settlement. *Stylocus* flatworms and *Cymatium* snails which are predatory molluscivores, were recovered at all four sites within collection bags.

Lack of recruitment of *P. margaritifera* and absence of oysters of small size on transects may suggest limited present recruitment.

The circulation pattern within Kāne'ohe Bay creates an average water residence time of two weeks, theoretically allowing sufficient time for larvae to contact substantial areas of suitable substrate within the bay. A water circulation model for Kāne'ohe Bay, SPECIES can predict the retention time of larvae at different time intervals in various locations throughout the bay. This model can be useful in stock enhancement assessment and lagoon comparisons.

The effectiveness of artificial collectors to measure recruitment may be limited by the number of sites. Recruitment occurs over a wide settlement area. A larger number of replicates may be necessary for assessment of recruitment in populations with patchy distributions or low numbers.

Recruitment may be density dependent. Close proximity is essential in maintaining numbers of reproducing adults. Females must be close enough to males to sense they have spawned before they will release their eggs. Populations that are patchy and widely dispersed may not foster favorable reproductive conditions for populations to recover naturally.

Although *P. margaritifera* did not recruit, overall bivalve recruitment can be compared between sites (Fig. 3). Bivalve recruitment was the heaviest at the Ship Channel at the northern end of the bay where veligers may enter or exit with tides and currents. This pattern was not reflected in settlement at the shallower Sampan Channel site in the Central sector of the bay.

Growth and Mortality

Growth is associated with oceanographic conditions of the area. Numerous factors influence growth in *P. margaritifera*: water quality, phytoplankton availability and quality, disease, parasites and biofouling. Water quality parameters include temperature, salinity, pH levels, and nutrient levels. Growth rates can be used to indicate fitness in oysters (Sims 1993).

Growth rates varied between individuals within size classes. Highly variable growth rates have been recorded elsewhere (Nicholls 1931, Coeroli et al 1984, Nasr 1984). Factors influencing growth variability may include genetic differences, annual or seasonal variations and effects of decrease in shell diameter. Decreases in shell size may be due to attempted predation or abrasion by herbivorous grazers which results in loss of the outermost non-nacreous border. Natural sloughing of digitate, growth processes at the edge of the non-nacreous border, by oysters under stressful conditions may also result in shell diameter decreases (Sims 1994). Sims (1993) suggests growth conditions may vary year to year.

Growth measurements were taken from individuals in Kāne'ohe Bay's south bay where the most restricted water flow and longest residence times occur. Kafuku and Ikenoue (1983) demonstrated for *Pinctada fucata*, that more exposed lagoons result in better culture conditions due to increased water motion. Currents may stimulate growth (Galtsoff 1933) and increase resource availability. Stress from handling may also affect linear growth (Powell 1960).

Comparative trials in the north and central sectors of Kāne'ohe Bay, where a larger percentage of the adult population occurs than in the southern part of the bay, may show larger increases in dorso-ventral measurements.

Mortality rates were low for both size classes. Mortality factors include predation, disease and sedimentation. Rates may be site specific.

Conclusion

Based on record of occurrence, Kāne'ohe Bay is one of the richest habitats for this rare species, yet only about 800 individuals remain. Populations appear to be maintaining themselves at a low density. They are most abundant in central region of the bay where high water quality and increased circulation occur. Recruitment is very low.

Previous histories of overfishing are reflected in the low density numbers. The limited distribution of *P. margaritifera* in the Central Basin and narrow depth range may increase its susceptibility to environmental stresses or stochastic, catastrophic events

Kāne'ohe Bay has conditions favorable to growth of *P. margaritifera.* Growth rates in the bay are comparable to growth rates of cultured oysters elsewhere. Slow recruitment may point to a small population with low density and patchy distribution. Recruitment may also be limited by local circulation patterns. Water circulation models can assist stock enhancement efforts by determination of larval retention times.

The effects of environmental, demographic, and genetic stochasticity can be dramatic in small populations. Broodstock protection is critical to the effective population size. Initial recovery may be slow in a long-lived species. A combination of low reproduction rates due to a small population and low recruitment, may hinder restocking efforts of depleted populations.

P. margaritifera is a protected marine fisheries resource. It is illegal to take, kill, possess, remove or sell this species in Hawai'i without a permit (§13-83-1,2). Continued legal protection is vital to this species. A powerful resurgent movement to preserve Hawaiian traditions has recently emerged. The black-lip pearl oyster was a vital part of the native culture (Summers 1990). Native species must be retained, protected and managed for the survival of cultural practices and spiritual values.

The number allowed for collection by permit should be related to standing stock and turnover rate. Based on this survey, turnover rate is approximately 16 years with 50 new recruits per year. Removal of individuals from the natural population may not be advisable and caution in permit issuance is suggested.

Recent advances in laboratory larval rearing techniques can eliminate dependence on natural populations to support enhancement. Broodstock can be grown out from hatcheries in land based or nearshore environments. This can completely eliminate the need to collect adult oysters from the wild. This has been successfully demonstrated in French Polynesia and the Cook Islands. The hatchery oysters mature in the field, releasing gametes to expand the base available for recruitment. One hundred mature oysters are currently being maintained at Moku o Lo'e under natural conditions. The effects of this aggregation on future density may be very significant in supplemental recruitment. Growth and mortality rates show sufficient resource availability and limited predation to support restocking of depleted populations. Conservation efforts can also be enhanced through commercially based industries to increase public awareness of marine conservation. Self-sustaining stock re-establishment programs can be provided by private operations to protect broodstock reserves and genetic diversity. Programs of this design create a dual purpose agenda by supplying both the commercial pearl industry and the depleted natural stock with re-establishment of the natural population to prior abundance.

Growth rates near the Sampan Channel may be higher than at Moku o Lo'e due to increased water flow and more suitable substrate. Given that the concentration of the natural population occurs around Sampan Channel, natural growth should be monitored. Monitoring known individuals at these sites would palliate constraints of disappearance of stock placed there.

This study provides a baseline to monitor the stability of the population and effects of stock enhancement programs. Although changes in stock abundance and distribution can be measured by resurveys, mortality and recruitment must also be monitored to fully assess the health of a population.

Expanded research is needed to resolve these issues. Studies of ecological and biological processes and interactions, reproductive studies, monitoring current populations, tagging, mark and recapture can provide necessary information vital to protection and conservation measures. Further assessments of abundance and distribution in the main Hawaiian Islands and the northwestern chain can provide baselines for research, education and management. These studies can provide data to determine the feasibility of restocking efforts.

Hawai'i is one of the best natural laboratories in the world. There is enormous value in the State's biodiversity. Our native biota is rapidly becoming Hawai'is most important resource. With the loss of our native marine species comes the loss of valuable contributions to science, medicine, education and economics. The loss of these species is irreversible. Hawai'is health and economic productivity is directly dependent on the conservation of our marine resources.

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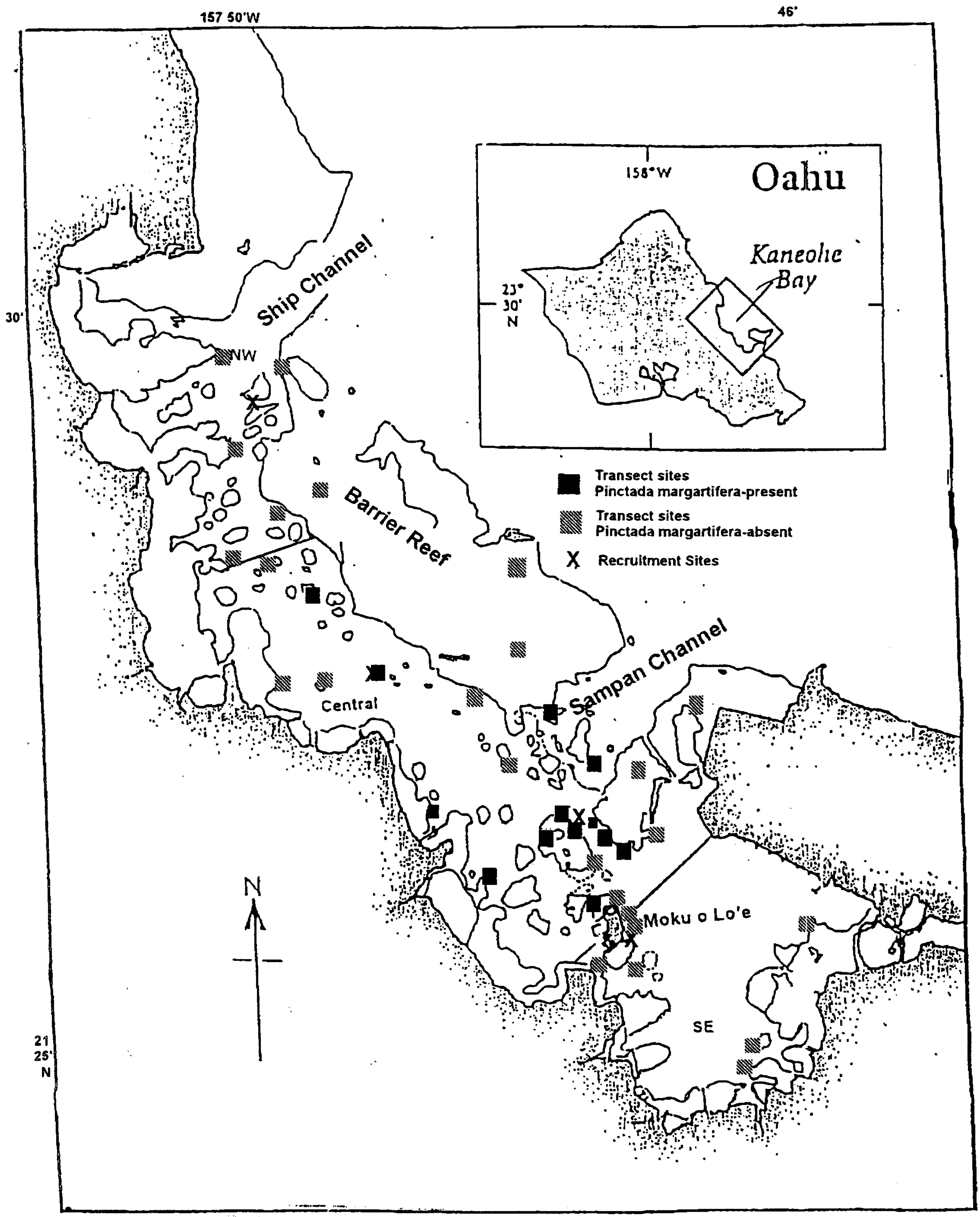


Figure #1 Kāne'ohe Bay, O'ahu, Hawai'i
Transect and recruitment sites
1989 transects located on the patch reefs

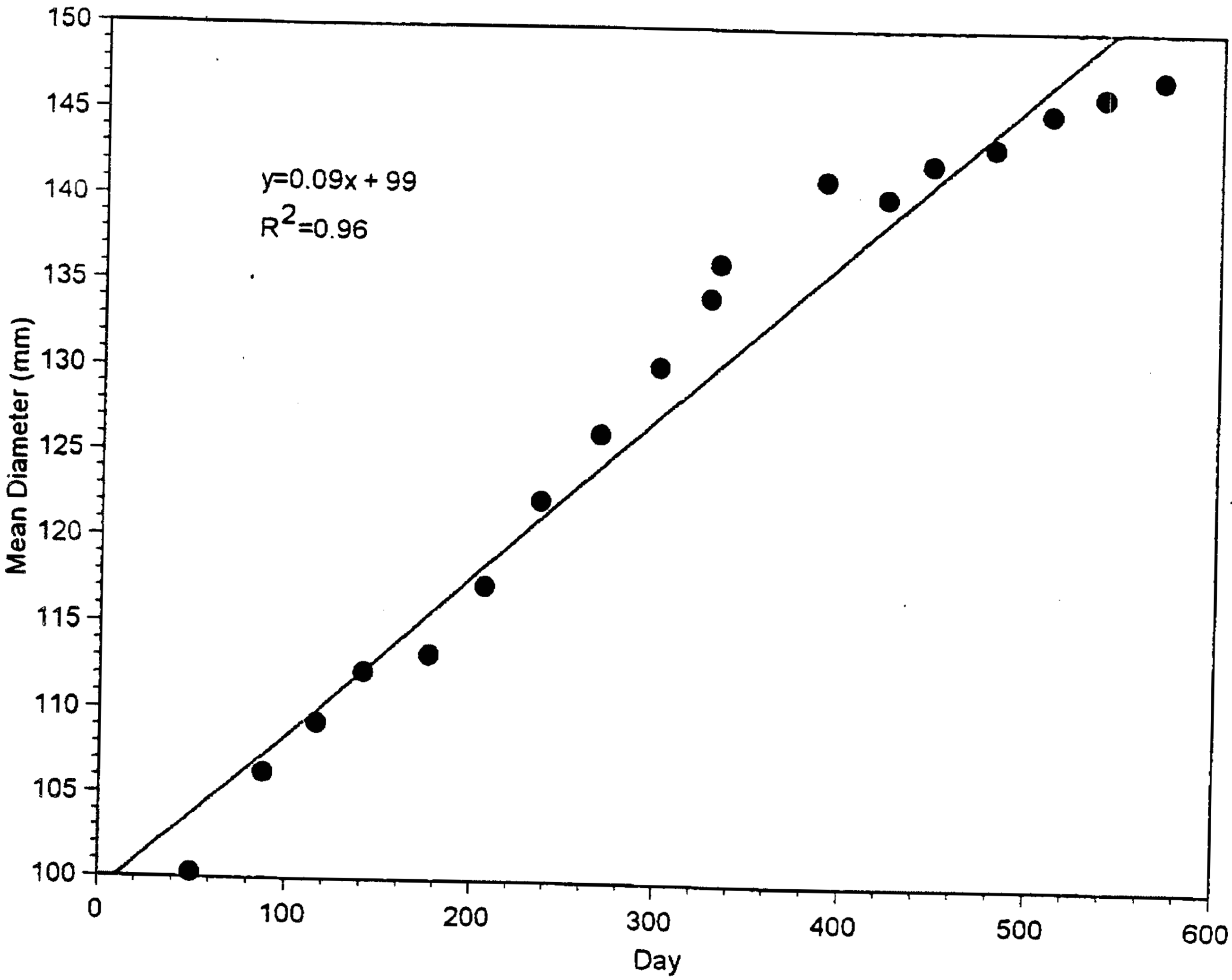


Figure #2 Growth of Adult *Pinctada margaritifera* at Moku o Lo'e

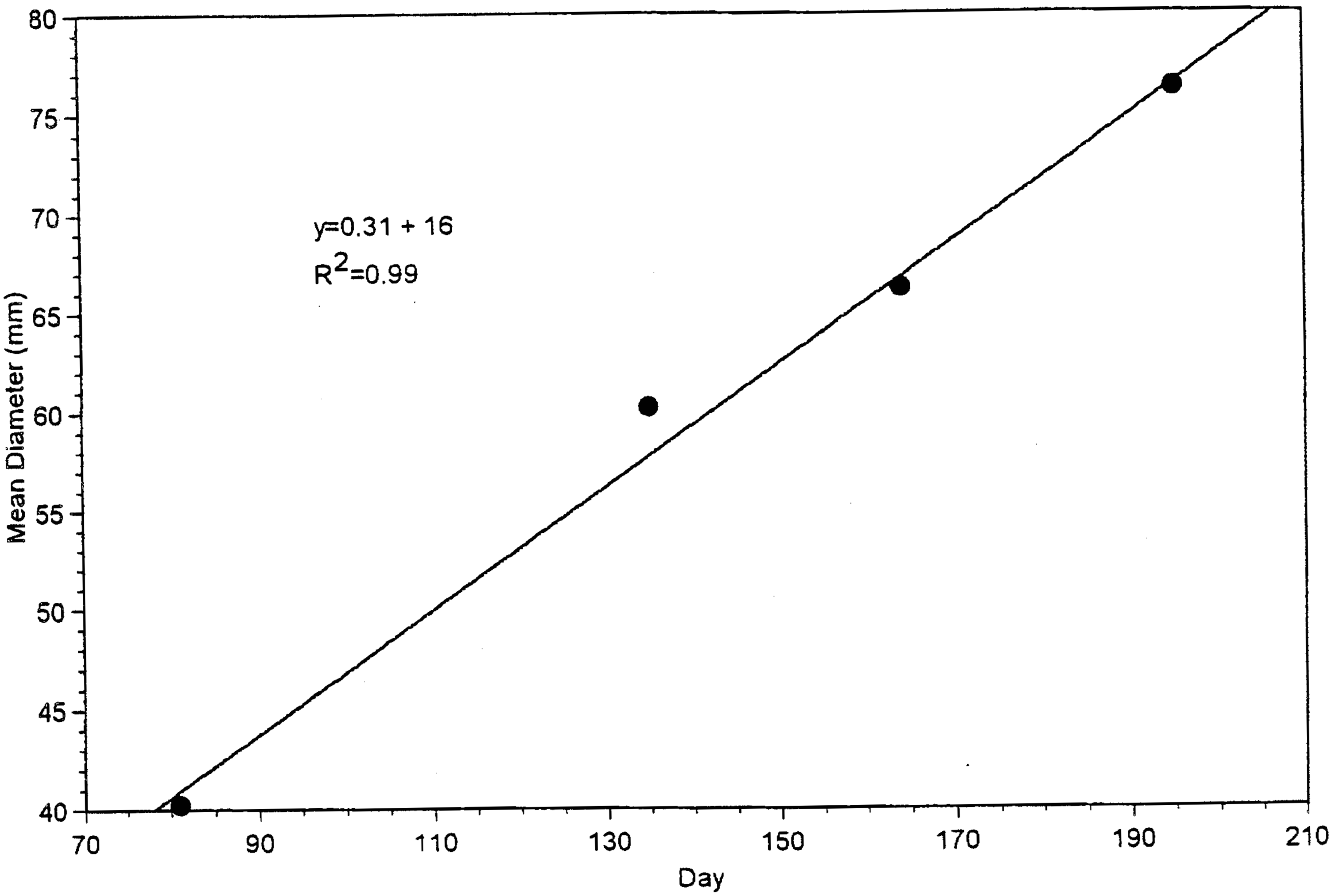
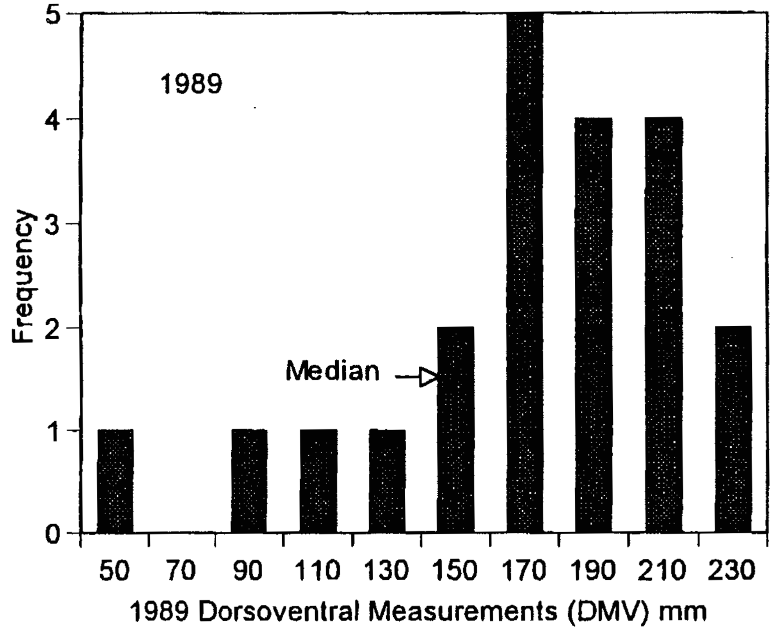


Figure #3 Growth of Juvenile *Pinctada margaritifera* at Moku o Lo'e



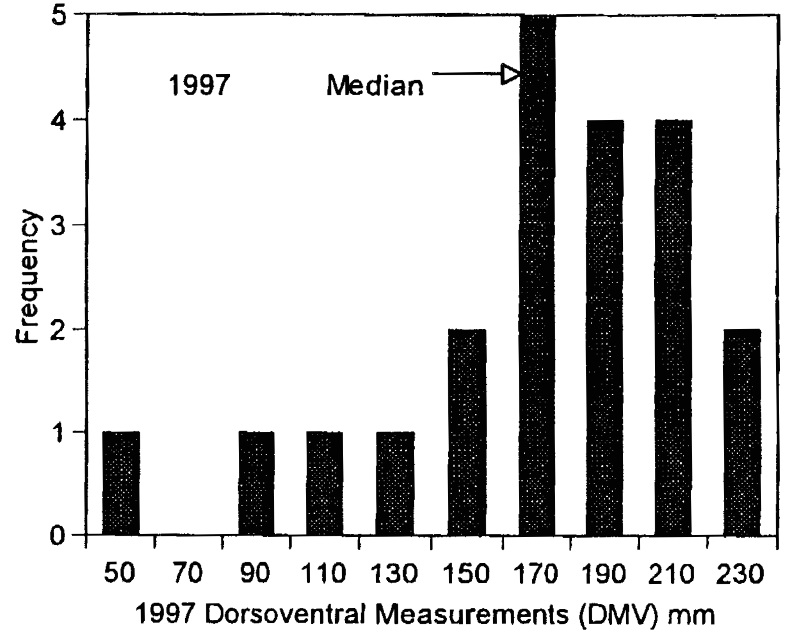


Figure #4
Size Frequency for *Pinctada margaritifera* on Transects
1989 (n=17) 1997 (n=22)

Table #1
Patch Reef Density of Oysters

Pearl oyster abundances and sizes at each station

Station No.	**Area(m^2)**	Pearl **No.**	Oysters 1989 **density (No./100m^2)**	Pearl **No.**	Oysters 1997 **density (No./100m^2)**	**Notes**
1	1000	3	0.3	0	0	Diverse corals
2	1000	0	0	0	0	Diverse corals
3	1000	4	0.4	0	0	sand patches with heavy algal overgrowth,
4	1000	4	0.4	2	0.2	Some algal overgrowth
5	500	0	0	0	0	Porites prolific, wave action evident
6	500	0	0	0	0	Heavy algal growth
7	500	0	0	1	0.2	Diverse corals, coarse sand and rubble, Heavy algal overgrowth
8	500	0	0	0	0	Heavy algal overgrowth
9	500	0	0	1	0.2	Diverse corals, coarse sand and rubble, heavy algal overgrowth
10	500	0	0	0	0	Diverse corals
11	200	0	0	0	0	Dredged patch reef with diverse corals, sand areas
12	500	0	0	0	0	Silt, little live coral shallower than 2m depth
13	500	0	0	2	0.4	Patch reef embayment with sand and silt
14	500	2	0.4	3	0.6	Diverse corals
15	500	1	0.2	0	0	Diverse corals
16	500	0	0	1	0.2	Steep face, diverse corals
17	500	0	0	0	0	Diverse corals
18	500	0	0	0	0	Steep face, diverse corals
19	500	2	0.4	1	0.2	Silt and sand, some coral with algal overgrowth
20	500	0	0	10	2	Strong wave action
21	500	1	0.2	1	0.2	Sand, some coral
	Total	Total	Grand Mean	Total	Grand Mean	
	12,200	17	0.14	22	0.18	

Table #2

Fringing Reef Density of Oysters

new sites surveyed in 1997

Pearl oyster abundances and sizes at each station

Station No.	**Area(m^2)**	Pearl **No.**	Oysters 1989 **density (No./100m^2)**	**Notes**
1	1000	0	0	*Halophila* beds and coral, silt below 15'
2	1000	0	0	diverse corals, silt below 15'
3	1000	0	0	diverse corals, silt below 15'
4	1000	0	0	diverse corals, silt below 15'
5	1000	1	0.2	diverse corals, silt below 15'
6	1000	0	0	diverse corals, silt below 15'
7	1000	0	0	diverse corals, silt below 15'
8	1000	0	0	silt after 15'
9	1000	0	0	diverse corals, *Galaxaura*, silt below 15'
Totals	9,000	1	0.1	

Barrier Reef Density of Oysters

new sites surveyed in 1997

Pearl oyster abundances and sizes at each station

Station No.	**Area(m^2)**	Pearl **No.**	Oysters 1989 **density (No./100m^2)**	**Notes**
1	1000	0	0	95% Porites, sand at 25'
2	1000	0	0	Few corals, *Dictyosphaeria* and *Kappaphycus*, sand and silt at 20'
3	1000	2	0.2	100% coral cover
4	1000	0	0	Diverse algae, few corals, flat rock and sand, high wave action
5	1000	0	0	Rubble, few corals, diverse algae, large *lobata* heads, high wave action
6	1000	0	0	Rubble, sand, few corals, diverse algae, high wave action
7	1000	0	0	Rubble, sand, few corals, diverse algae, high wave action
8	1000	0	0	Few corals, diverse algae, rubble, high wave action area
9	1000	0	0	Few corals, diverse algae, rubble, high wave action area
Totals	9,000	2	0.02	

Table #3
Transcect Summary

Patch reefs	Reef slope area	No. Transects	#oysters	Transect area	density	estimated no.
South bay	m^2				no./100m^2	oysters
	21,171	**2**	**0**	**700**	**0**	**0**
Central basin	**256,975**	**12**	**16**	**7,000**	**0.23**	**587.37**
North bay						
	166,452	**3**	**1**	**1500**	**0.07**	**110.97**
Patch reef total	**444,598**	**17**	**19**	**8,500**	**0.22**	**698.34**
Fringing reef	Reef slope area	No. Transects	#oysters	Transect area	density	estimated no.
South bay	m^2				no./100m^2	oysters
	41,868	**3**	**0**	**3,000**	**0**	**0**
Central basin						
	122,027	**3**	**1**	**3,000**	**0.03**	**48.68**
North bay						
	109,315	**3**	**0**	**3,000**	**0**	**0**
total	**273,210**	**9**	**1**	**9,000**	**0.01**	**48.68**
Barrier reef	Reef slope area	No. Transects	#oysters	Transect area	density	estimated no.
Back reef slope	m^2				no./100m^2	oysters
total	**82,000**	**3**	**2**	**3,000**	**0.07**	**30**
Reef flat	m^2					
total	**5,859,225**	**6**	**0**	**5,000**	**0**	**0**

	Reef slope area m^2	No. Transects	#oysters	Transect area	density no./100m^2	estimated no. oysters
Patch reefs	**2,509,101**	17	19	8,500	**0.24**	**698.34**
Fringing reef	**12,034,695**	9	1	9,000	**0.01**	**40.68**
Barrier reef	**22,492,170**	6	2	8,000	**0.03**	**30**
Bay total	**56,700,225**	32	22	25,500	**0.09**	**769.02**