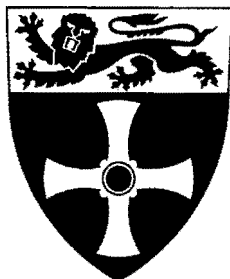


**AN INVESTIGATION INTO THE EFFECT OF A MARINE
PROTECTED AREA ON THE JUVENILE CORAL
DENSITIES AND COMMUNITIES AROUND ST. CROIX
AND BUCK ISLAND REEF NATIONAL MONUMENT,
U.S. VIRGIN ISLANDS.**

William Hatfield Wright

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UNIVERSITY OF
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Abstract

The density and community structure of juvenile corals were examined at depths from 0.5m to 4m on the reefs of St. Croix, Buck Island Reef National Monument (BIRNM) and St. John (U.S. Virgin Islands), to see if a no fishing policy indirectly enhanced juvenile coral recruitment. The substrate composition, topography, and the grazing pressure were also recorded to test for associations with the juvenile coral density and community composition. There was no significant difference in the mean density of juvenile corals inside and outside a marine protected area (BIRNM, Marine Garden), even though the area had been protected for over 30 years. The study also showed that there was no significant difference in the substrate composition or the topography between these two areas. There was however significantly different densities of urchins, higher outside the BIRNM, Marine Garden and triggerfish, higher inside the BIRNM, Marine Garden. There was also evidence to support a strong predator/prey relationship between triggerfish and urchin densities. The diversity of fish species was also found to be significantly higher inside the BIRNM, Marine Garden, indicating a more stable and robust fish community, that is less likely to suffer from changing environmental conditions.

The study also showed that the percentage cover of rock had a significant positive relationship with the density of juvenile corals and was the best single predictor, and that a combination of rock and algae >5cm was the best combined predictor. With algae >5cm having an inhibitory effect on juvenile coral densities. The density of grazers did not seem to have a direct relationship with the density of juvenile corals.

Juvenile coral community analysis showed that there was no significant difference in the communities inside and outside the BIRNM, Marine Garden, or those found in different reef zones. The study also suggested that there might be a relationship between parrotfish densities and juvenile coral communities although this was not proved.

The main conclusions that can be drawn from this project are that the creation of a marine protected area did not have a significant affect on juvenile coral densities. Thus if active management practices cannot enhance recruitment, they should concentrate on protecting the new recruits as well as the corals already present. Since post-recruitment mortality may be the most important factor controlling adult community structure. This project also suggests that the amount of rock is important in successful coral recruitment, and thus grazing, which creates areas of rock must also be important. Thus management of grazer populations, could be the key to successful healthy coral reefs.

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Introduction

1.1 Background

The effect of introducing marine protected areas has previously been studied in a number of different ways, however, most research has concentrated on the effect marine protected areas have on the abundance and diversity of fish and urchins e.g. (McClanahan and Shafir 1990; McClanahan 1994; Polunin and Roberts 1993). This study aims to take a new perspective on the impacts that marine protected areas can have, and to see whether marine protected area management practices could affect juvenile coral densities and community structures. The study also investigates the substrate composition and grazer abundance, factors which could affect juvenile coral distribution. The following sections provide a general introduction into the topics of coral reproduction and coral reef ecology as well as a background to the study area (St. Croix in the U.S. Virgin Islands).

1.2 Coral reefs

Coral reefs are generally found between the latitudes of 20°N and 20°S, and are restricted to areas of warm and clear water. Coral reefs are important as they can act as a natural barrier around islands, providing coastal protection, as well as providing a source of revenue from fishing and tourism. Coral reefs are also biologically interesting as they, along with rain forests, they are regarded as one of the most diverse systems on the planet. Global surveys have shown that most of the worlds reefs are in good to excellent condition, because they are either remote, or under good management (Wilkinson 1998). However, Wilkinson (1998) also suggests that 56% of the worlds reefs are threatened, and that approximately 10% of the worlds reefs are severely damaged or destroyed. On top of this, global warming models are predicting environmental conditions which could impose very stressful conditions on the worlds reefs, thus leading to substantial losses.

What is a coral reef ?

Coral reefs are shallow-water tropical marine ecosystems with a rich faunal and floral diversity, that have their structure formed by calcifying corals. Scleractinian corals secrete a calcareous skeleton as they slowly grow, and over a period ranging from a few thousand to millions of years, coral skeletons can cement together to form reefs. Coral reefs can be divided into three major types, fringing reefs, projecting seawards directly from the shore, barrier reefs, separated by a shallow lagoon from the shore, and reef atolls, that are generally oval or circular, and have a central lagoon.

Coral reef ecosystems produce relatively high amounts of biomass, and are considered to be dynamic, with different species' cycles occurring at different rates e.g. an algal life-cycles can occur in weeks and months whereas coral life-cycles can span decades to centuries. Coral reef benthic flora and fauna can also support a wide variety of different, very specialised fish species. Studies of coral recruitment are particularly needed given the lack of information at different spatial scales (Hughes et al. 1999)

1.3 Coral reproduction and growth

Forms of reproduction

Coral reproduction and recruitment is vital for continued health and growth of coral reefs, as if either of these two stages of replenishment of corals are impaired, the general long term health of a reef could severely deteriorate. As the structural support and topographical diversity that is provided by the growth of Scleractinian corals, would reduce. Corals can reproduce in a wide range of different ways. However, a clear distinction can be made between asexual and sexual reproduction. Asexual reproduction involves the creation of new individuals from a single parent, without the formation of gametes (Martin et al. 1996) and includes a wide range of different types of fragmentation. Sexual reproduction involves the fusion of two reproductive cells (gametes), to form embryos, that develop into free-swimming planula larvae, (although the two gametes can come from the same parent coral). Asexual reproduction can be advantageous in some circumstances, allowing the spread of a species from a small adult population. However, the lack of new genetic information can make the offspring very susceptible to changing conditions, and can reduce genetic diversity. The two forms of reproduction are not mutually exclusive, with some corals using both types of reproduction, within the same time period (Richmond 1997).

Reproduction does not have to involve the combination of separate eggs and sperm from different individuals (gonochorism), it also includes the combination of gametes produced from the same individual (hermaphroditism), this being a form of self-fertilisation. Although the new self-fertilised individual is similar genetically to its parents, it is not identical, as variation is introduced during the meiosis stage of egg formation.

A further reproductive distinction is made, between the mode in which sperm and eggs come into contact with each other. In brooding species, the eggs are fertilised internally, and initial growth of the larva takes place within the adult, before it is released. In spawning species, the combination of the gametes and subsequent growth takes place exclusively in the water column. Research has shown that the larvae produced via these two different mechanisms can have different colonisation strategies. With brooding larvae more

suited to settlement and metamorphosis immediately, being bigger and containing zooanthellae (Richmond 1997).

Coral Life stages

Once in the water column, planula larvae can use chemoreceptors to influence, to some degree, where they will settle. Experiments have shown that variables like substrate type, water motion, salinity, light, and rates of sediment deposition can all affect larval settlement. Other features like surface orientation and depth have not only been shown to affect larval recruitment rates, but also rates of growth and survival. Once a larva settles on the substrate it undergoes a series of developmental stages (metamorphosis) which see it transform from a planktonic to a benthic organism. During this period the larva will secrete a basal plate and a skeletal cup, as well as form tentacles around its mouth (in some larvae the acquisition of zooanthellae also occurs at this stage).

Once the first or primary polyp has been formed, the coral grows asexually with the primary polyp dividing into two (a process known as budding). Thus most reef building corals are actually colonies of hundreds to thousands of interconnected polyps. This does however, raise the question what is considered colony growth and what is considered as the creation of a new individual, as both forms are created asexually. Generally people regard the formation of a new colony, as a colony in which the polyps or buds become detached from the parent colony.

What are juvenile corals?

Juvenile corals are essentially corals that have not developed the ability to reproduce sexually. Studies have shown (Connell 1973; Kojis and Quinn 1985; Szmant-Froelich 1985) that in some species the size rather than the age of the colony seems to be the main factor for determining when maturation first starts. This means that most corals can accurately be classed as juveniles if they are found with diameters smaller than 5cm (Szmant 1986; Soong 1993). Although this is true in most cases, there are some inherently small corals e.g. *Favia fragum* and *Siderastrea radians*, (which are rarely found at sizes greater than 20cm² (Soong 1993) and these corals have been shown to reach maturation at sizes between 2-4cm². This definition however, excludes corals of the appropriate size that were formed by partial mortality or fragmentation (Bak and Engel 1979; Chiappone and Sullivan 1996).

Why are juvenile corals important?

Recent research (Hughes 1999) on the Great Barrier Reef, showed that there was a difference between adult abundance and recruitment rates of coral larvae i.e. that sites with the most coral did not necessarily have the highest rates of recruitment. This lack of conformity implies that rates of post-recruitment survival are higher in some areas than in

others, as areas with fewer recruits, had a high adult coral abundance. Thus although reefs may be similar in terms of abundance of corals, they may show profound differences in dynamics and turnover. There could however be another explanation, as due to the long life span of corals there could be a lengthy lag time between low recruitment and low adult coral abundance.

Hence if studying coral larvae distribution patterns does not give an indication of the probable distribution of adults, does studying the juvenile corals? Richmond (1997) suggested, that differences in species distribution patterns are more likely the result of larvae selection than colony survivorship. However, although some studies have suggested that the composition of parental coral assemblages is not a direct function of juvenile abundance (Bak and Engel 1979) other studies have shown a positive relationship (Connell 1973; Grigg and Maragos 1974). One of the most recent studies Chiappone and Sullivan (1996) found that, at least for some species (*Agaricia agaricites*, *Porities astereoides*, *Porites porites*), the composition of the parental coral community was a direct function of juvenile abundance. Thus although not all species of juvenile corals have a direct relationship with their adult corals, studying the differences in abundance in two different environmental conditions could highlight some of the underlying dynamic effects which affect juvenile growth and survivorship.

1.4 Coral reef ecology

Community relationships

Traditionally people have viewed all species within an ecosystem as being intrinsically linked to each other. So by decreasing or increasing one species not only would that species' immediate prey and predator populations be affected, but there could be subsequent affects on that the preys prey and so on. This is generally referred to as an Indirect Cascade Effect

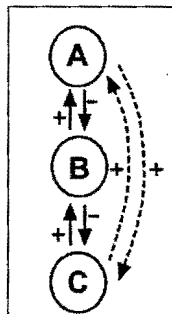


Fig.1.1 A simplified representation of a trophic cascade. If species A (the predator) increases species B (the prey) will decrease, thus having an indirect positive effect on species C (species B's prey). Direct effects are indicated by solid lines, and indirect effects by dotted lines. (Pennings 1997)

It is also true that some species compete with other species for a very similar resource, thus by decreasing a population of one species, the unaffected species gains an advantage in utilising the resource. Allowing the competing population to potentially increase (Fig.1.2).

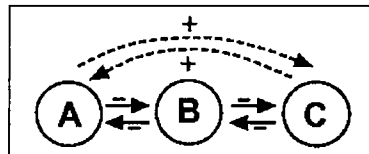


Fig.1.2 A simplified representation of apparent mutualism. If species A and B are both competing for the same resource and species A increases, species B will gain less of the resource and thus reduce. This then means that Species C, which is in competition with species B, could indirectly increase. Direct effects are indicated by solid lines, and indirect effects by dotted lines. (Pennings 1997)

McClanahan and co-workers (McClanahan 1994; McClanahan and Muthiga 1988, 1989, and McClanahan and Shafir 1990) argue for the existence of cascading effects caused by fishing. They showed that with increased predation from triggerfish and wrasse, urchin and mollusc prey populations were reduced, whereas when triggerfish and wrasse populations were reduced by fishing, their prey populations increased. Unfortunately these experiments like many others, which compare marine protected areas to non-protected areas, incur the problem that the reserves are not designated randomly with respect to the biota. This has lead Pennings (1997) to state that there is relatively little evidence that cascading effects of predation actually take place on coral reefs. This is supported by Hixon (1991) who suggests that although there is substantial circumstantial evidence, it has not been conclusively proven that predatory fish actually affect populations of prey fish. Russ (1991) investigated the trend that fishermen are selective in their fishing, tending to remove more predatory fish than prey fish from reefs. Unfortunately he found little evidence that this caused a rise in prey fish populations. Again, as with many fishing studies, proper scientific methodology was hard to apply as unavoidable problems like poor replication and a lack of controls make definite conclusions hard to reach.

Although it can be argued whether cascade affects actually occur, other factors like, planktonic settlement (Birkeland 1982) disease (Lessios et al. 1984), and physical factors (Hughes et al. 1999) can also be important in determining species composition. Species specific characteristics like the corals regenerative capability and interspecific competition such as aggressiveness to other corals' (Rogers et al.1984) can also be important.

In some marine examples a decrease or absence, of a predator's population has been shown to cause shifts in prey species composition, as new competitive interactions become more important (Paine 1966; Lewis 1986). Research has also shown that a change in species

composition can also result in a change in some fundamental ecological processes, like productivity (Carpenter 1985), nutrient dynamics (Williams and Carpenter 1988) and the calcium carbonate balance (McClanahan and Muthiga 1988).

Interactions for space

Space within coral reef systems is at a premium, and so sedentary benthic organisms have to develop strategies to compete for any free space on the reef. Hence coral larvae can find themselves in direct competition with microalgae and other encrusting invertebrates for space (Richmond 1997). Brawly and Adey (1977) highlighted this relationship with experiments that showed that juvenile corals were unable to settle and survive on substrate that was heavily covered with filamentous, non-coraline algae. This could be one reason why some corals tend to grow horizontally, acquiring space, before they start growing up and out.

As space is at a premium, benthic grazers like sea urchins (Fig. 1.3) can play a vital role in creating space where coral larvae can settle, by removing one of the coral larvae's main competitors, algae. For the same reason, benthic grazing fish (parrotfish and surgeonfish) are also important (Fig. 1.3), as they create space by disturbing the substrate as well as grazing down the algae. Thus experiments have shown that under high urchin and fish grazing pressures filamentous non-coraline algae is unable to monopolise the available space, creating a habitat in which corals are more likely to settle (Dart 1972; Sammarco 1975; Brock 1979).

Although increasing the grazing pressure is important in creating space, urchin (*Diadema antillarum*) grazing can be found at levels which are so intense that juvenile corals are scraped off, as well as the algae, thus decreasing coral recruitment (Sammarco 1975; 1980). However the urchin densities recorded in this project, were much lower than those found by Sammarco (1980) and thus urchin grazing in this case probably do not have a negative effect on juvenile coral densities. Another factor, which can inhibit coral recruitment, is the behaviour of damselfish (Fig. 1.3). Damselfish are notoriously territorial (Vine 1974) and within their territory they promote the growth of a mat of algae on the substrate, thus inhibiting juvenile coral settlement.

Predation

Bak et al. (1977) came to the conclusion that the effect of predation on corals in the Caribbean is difficult to assess but seems to be limited. In some areas of the world the sea urchin *Eucidaris thouarsii* (Galápagos) and the crown-of-thorns seastar, *Acanthaster planci* (throughout large portions of the Indo-Pacific) are major coral predators and can have a huge impact in areas of live coral cover. Although the Caribbean has coral predators, they are not

seen on the same magnitude, and have such a drastic effect as *E. thouarsii* and *A. planci*. Bak et al. (1977) identified the gastropod *Coralliophila abbreviata*, and the polychaete *Hermodice cunculata* as minor predators. However Knowlton et al. (1981) showed that predation by these minor predators can be important after major environmental disturbances (like a hurricane).

The few studies that have taken place indicate that corallivorous fish (e.g. butterflyfishes) have little if any tangible effect on coral standing crop (Hixon 1997). However, even though parrotfish are herbivorous, their rasping form of grazing, can damage live coral and Bythell et al. (1993) showed that parrotfish grazing accounts for a large proportion of the chronic partial mortality in some species of coral (e.g. *Montastraea annularis* and *Porites asteroides*). There have also been reports of the damselfish *Stegastes planifrons* killing some species of coral e.g. *Montasrea annularis* and *Acropora cervicornis* (Hixon 1997). There have however, been counter reports of herbivorous fish avoiding recently recruited coral (Birkland 1977), thus the exact effect that herbivorous fish can have on coral growth is not fully understood. The main predator of *Diadema antillarum* in the U.S. Virgin Islands was found by Randall (1967) to be the queen triggerfish *Balistes ventula* (Fig. 1.3), although Randall et al. (1964) also showed that the king helmet snail *Cassia tuberosa* also predate on *D. antillarum*.

There are a large number of different piscivores (e.g. Baracuda), which can feed on the herbivorous fish (Gladfelter 1988). However, coral reef piscivours are generally opportunistic and feed on a range of different pray (Gladfelter 1988). As well as this fishing pressure from man is also an important pressure on fish populations (McClanahan 1994).

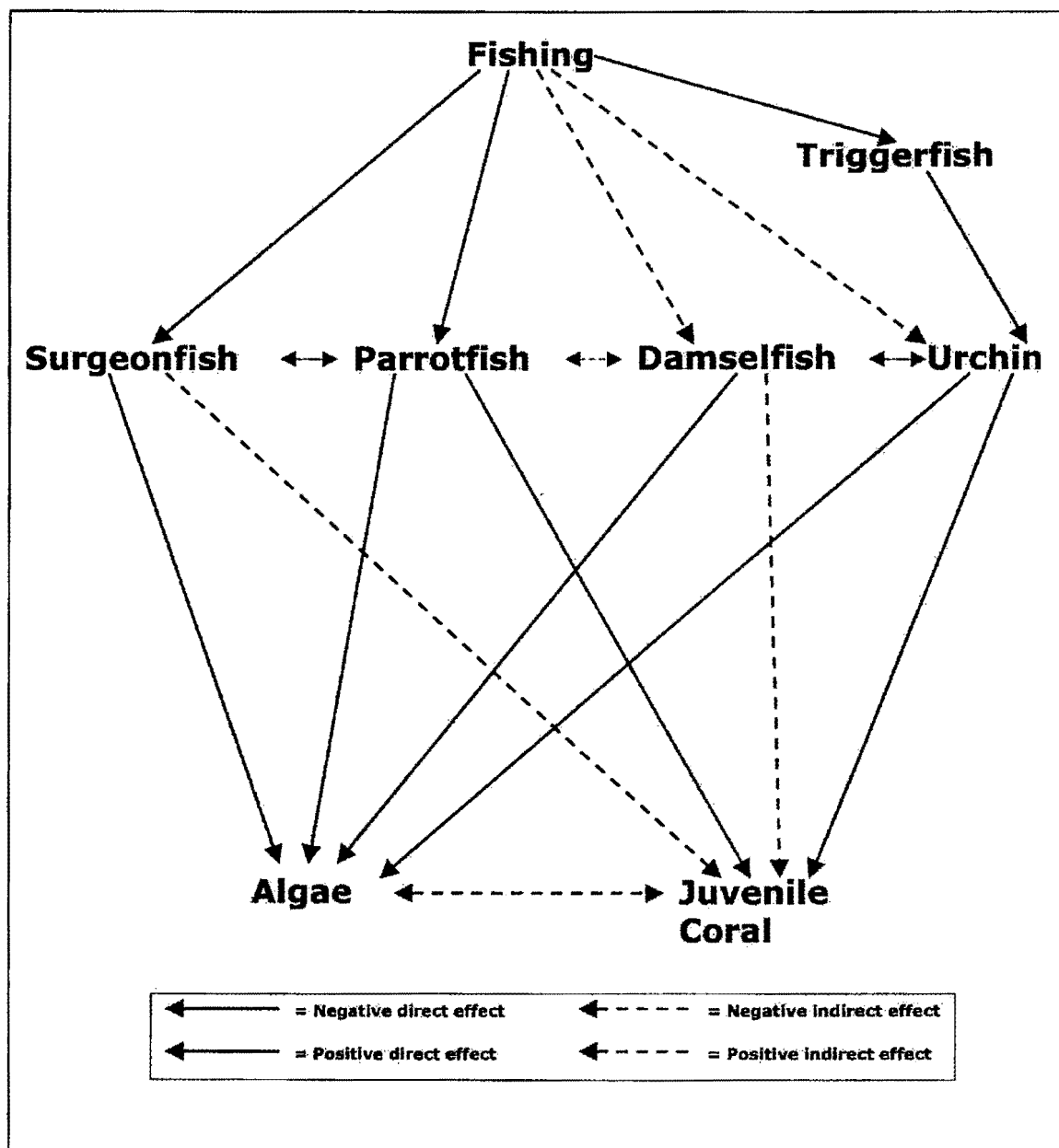


Fig 1.3 A representation of the direct and indirect interactions that could affect juvenile coral densities.

1.5 The effect of creating marine parks

Effect on fish

There have been several reports investigating the effects that creating marine fisheries reserves has on the fisheries stocks they are set up to protect. In general, reserves increase the abundance and average size of exploited species (e.g. Polunin and Roberts 1993). Unfortunately many of the other perceived advantages (like the protection of biodiversity, export of larvae and recruits to areas outside the park and ensuring genetic protection of the stocks) have not been conclusively proven and claims are usually based on empirical or circumstantial data (e.g. Porch 1993; DeMartini 1993).

Effect on Urchins

McClanahan and Shafir (1990) studied the effect of fishing pressure on the abundance and diversity of sea urchins in Kenyan coral reef lagoons. The study showed that there were fewer urchins in unprotected than in protected areas (100 times less dense), and that predation rates on a specific urchin species, were four times lower. They also showed that the triggerfish population density was higher inside the park than outside. This data thus lead to the suggestion that predation acts as a controlling force on sea urchin community structure. The paper also suggests that coral cover and topographic complexity are both negatively correlated with total urchin density. This observed relationship could reflect the major bioerosive effect that urchins have compared to finfish grazers like parrotfish (Birkeland 1988). McClanahan (1992) reviewed the competitive relationship between urchins and herbivorous fish and suggested that urchins are superior resource competitors but are less tolerant of predation than herbivorous fish.

Other effects

McClanahan and Shafir (1990) also recorded the coral reef substrate cover, and found that there was a large degree of variation in the substrate cover, suggesting patchy distribution. They did however find that the protected reef had a greater cover of hard coral, calcareous and coralline algae and coral sand than unprotected reefs as well as a higher substrate diversity, whereas the unprotected reefs had more algal turf and sponge cover than protected reefs.

1.6 Background to the U.S. Virgin Islands -St. Croix and St. John

Location

Both islands are part of the U.S. Virgin Islands and are located just east of Puerto Rico in the Caribbean (See Fig.1.4).

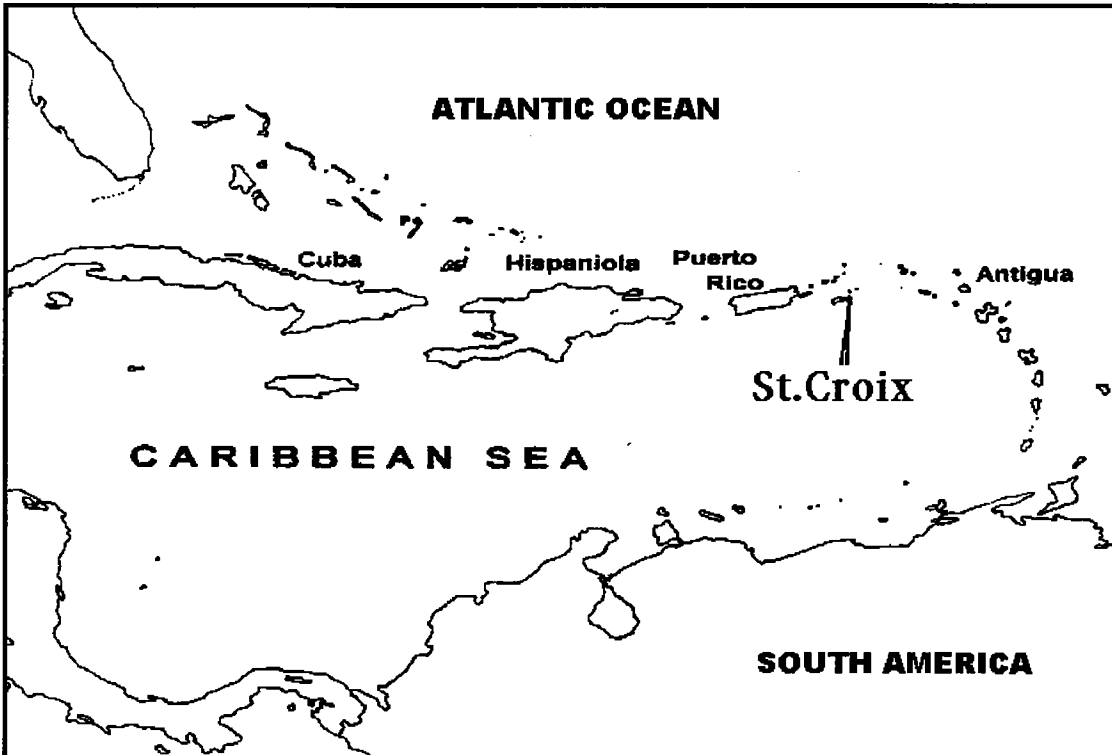


Fig.1.4 A map of the Caribbean Sea.

A study of both islands was decided upon as they both have large protected and unprotected areas (Fig.1.5). These islands are also a good example of a working, long running, relatively well funded park (compared to more poorly funded parks in developing countries). The vast majority of the study was concentrated around St. Croix and Buck Island Reef National Monument (BIRNM) (37 out of 38 sites). Which was mainly due to logistical reasons.

The history of St. Croix and Buck Island Reef National Monument

St. Croix

St. Croix is the largest of the Virgin Islands (84 square miles) and lies 75 miles east of Puerto Rico and 40 miles south of St. Thomas with a current population of about 55,000. Traditionally agriculture (cattle and sugar) was the staple of the islands economy, however these industries have gradually declined. Today the majority of the islands income comes from the Hess oil refinery (one of the largest in the world) and tourism, although St. Croix is presently over a billion dollars in debt.

Buck Island

BIRNM (Fig.1.6) lies 6 miles east-northeast of Cristiansted (the largest town on the island) and was established in 1961 by Presidential Proclamation. BIRNM consists of 180 acres of tropical dry forest island and over 700 acres of submerged lands (Hills 1996) and is one of St. Croix's major tourist attractions.

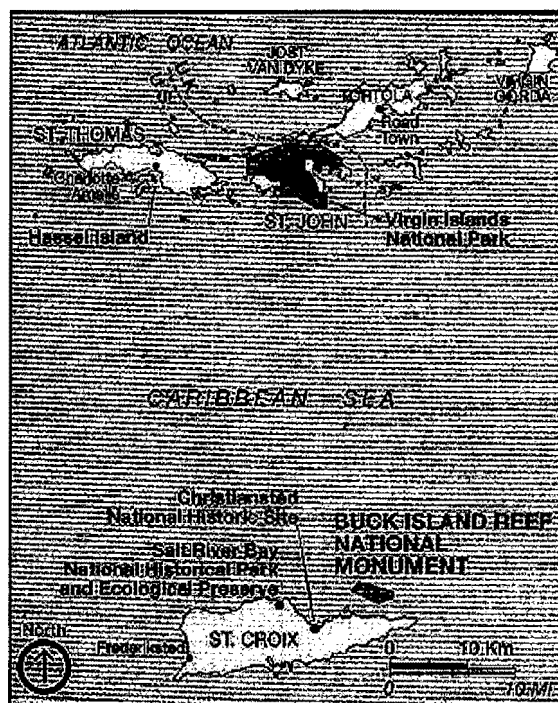


Fig.1.5 A map highlighting the relative areas and positions of the National Parks in the Virgin Islands. (Taken from the NPS Buck Island information leaflet).

Regulations

The US Virgin Islands currently have a US territory status and thus has powers to legislate and govern the territorial waters around St. Croix. Buck Island however, is managed by the National Park Service (NPS), which means that it comes under federal rather than state (USVI) rule. This means that the park service has complete power over this area and can impose regulations equal to or greater than the state laws.

BIRNM is administered by the Virgin Islands National Park Service, in St. John, however, there is a NPS office in Christiansted, which consists of two district managers, one biological technician and one law enforcement ranger.

BIRNM was created to preserve "...one of the finest marine gardens in the Caribbean sea..." and it is managed to maintain the islands "outstanding scientific, aesthetic and educational importance." The coral, fishes and geology of the reefs around BIRNM and more specifically around the Marine Garden, have been monitored and studied since the 1970's.

History of fishing

Archaeological evidence shows that fishing has taken place in the waters around the Virgin Islands for hundreds of years, and traditionally was conducted using wooden traps and handlines. These techniques were generally used until the end of the Second World War, at which time more advanced technology was employed to increase catches. As the tourism industry expanded so did the demand for fisheries resources, and this has eventually lead to their over exploitation (Beets 1987). Although fishermen actively debate when this acctually occurred, there is a general consensus that the fisheries resources are in decline, and fishermen have seen their catches which were once dominated by groupers and snappers (Moore and deGraf 1987), now dominated by parrotfish and surgeonfish (Beets 1987).

Fishing is regulated on St. Croix and within the BIRNM boundaries. Within the BIRNM there are two different areas with different fishing regulations, there is the Marine Garden (which has a complete ban on all forms of fishing) and the rest of the Park which allows some forms of fishing. A list of federal regulations drawn up in 1978 stated that fishing with a rod or handline, 'conventional' trap fishing and net fishing to catch fish bait was allowed within the rest of the park, however, spear fishing was outlawed. The regulations also cover three species of invertebrates, whelks (*Cittarium pica*), conch (*Strombus sp.*) and the spiny lobster (*Panulirus argus*). Currently the park service is also facing a logistical enforcement problem, as at present there is no 'law enforcement' ranger. Thus illegal fishing which probably occurs when enforcement is more prominent (Beets 1993) could presently be carried out at a higher rate.

Problems with classifications of the BIRNM Marine Park and Marine Garden

As mentioned above due to the 1978 Federal Regulations, only a small area of the BIRNM has a complete ban on fishing (the Marine Garden), with the rest of the park subject to few fishing restrictions. The problem with using these legal boundaries is two fold, first it is hard to know exactly where the boundaries are, and second it is hard to know where fishermen actually think the boundaries are. The definition of the Marine Garden boundary "the outer fringes of the barrier reef and the shore line of Buck Island eastward of the recognisable extremities of the sand beach on the north and south sides of the island" seems clear enough, but as (Fig.1.6) shows, the barrier reef tends to break up into patch reef on the north side of the island. As nobody has actually legally tested whether the patch reefs are classed as inside the Marine Garden, views can vary and it is still a grey issue. It is however, generally acknowledged that the patch reefs closest to the shore are part of the Marine Garden. This however, leads on to the second point, where do fishermen actually think the park boundaries are? Unfortunately due to a succession of hurricanes, some of the buoys that mark the boundaries to the BIRNM are missing, leading some fishermen to treat the area

outside the Marine Garden as a normal fishing area (especially when there is no park ranger). Thus the real question that should be asked is do fishermen think that the patch reefs are part of the Marine Garden? Again the answer is not clear but some fishermen do fish on the outer patch reefs.

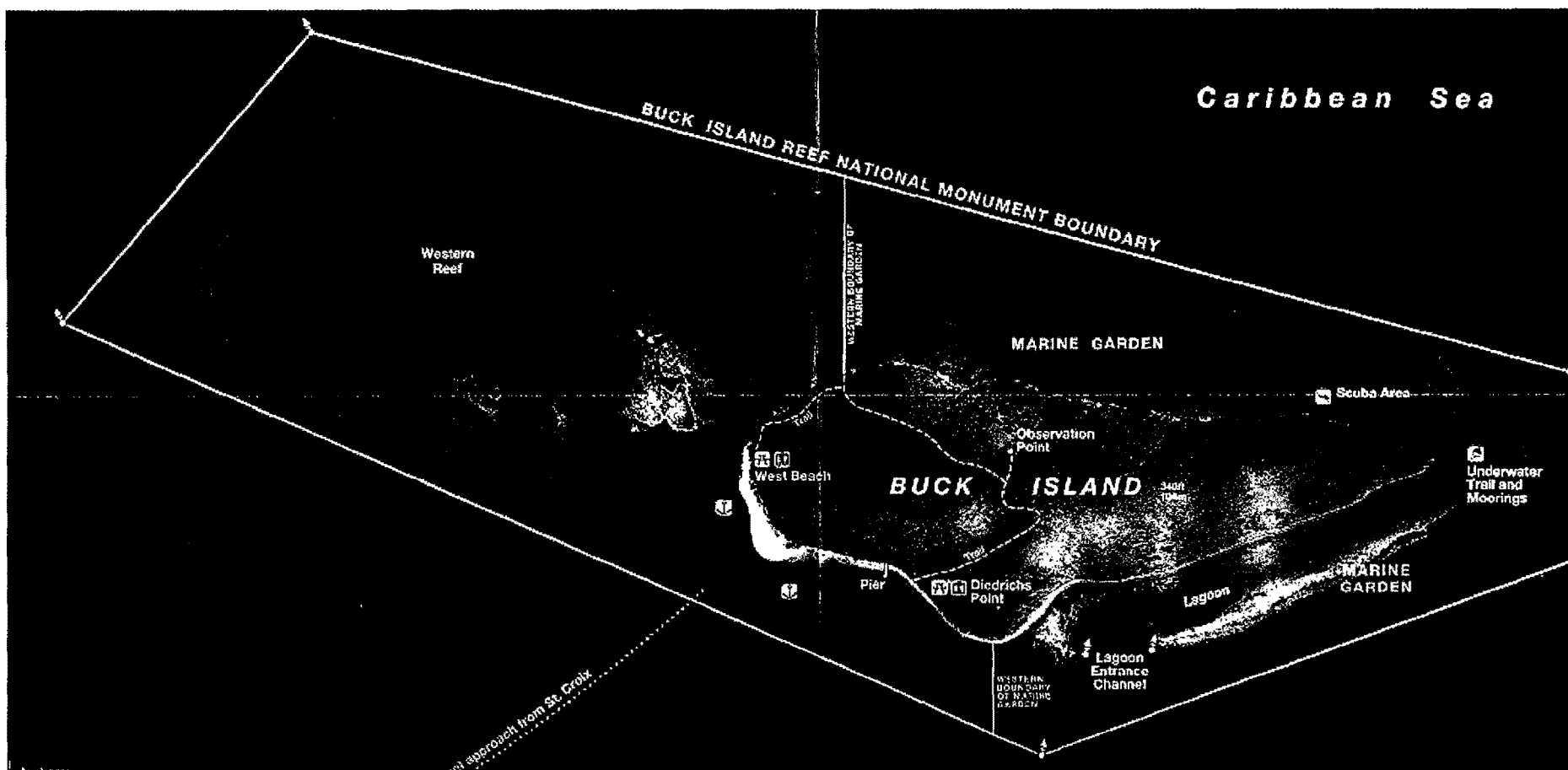


Fig.1.6 An aerial photograph of Buck Island Reef National Monument. Taken from the NPS Buck Island information leaflet

1.7 Aims of the study

- 1)** The initial question being asked is 'is there a significant difference between the density of juvenile corals found in a marine protected area (i.e. inside the BIRNM Marine Garden where there is no fishing) and outside the marine protected area where fishing still continues'.

- 2)** Are there any significant differences in the substrate cover, the topography and grazer densities inside and outside the Marine Garden.

- 3)** What is the best indicator of juvenile coral densities, so that this information could be used as a management tool.

- 4)** Are the Marine Gardens juvenile coral communities significantly different from those outside the Marine Garden, and then to identify factors which could have an effect on juvenile coral community structures (e.g reef habitats and grazing pressures).

- 5)** Finally the spatial distribution of juvenile coral densities, will be investigated, to identify areas of high recruitment, and to see how densities vary within and between reefs.

2. Methods

2.1 Choosing sampling sites

Each area sampled was surveyed by snorkelling, and chosen to try and encompass as wide a range as possible, of different reef systems around St. Croix and BIRNM. Within each area an attempt was made to try and sample two different sites. The exact location of each site (Fig.2.1) was determined by the distance from the point of entry, and the relative position of previous sites (at least 40m from any other site). Table 2.1 lists the sites at which juvenile coral densities, and fish densities were estimated.

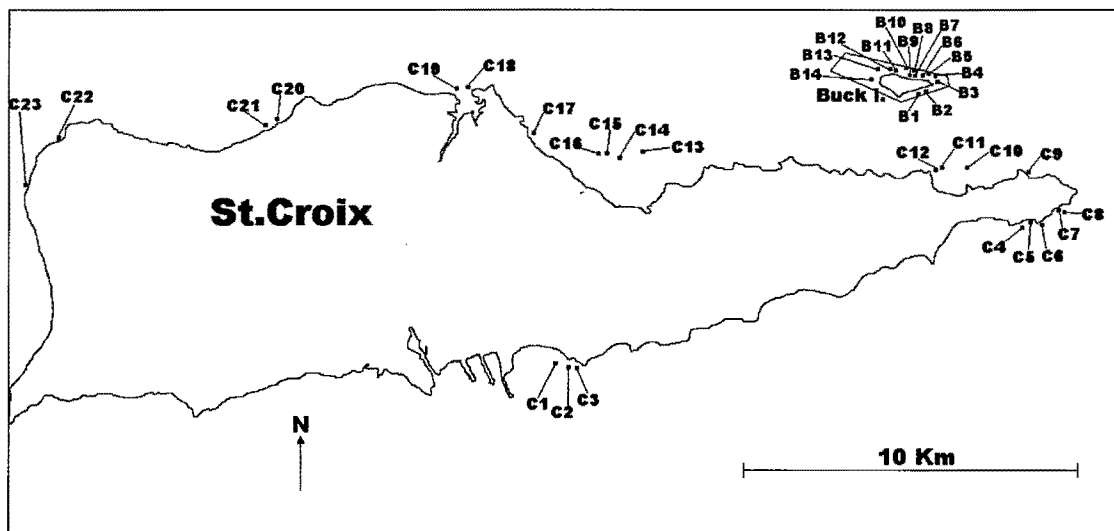


Fig. 2.1 Locations of the sites sampled around St.Croix and BIRNM.

Table 2.1 The sites at which juvenile coral densities, and fish densities were estimated. There was one additional site at which fish densities were estimated but juvenile corals were not, this was around the Underwater trail in the BIRNM (See Fig.2.1 for location).

Site	Coral	Fish	Site	Coral	Fish	Site	Coral	Fish
C1	X		C15	X	X	B1	X	X
C2	X	X	C16	X	X	B2	X	X
C3	X		C17	X	X	B3	X	X
C4	X	X	C18	X	X	B4	X	
C5	X		C19	X	X	B5	X	
C6	X		C20	X		B6	X	
C7	X	X	C21	X	X	B7	X	
C8	X	X	C22	X	X	B8	X	X
C9	X		C23	X	X	B9	X	
C10	X	X				B10	X	X
C11	X					B11	X	
C12	X					B12	X	
C13	X	X				B13	X	X
C14	X	X				B14	X	X

2.2 Site histories

Although the types of coral found around St. Croix and BIPNM are all relatively similar, the current day pressures and the historical impacts on the sites, have been and are very different. For this reason a brief summary of the different pressures on the sites, was created (from discussions with Ms. Zandy Hills, (Resource Management Specialist for the NPS) Mr. Roy Pemberton Jr.(local fisherman and research scientist) and Dr. John Bythell (coral reef expert)). The pressures that the reefs faced were divided into four main categories, a) Damage to the reef from storms, b) the relative level of fishing intensity, c) the relative level of tourism on the reef (diving/snorkelling), d) the relative level of pollution and e) general observations/ general state of health.

2.3 Surveying juvenile coral densities

At each site the boundaries of the site were estimated (30m x 30m) and distinct topographical features were identified as close to the corners as possible. Before starting to sample, distinct shoreline features were identified, from the centre of the site, so that the exact position of the site could be recorded. From the middle of the site 10 fin kicks were swum towards one of the corners. After 10 fin kicks a 0.5m x 0.5m quadrat was placed on the reef, by diving to the bottom (with eyes closed) and laying the quadrat on top of the reef.

Once the quadrat was lying as flat as possible on the reef, an initial inspection was made (particular attention was paid to small juvenile corals). The number of juvenile corals within the quadrat was then recorded. Each juvenile coral was then identified to species and allocated to a size class (either 0-1cm, 1-3cm, 3-5cm or 5-10cm), with borderline corals measured using a ruler.

Colonies of less than 5cm maximum diameter were considered juvenile corals, following the convention of Bak and Engel (1979) and (Kojis and Quinn 1985; Szmant-Froelich 1985). Based on previous studies of size at reproduction of Caribbean reef corals, colonies of less than 5cm in diameter are a good estimate of most juvenile abundance (Szmant 1986; Soong 1993). There are however, two species, *Siderastrea radian* and *Favia fragum*, which reproduce at sizes between 2-4cm in diameter (Soong 1993), for this reason only *Siderastrea radian* and *Favia fragum* colonies found in the size class 0-1cm were regarded as juvenile corals.

The composition of the substrate cover was then estimated. First the percentage cover of each coral species present inside the quadrat was estimated. Then the percentage cover of algae was estimated. Within this category distinctions were made between algae less than a pencil tip high (between 0.2cm-1.5cm), between 1.5-5cm, and greater than 5cm high. The percentage cover of bare substrate was then assessed. Bare substrate was either

classed as rock (if the algae cover was less than 0.2cm high) or sand (if the covering of sand was deeper than a pencil tip (1.5cm)).

Next an estimation of the urchin density was undertaken, by initially recording the number of urchins within the quadrat, and then measuring the number of urchins within 0.5m of the edge of the quadrat e.g. Fig.2.2

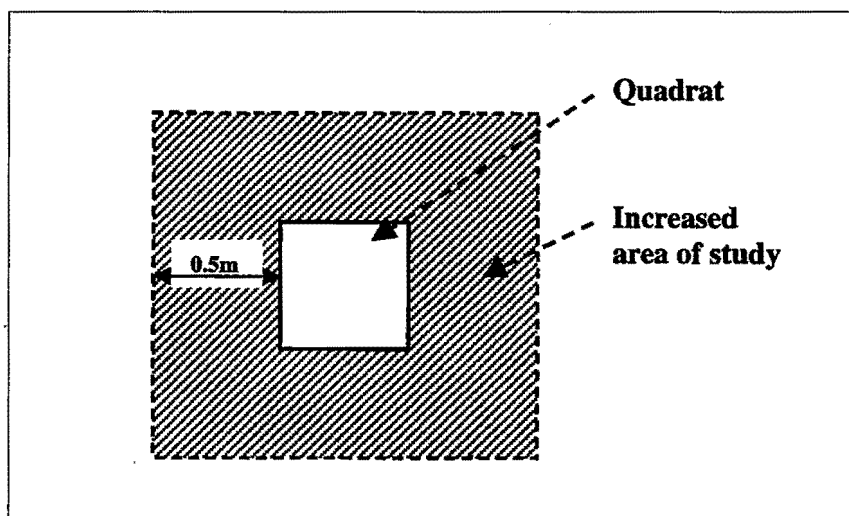


Fig. 2.2 A representation of the increased area that was used to sample urchin populations.

Finally the rigosity of the site was estimated using a five-point scale (Table 2.2.).

Table. 2.2 The structural characteristics used to classify the topography within each quadrat.

RANK	Characteristics
1	No crevices and holes, relatively flat (sand/reef pavement)
2	No crevices, simple 3-D structure, undulations less than a pencil high <16.5cm (<i>Porities asteroides</i>)
3	A few crevices and holes, undulations greater than a pencil length high >16.5cm (large <i>Diplora</i> heads)
4	A lot of crevices and holes (simple <i>Acropora plamata</i> stand/ <i>Porities porities</i>)
5	Very complex 3-D structure (dense <i>Acropora Palmata</i> stand)

Once a quadrat was completed the position of the next quadrat was determined by swimming ten fin kicks in the direction of a marked side on the quadrat, then turning left and swimming a further 10 fin kicks. The quadrat was then placed on the bottom, and exactly the same measurements were taken as in the previous quadrat.

2.4 Fish census

To estimate the relative abundances of the grazing pressure from fish a census, was taken at the same site and at the same time. Numbers of four important fish families parrotfish (Scaridae), damselfish (Pomacentridae), surgeonfish (Acanthuridae), and triggerfish (Balistidae) were recorded using a variation on the Bohnsack and Bannerot (1986) method, as well as the total number of different fish species seen (the diversity). At each site, 6

individual censuses were taken. Each individual census site was chosen by swimming a random number of fin kicks from the centre of the site then turning left and swimming a further ten fin kicks. At each census point a cylinder with a diameter of 8m was estimated as well as the depth (estimated to the nearest 20cm) Fig.2.3.

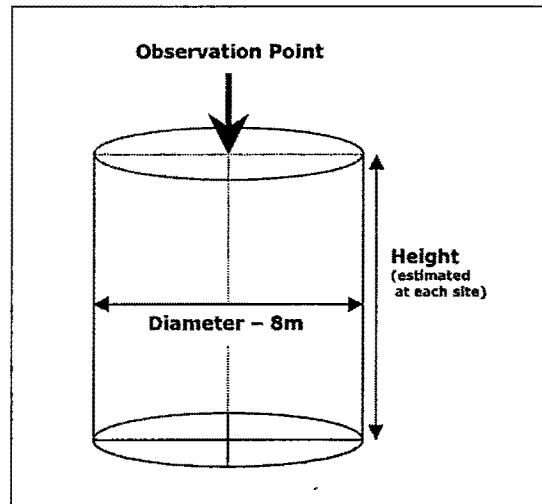


Fig. 2.3 A 3-D drawing showing the imaginary cylinder that was used to estimate fish densities (in accordance with Bohnsack and Bannerot (1986)).

The cylinder was then divided into quarters and the number of fish present in each quarter was recorded. The observation time for each quarter was exactly 1 minute. After each of the quarters had been studied, a further minute was spent checking the data and recording any fish which had entered the cylinder since the start of the count. Unlike the Bohnsack and Bannerot (1986) method, the observations were made from the top of the cylinder, floating at the surface, rather than submerged at the bottom. After the completion of each census the next census point was chosen by swimming ten fin kicks in the direction of the last quarter of the cylinder, and then turning right (then left, at alternate sites) and swimming a further ten fin kicks.

2.5 Data Analysis

Initial Analysis

All the data was stored and manipulated, using Microsoft Excel (Fig. 2.4). The first manipulation of the data undertaken was the calculation of the number of juvenile corals found per meter squared of available substrate. Juvenile coral densities per meter squared were divided by the amount of available substrate to try to account for the fact that different sites have different amounts of space which juvenile corals can actually physically colonise. The problem however, comes in defining the amount of available space. Coral larvae generally do not settle on sand or adult corals but do settle on bare rock. However, do they settle in areas of algae cover? Although they compete for space directly with algae the

estimate of algae coverage is probably not very accurate, on the small micro-scale of a coral larvae, where a juvenile could potentially settle between two algae filaments. Algae also has a faster life cycle than coral, thus although the algae might be present at the time of the study, it might not have been present 3-4 years ago when the juvenile corals were settling on the reef. This was actually observed at sites C1 and C2 where juvenile corals were found growing in a near blanket coverage of algae. For this reason algae was, with rock, classed as available space. Thus the calculation was achieved by dividing the number of juvenile corals found per meter squared, by the total amount of rock and algae (of all the three categories) per meter squared.

All the data were then checked for normality using an Anderson-Darling normality test (Minitab 12). If the data was significantly different from the normal ($p < 0.05$), it was then mathematically transformed using a Box-Cox approximation (Minitab 12) (Table 2.3). Using the transformed data, a student-t test was used to see if there was any significant difference in the densities of the juvenile coral inside and outside the Marine Garden.

Table 2.3 The mathematical transformations used to normalise the data.

Variable	Transformations	Variable	Transformations
Juvenile corals	$\sqrt{\sqrt{n}}$	Coral	$n^{0.45}$
Urchins	$\sqrt{\sqrt{(n+1)}}$	Total-Algae	None
Parrotfish	$n^{0.113}$	0.02mm-1.5mm Algae	None
Damselfish	None	1.5mm-5cm Algae	$(n+1)^{0.23}$
Surgefish	None	>5cm Algae	$(n+1)^{\log}$
Triggerfish	$(n+1)^{-5}$	Rock	None
No. of Species	None	Sand	$\sqrt{\sqrt{(n+1)}}$

Next a Student-t test was used to see if there was a significant difference, in any of the substrate categories measured, between inside and outside the Marine Garden (a Mann-Whitney-U test was used to see if there was a significant difference in the topography). As a follow on from this, further Student-t tests were used to see if there was any significant difference between the grazer densities and the number of different fish species seen inside and outside the Marine Garden.¹

¹ Due to the observed relationship between urchin and triggerfish densities a Pearsons correlation was used to test whether the relationship was significant.

The Plymouth Routines in Multivariate Ecological Research (PRIMER) software was used for multivariate (community structure) statistics (Clarke and Warwick 1984), with the transformed substrate values having to be converted into a PRIMER format, before the PCA programme could be run. PCA values were created by taking the best (PCA 1) and the second best (PCA 2) combined indicators of the substrate, thus they condense all the substrate information at each site into two values. Using this information the two PCA values can be plotted, to show how the substrate composition at each of the sites are related to each other. The juvenile coral densities were also regressed against the PCA values to see if these values could adequately explain the juvenile coral distribution. Finally, the individual substrate values were regressed against the PCA values to show the major contributing factors to PCA values.

To find best predictor of juvenile coral densities, a series of best sub-set analysis tests were used (Minitab 12). The best predictor and best set of predictors identified from the best sub-sets analysis were then regressed against the juvenile coral densities using a least-squares line as a regression.

Community analysis

Using the abundance of each juvenile coral species found at each site, an MDS plot of the juvenile coral communities was created in PRIMER using the CLUSTER and MDS programmes. ANOSIM was then used to see if there was a significant difference between the juvenile coral communities inside and outside the Marine Garden and between the different reef habitats. The Overlay function was then used to see if grazer densities had a noticeable effect on the juvenile coral communities. BIOENV was also used to measure the relationship between the juvenile coral communities and the density of fish studied.

Size-class analysis

Finally the relative mean density and the total abundance of juvenile corals in each of the size classes, at each of the sites was calculated in Excel. This value was then and converted into a circle of the equivalent relative size in Paint shop Pro, and plotted on a map of St. Croix and BIRNM, to highlight any spatial trends.

AT EACH SITE

20 - 0.25m² Quadrates
(Site area 30m x 30m)

RECORDED

- No. of juvenile corals (to species)
- Size of juvenile corals
- Substrate cover
- Topography
- Urchin density

6 - Fish censuses (point counts)

- 8m diameter
- Estimate depth
- 5 minutes

RECORDED

- No. Parrotfish
- No. Damselfish
- No. Surgefish
- No. Triggerfish
- No. Species

OVERLAY

(Identify grazer relationships with the juvenile coral community)

RELATE

(to identify significant difference between groups)

CREATE MDS PLOTS

BIOENV

(Used to find the best explanation of the juvenile coral communities)

PLOT MDS VALUES

STORE DATA CALCULATE

- Means and SD
- Amount of available space

**STUDENT-T test
JUVENILE CORALS**
Inside/Outside –
Marine Garden

**STUDENT-T test
SUBSTRATE and
TOPOGRAPHY**
Inside/Outside –
Marine Garden

**STUDENT-T test
GRAZER
DENSITIES**
Inside/Outside –
Marine Park

BEST-SUBSETS ANALYSIS
(find factors which best explain juvenile coral densities)

**TEST DATA FOR
NORMALITY**
(using Anderson-Darling)
IF NOT NORMALLY
DISTRIBUTED
Transform using
BOXCOX graphs

**REGRESS FEATURES
IDENTIFIED**
(to see if the relationships are significant)

SIZE CLASS ANALYSIS

**PLOT PCA
VALUES
AGAINST
JUVENILE CORAL
DENSITIES**

**PLOT JUVENILE CORAL
SIZE CLASS
VALUES
AGAINST PCA**

REGRESS SUBSTRATE VALUES AGAINST PCA VALUES

(to identify the major constituents of the PCA values)

PLOT PCA VALUES

REGRESS PCA VALUES

(to see if there is a significant relationship with the juvenile coral densities)

CREATE PCA VALUES
(Condensing the substrate data)

SEPARATE VALUES

Inside/Outside
Marine Park
(to see if relationships different Inside/Outside the protected area)

BASIC ANALYSIS

EXCEL

MINITAB

POINT COUNT PRO

PRIMER

3. Results

3.1 Site histories

Interviews showed that the northeast part of the island was severely affected by Hurricane Hugo and the south shore of St. Croix was totally obliterated with only bare rock remaining. Other interesting points raised by the discussions was that the sites on the southeast coast (C4-C5) were considered very remote by the locals and thus had relatively little fishing, tourism, or pollution thus this area was not a typical non-protected area (Table 3.1).

Table 3.1. A summary of the range of anthropogenic and human pressures found at each site.

Site Nos.	Reef type	Pressures on the sites
C1 C2 C3	Fore reef Back reef Back reef	a) Suffered sever damage from hurricane Hugo (large amounts of coral rubble present) b) Very little fishing (maybe some trap fishing). c) No tourism, or boat traffic. d) Situated very close to the Hess oil refinery, could be affected by oil waste and sewage from the sewage treatment plant on site, although it is up stream of these inputs. e) Dominated by macroalgae.
C4 C5 C6 C7 C8	Fore reef Back reef Back reef Fore reef Fore reef	a) Very exposed area affected by hurricane Hugo. b) Relatively low levels of fishing, usually only line fishing. c) No tourism or boat traffic. d) Possible run-off from land (low levels) e) Generally viewed as a remote area.
C9 C10 C11 C12	Back reef Fore reef Back reef Back reef	a) Decimated by hurricane Hugo. b) Was extensively overfished, however, the fish stocks are starting to recover and fishing is starting to return. c) Very little recreational diving although a lot of boat traffic. d) Relatively low levels of pollution although the work taking place on boats in the boat club could pose a potential risk. e) Generally healthy.
C13 C14 C15 C16 C17	Fore reef Back reef Fore reef Fore reef Reef pavement	a) Damaged extensively by hurricanes Hugo and Marylin can also be subject to large surges. b) Heavily fished area. c) Popular dive site with may be 50-60 people per day. d) High levels of sewage, as the local sewage works has a pipe which releases raw/1° treated sewage out on to the reef. e) Signs of good recovery.

Site Nos.	Reef type	Pressures on the sites
C18 C19	Back reef Fore reef	a) Severely damaged by hurricane Hugo suffering substantial scouring. b) Heavily fished area c) Popular dive site 200-300m from the reef d) The main pollution problems come from high sediment levels in the water, flowing out with the river. (mainly due to the lack of mangrove swamp, which was destroyed by hurricane Hugo and land clearing). The Salt River Marina, in Sugar Bay may also pose potential pollution problems, especially from marine paint. e) Historically quite a diverse site.
C20 C21	Reef pavement Reef pavement	a) Suffered considerable damage from hurricane Hugo in 1989, and areas were scoured by coral rubble by hurricane Marilyn in 1995. The reef also suffered from substantial bleaching between the years 1986-8. b) Heavily fished site both commercially and recreationally (mainly spearfishing). c) One of the most popular dive sites on the island with between 50-200 divers per day. d) Some run-off from land e) Generally quite a high diversity of species.
C22 C23	Reef pavement Reef pavement	a) Relatively little hurricane damage compared to the rest of the island. b) Relatively little fishing (some trap and line fishing). c) A large amount of tourism especially nearer Fredricksted, both snorkelling and diving. d) A large amounts of sediment tend to be washed down from the hills during storms, this can contain high nutrient levels as cattle is kept in this area. e) Before destroyed by hurricanes this was a very diverse area dominated by Gorgoians. Generally down current of the rest of the island.
B1 B2	Fore reef Fore reef	a) Heavily scoured from hurricane Hugo (reef crest moved back 30 meters). b) Some fishing. c) No tourism, or diving. d) No real sources of pollution. e) Showing very good signs of recovery.
B3 B4 B5 B6 B7 B8 B9 B10 B11	Back reef Back reef Back reef Back reef Back reef Haystack Back reef Haystack Back reef	a) On the more sheltered side of BIRNM but affected but hurricane Hugo. b) Only illegal fishing, however, some legal fishing does occur in the patch reefs on the outside of the Marine Garden. c) The snorkel trail on BIRNM is one of St. Croix's main tourist attractions and can have several hundreds of people visit it per day. However, studies have shown that the snorkel trail is well managed and suffers minimal negative effects from the huge influx of people. d) Possible pollution from charter boats, however this is generally very well managed. e) Generally good state.

Site Nos	Reef type	Pressures on the sites
B12	Back reef	a) Affected by hurricane Hugo
B13	Back reef	b) Only illegal fishing.
B14	Back reef	c) Large amount of boat traffic, both local and charter boats, thus possible problems associated with anchor damage and litter. Little to no diving on associated reefs.
		d) Possible effects from sand deposition.
		e) Generally in good condition.

3.2 Mean density and percentage composition of juvenile corals

Juvenile coral densities ranged from 0.5 juveniles.m⁻² (of total available substrate) to 26.8 juveniles.m⁻², with an overall mean for St Croix and BIRNM of 4.4 juveniles.m⁻².

In total, fifteen different species of juvenile corals were observed during the study. Juveniles of *Porites astreoides*, *Porites porities* and *Agaricia agaricites* were found to be the three most common species, and contribute about two thirds of the juvenile density. Outside the Marine Garden, *Porites astreoides*, *Porites porities* and *Agaricia agaricites* (again making up two thirds of the species) still dominated. Whereas inside the Marine Garden the species distribution changed slightly with over half the species consisting of *Porites astreoides*, with *Favia fragum* (13%) as well as *Agaricia agaricites* (12%) and *Porites porities* (10%) also abundant.

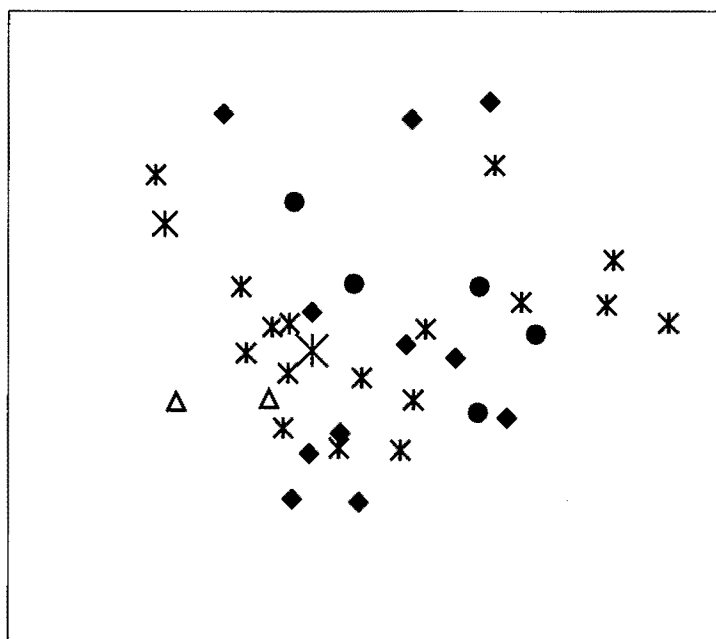


Fig. 3.1 An MDS plot of the juvenile coral communities, highlighting the differences between communities in different reef zones. (Diamonds = Fore reef, Stars = Back reef (Blue = St. John), Circles = Reef pavement, Triangles = Haystacks).

The community composition of the juvenile corals was not apparently affected by the reef type, i.e there was no obvious bunching of the different classifications made (Fig. 3.1).

This observation was supported by ANOSIM analysis, with no significant difference between the groups (Global $R = 0.088$, $P = 0.121$).

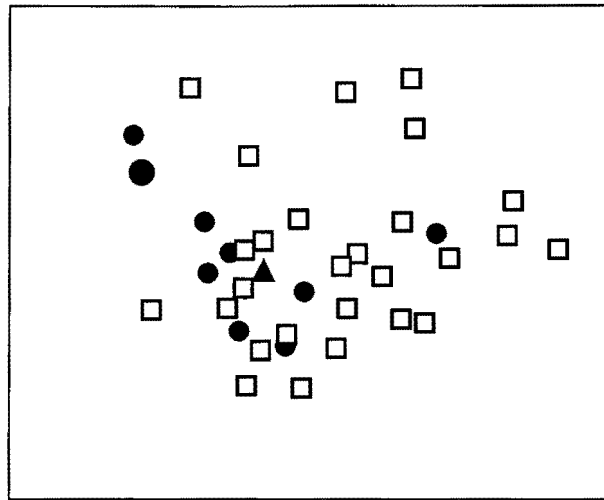


Fig. 3.2 MDS plots of the juvenile coral communities, inside and outside the BIRNM Marine Garden, with a stress value of 0.19. (Circles = BRINM, Squares = St. Croix and Triangle = St. John).

Juvenile coral community structure found within the Marine Garden do seem to separate to the left and the right of the plot suggesting that the marine park may have a slightly different community structure to the other sites studied (Fig 3.2). However, ANOSIM analysis shows that the Marine Garden does not seem to have a significant effect on the community structure (Global $R = 0.139$, $P = 0.069$).

3.3 Is there a significant difference between the density of juvenile corals inside and outside the BIRNM Marine Garden?

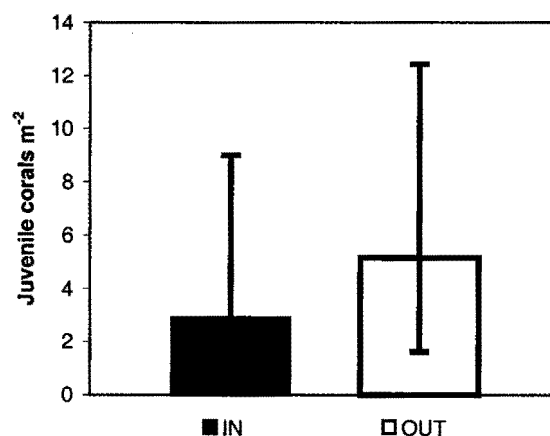


Fig. 3.3 Back-transformed mean densities, and standard deviations of juvenile corals inside and outside the Marine Garden.

There was no significant difference in the mean densities of juvenile coral inside or outside the Marine Garden (Fig 3.3 Student-t test $T = -1.48$ $P = 0.16$). Surprisingly there were more juvenile corals outside the Marine Garden than inside.

3.4 Are the habitats significantly inside and outside the Marine Garden different?

Table 3.2 The difference in percentage cover inside and outside the BIRNM Marine Garden, for all the substrate categories studied (using Student-t test), as well as the topography (using Mann-Whitney). (Inside the Marine garden n=10, outside the Marine garden n=27).

Student-t test Inside/outside Marine Garden (m ²)	Inside	Outside	P value	Significant difference
Coral	10.97	7.53	0.07	NO
Algae (Total)	54.45	49.65	0.46	NO
Algae Small (0.2-15mm)	31.21	34.25	0.62	NO
Algae Medium (1.5-5cm)	6.72	6.74	0.65	NO
Algae Large (>5cm)	5.01	4.92	0.62	NO
Rock	20.52	24.05	0.42	NO
Sand	13.91	7.51	0.07	NO
TOPOGRAPHY (Mann-Whitney)	2.55	2.45	0.32	NO

There was no significant difference in percentage cover, between inside the BIRNM Marine Garden and outside, in any of the substrate categories tested (Table 3.2). There was also no significant difference in the topography rankings between these two areas.

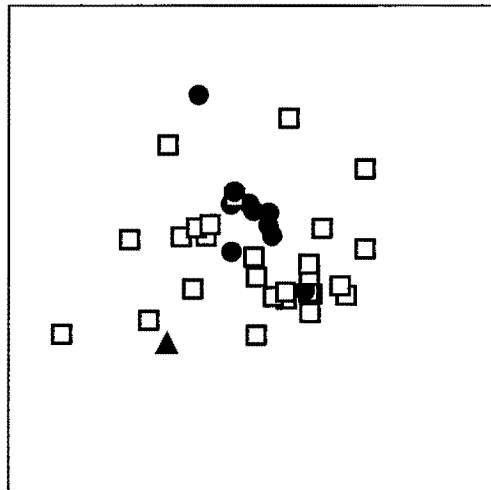


Fig. 3.4 A PCA plot of the substrate communities in the BIRNM Marine Garden, St. Croix and St. John. (Circles = BIRNM, Squares = St. Croix and Triangle = St. John).

The PCA data (Fig. 3.4), shows that the sites sampled within the BIRNM Marine Garden are found to be distributed in the middle of the PCA plot. This supports the univariate analysis suggesting that the composition of the substrate inside the BIRNM Marine Garden is similar to the composition outside the Marine Garden, although there seems to be more variation in the substrate composition outside the Marine Garden. These results support the findings from Table 3.2 as they both show that the maintenance of the Marine Garden does not seem to create a significantly different substrate composition.

Another interesting outcome of the PCA analysis (Fig. 3.4) is that the St. John site seems to have a very different substrate composition when compared with the BIRNM Marine Garden sites. Unfortunately as this is only one site it is hard to make any firm conclusions from this result.

Table 3.3 R^2 values showing which of the substrate types, best explain the PCA 1 and PCA 2 values.

PCA 1 Values		PCA 2 Values	
Substrate Type	R^2 value	Substrate Type	R^2 value
0.2-1.5 Algae	0.6617	Sand	0.4074
>5cm Algae	0.4418	1.5-5 Algae	0.3139
1.5-5 Algae	0.3507	Coral	0.2081
Sand	0.2727	Rock	0.0866
Rock	0.0921	0.2-1.5 Algae	0.0198
Coral	0.0277	>5cm Algae	0.0086

Regression of the PCA values (Table 3.3) shows that algae is the dominant substrate characteristic of the PCA 1 values (especially the small turf algae) and that coral cover was a relatively minor component. The dominant substrate characteristics in the PCA 2 values were sand, medium algae and coral. Regression analysis of juvenile coral density and PCA 1 ($P = 0.315$) and PCA 2 ($P = 0.980$) values did not show a significant relationship, thus PCA values were not used in further analysis.

3.5 Is the density of grazers significantly different inside and outside the Marine Garden?

Table 3.4 The difference in densities of grazers, inside and outside the BIRNM Marine Garden (using Student-t tests). (Inside the Marine Garden Urchins $n=10$ and the rest $n=4$, outside the Marine garden Urchins $n=27$, No. Species $n=17$ and the rest $n=19$).

Student-t test Inside/outside Marine Garden	Inside	Outside	P value	Significant difference
Urchins (m^{-2})	0.15	2.56	0.0001	YES
Parrotfish (m^{-3})	0.09	0.04	0.18	NO
Damselfish (m^{-3})	0.10	0.19	0.22	NO
Surgeonfish (m^{-3})	0.16	0.18	0.87	NO
Triggerfish (m^{-3})	0.012	0.003	0.015	YES
No. Species	6.04	5.24	0.048	YES

There was a highly significant difference between the urchin densities inside and outside the Marine Garden, with considerably more urchins found outside the Marine Garden than inside (Table 3.4). The results also show that there is a significant difference in the density of triggerfish and the number of different species of fish inside and outside the Marine Garden. However, there was no significant difference between densities of parrotfish, damselfish or surgeonfish.

3.6 Can the data be used to identify relationships that could help in predicting juvenile coral densities?

Table 3.5 A Best sub-sets regression showing the best substrate categories (with separate algae categories) and urchin densities that explain juvenile coral density.

	R ² values	Adjusted R ² values	Factors						
			Algae			Rock	Sand	Coral	Urchins
			0.2-1.5mm	1.5mm-5cm	>5cm				
1	12.3	9.8				X			
1	11.1	8.5			X				
2	19.3	14.6			X	X			
2	14.8	9.8	X			X			
3	21.4	14.2			X	X			X
3	20.0	12.7			X	X		X	
4	21.9	12.2		X		X	X		X
4	21.9	12.1				X	X	X	X
5	23.1	10.6	X	X		X		X	X
5	23.0	10.5	X		X	X		X	X
6	23.9	8.7	X	X		X	X	X	X
6	23.8	8.6	X	X	X	X		X	X
7	24.2	5.9	X	X	X	X	X	X	X

Rock was found to be the best single substrate feature that explains juvenile coral distribution. Regression analysis showed that this relationship is best explained using the equation

$$\text{Juveniles} = 1.23 + 0.0095 \text{ Rock}$$

Regression Analysis of Variance shows that this equation is significant ($P = 0.033$), and has an R^2 value of 12.3% and an R^2 (adjusted) value of 9.8%. It also shows that the best combination of variables to explain juvenile coral distribution is a combination of rock and algae >5cm. This again has a significant regression equation ($P=0.026$).

$$\text{Juveniles} = 1.43 + 0.00795 \text{ Rock} - 0.0871 \text{ Algae } >5\text{cm}.$$

The equation also shows that juvenile coral numbers have a positive relationship with the percentage cover of rock, but has a negative relationship with the amount of large algae cover. If all the algae is amalgamated (Table 3.6) then the picture changes slightly, with rock alone being the substrate feature that best explains juvenile coral variation. This highlights the advantage of dividing the algae categories into separate size-classes, as it shows that algae >5cm does play a significant role in juvenile coral distribution, while other size classes seem to be less important.

Table 3.6 A Best sub-sets regression showing the best substrate categories (with all the algae categories combined) and urchin densities that explain juvenile coral density.

	R^2 values	Adjusted R^2 values	Factors				
			Coral	Algae	Rock	Sand	Urchins
1	12.8	9.0			X		
1	0.6	0.0	X				
2	14.1	9.1			X		X
2	13.8	8.7		X	X		
3	14.9	7.2		X	X		X
3	14.4	6.7	X		X		X
4	15.1	4.5	X	X	X		X
4	14.9	4.3		X	X	X	X
5	15.1	1.4	X	X	X	X	X

As the regression analysis established a relationship between the juvenile coral and the percentage cover of rock for all the sites studied, the next step was to see if there was a significant difference in the relationship inside and outside the Marine Garden.

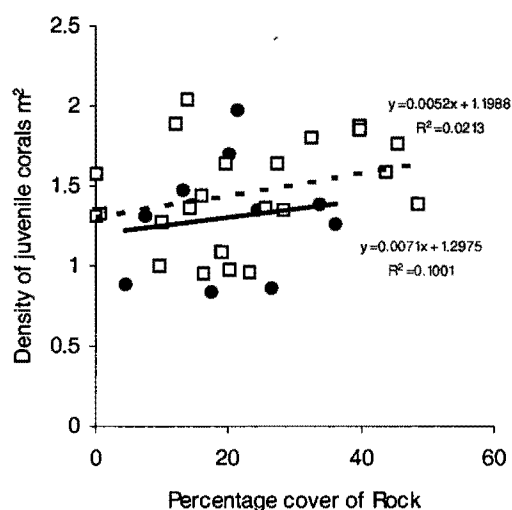


Fig. 3.5 The regression of juvenile corals against the percentage cover of rock, inside and outside the Marine Garden. (Circles = Inside the Marine Garden, Squares = Outside the Marine Garden, Bold regression line = Inside the Marine Garden, Dashed regression line = Outside the Marine Garden)

There was no significant difference between the relationship (Fig 3.5), the juvenile coral densities inside the Marine Garden seem to show a very similar relationship with the rock, as those areas outside. However, the graph suggests that less rock is needed outside the Marine Garden than inside, for the same density of juvenile corals ($P = 0.188$). General Liner Model analysis also showed that there was no significant difference between the regressions inside and outside the Marine Garden for a combination of percentage cover of rock and algae $>5\text{cm}$, and juvenile coral densities ($P = 0.203$).

Table 3.7 A Best sub-sets regression showing which grazers/ association of grazers best explain juvenile coral density.

	R ² values	Adjusted R ² values	Factors					
			Urchins	Parrotfish	Damselfish	Surgeonfish	Triggerfish	No. of species
1	8.9	3.9						X
1	5.3	0.0			X			
2	14.5	4.5			X			X
2	13.1	2.9		X	X			
3	19.9	4.9		X	X			X
3	19.0	3.8	X	X	X			
4	23.2	2.7		X	X	X		X
4	22.4	1.7	X	X	X			X
5	24.6	0.0	X	X	X	X		X
5	24.3	0.0		X	X	X	X	X
6	25.1	0.0	X	X	X	X	X	X

The single best indicator of the density of juvenile corals, when compared to grazing densities, was the number of different fish species seen at the site. However, the combination of the density of parrotfish and damselfish as well as the number of species found, had the highest adjusted R² value. Although this raises some interesting questions, the relevance of these results, there was not a significant relationship with the density of juvenile corals (P = 0.2 for the No. of Species, and P = 0.3 for the No. of Species, parrotfish and damselfish combined).

3.7 Evidence of trophic relationships

The relationship between triggerfish and urchins (Fig. 3.6), shows that inside the Marine Garden, there were significantly more triggerfish and significantly less urchins than outside. Unfortunately due to the small sample size it is hard to draw any firm conclusions from this. Thus all the sites were amalgamated to see if there was a significant trend of decreasing urchin densities with increasing triggerfish densities. The correlation showed that there was a significant relationship.

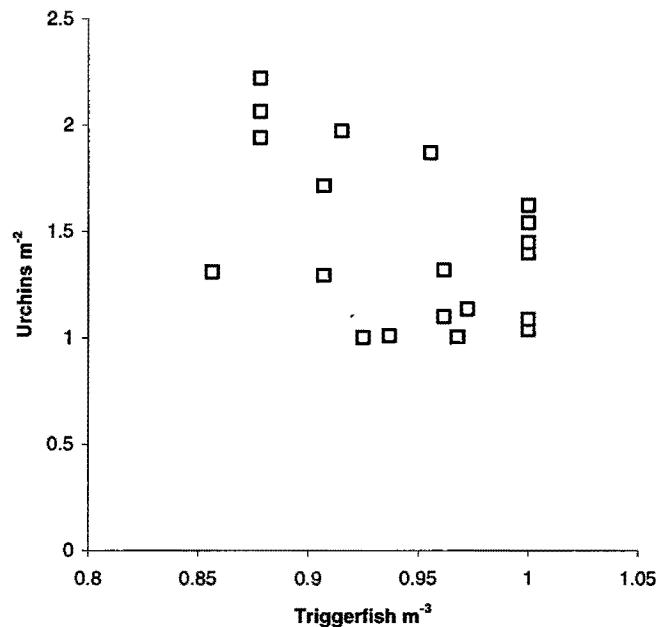


Fig. 3.6 The relationship between the density of urchins and the density of triggerfish, throughout all the sites studied. (The correlation was significant, -0.471 , $P = 0.036$)

3.8 The spatial distribution of the juvenile corals

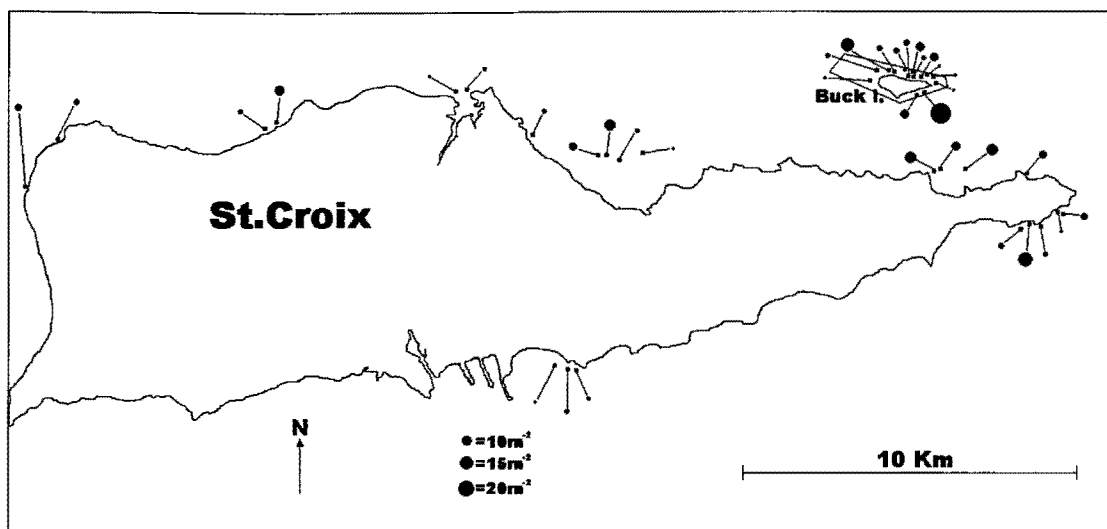


Fig. 3.7 The mean density of juvenile corals per meter squared of available substrate, at each of the sites studied, through out BIRNM and St. Croix.

The spatial distribution of corals (Fig. 3.7) shows that the northeast coast of St. Croix and the southern coast of BIRNM (Buck Island) seem to have high densities of juvenile corals compared to other areas of the island. The map also shows that some of the reefs studied seem to have low juvenile coral densities at all the sites studied within that reef (eg C1-C3 and C18-19). However, the intensive sampling around the BIRNM shows that there is a large amount of variation within a single reef system. This could be an example of juvenile coral variation occurring more on an inter-reef scale than on a smaller reef scale, although this is subjective.

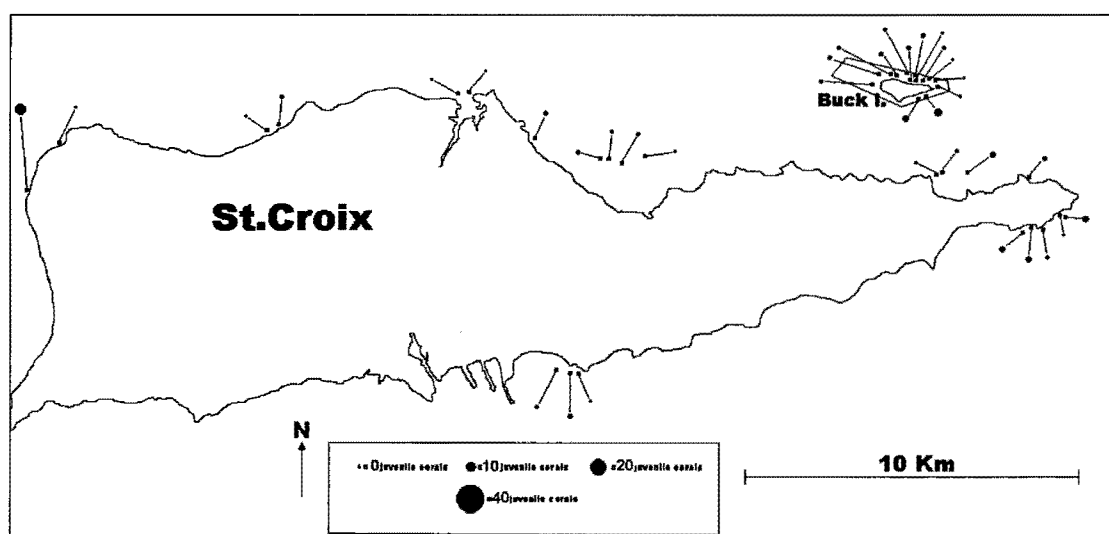


Fig. 3.8 The total number of juvenile corals found in the size category 0-1cm, at each of the sites studied throughout BIRNM and St. Croix.

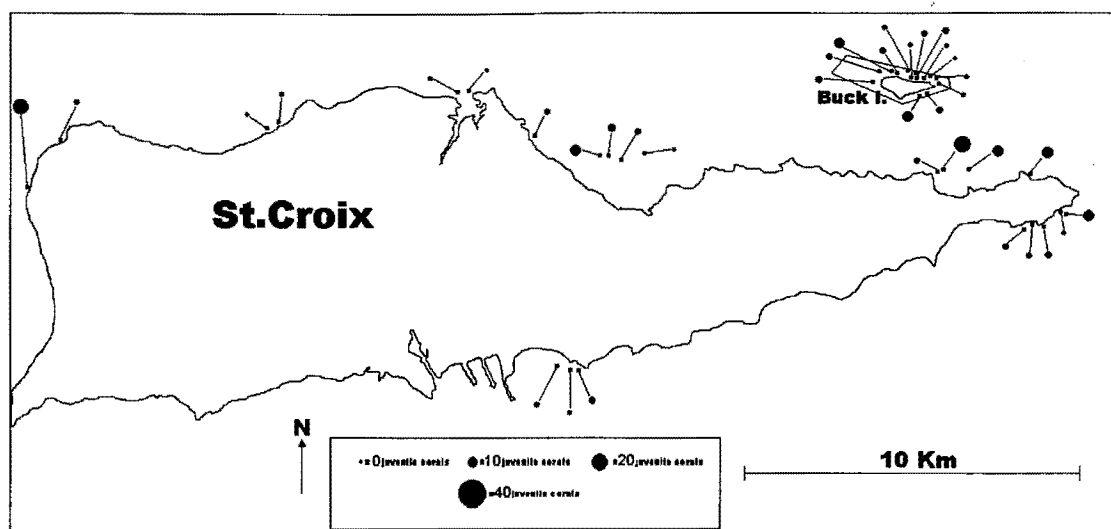


Fig. 3.9 The total number of juvenile corals found in the size category 1-3cm, at each of the sites studied throughout BIRNM and St. Croix.

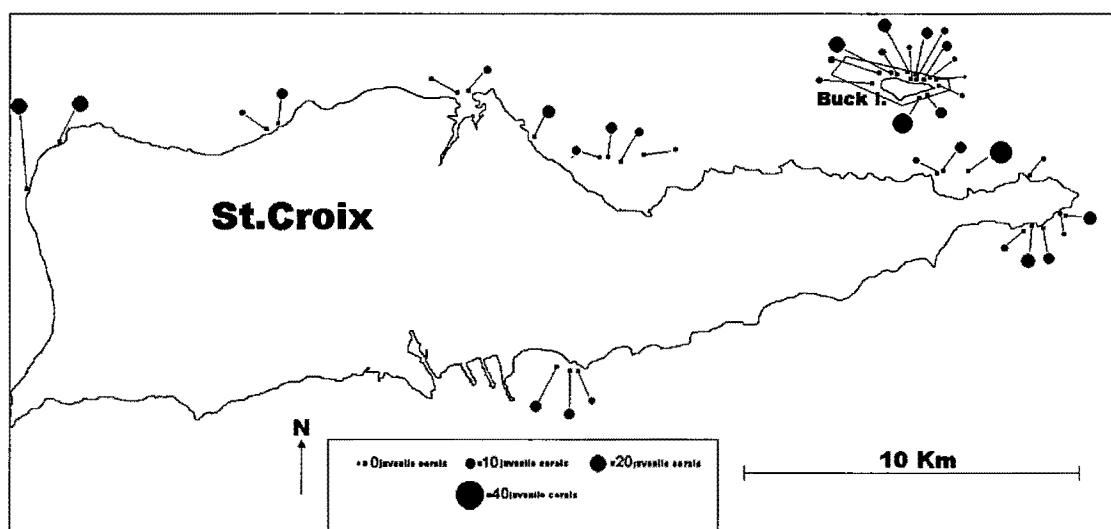


Fig. 3.10 The total number of juvenile corals found in the size category 3-5cm, at each of the sites studied throughout BIRNM and St. Croix.

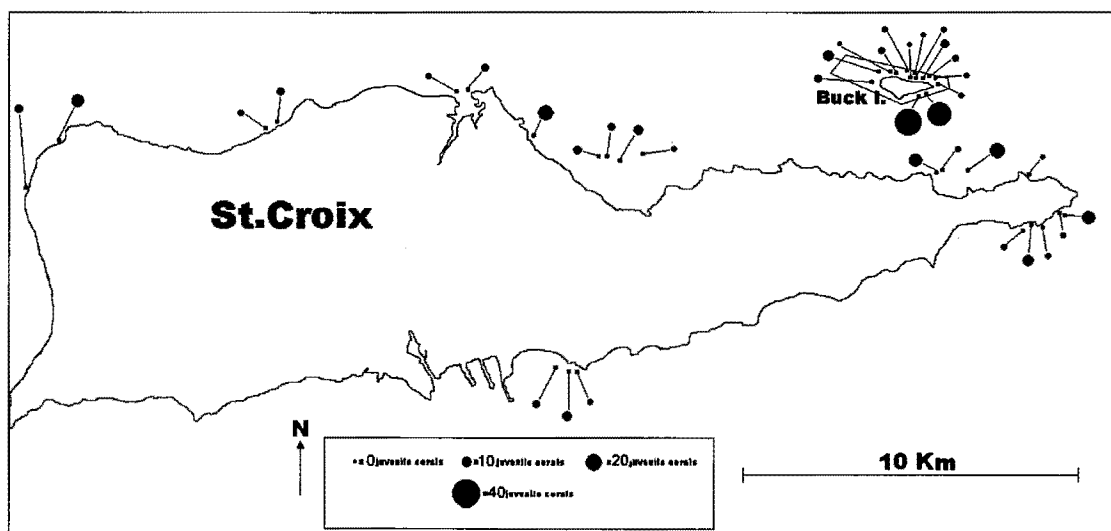


Fig. 3.11 The total number of juvenile corals found in the size category 5-10cm, at each of the sites studied throughout BIRNM and St. Croix.

The Size-class distribution maps (Fig.8-11) show that there were relatively few corals recorded in the size category 0-1cm and within distribution of juveniles seems skewed to the 3-5cm size class. The size class distribution also shows that the sites with the highest abundance alternate with the different size categories. The second interesting point was that the same part of the northeast coast of St. Croix and the southern coast of BIRNM (Buck Island), seems to dominate in most size classes.

3.9 Interactions between grazers and juvenile coral communities

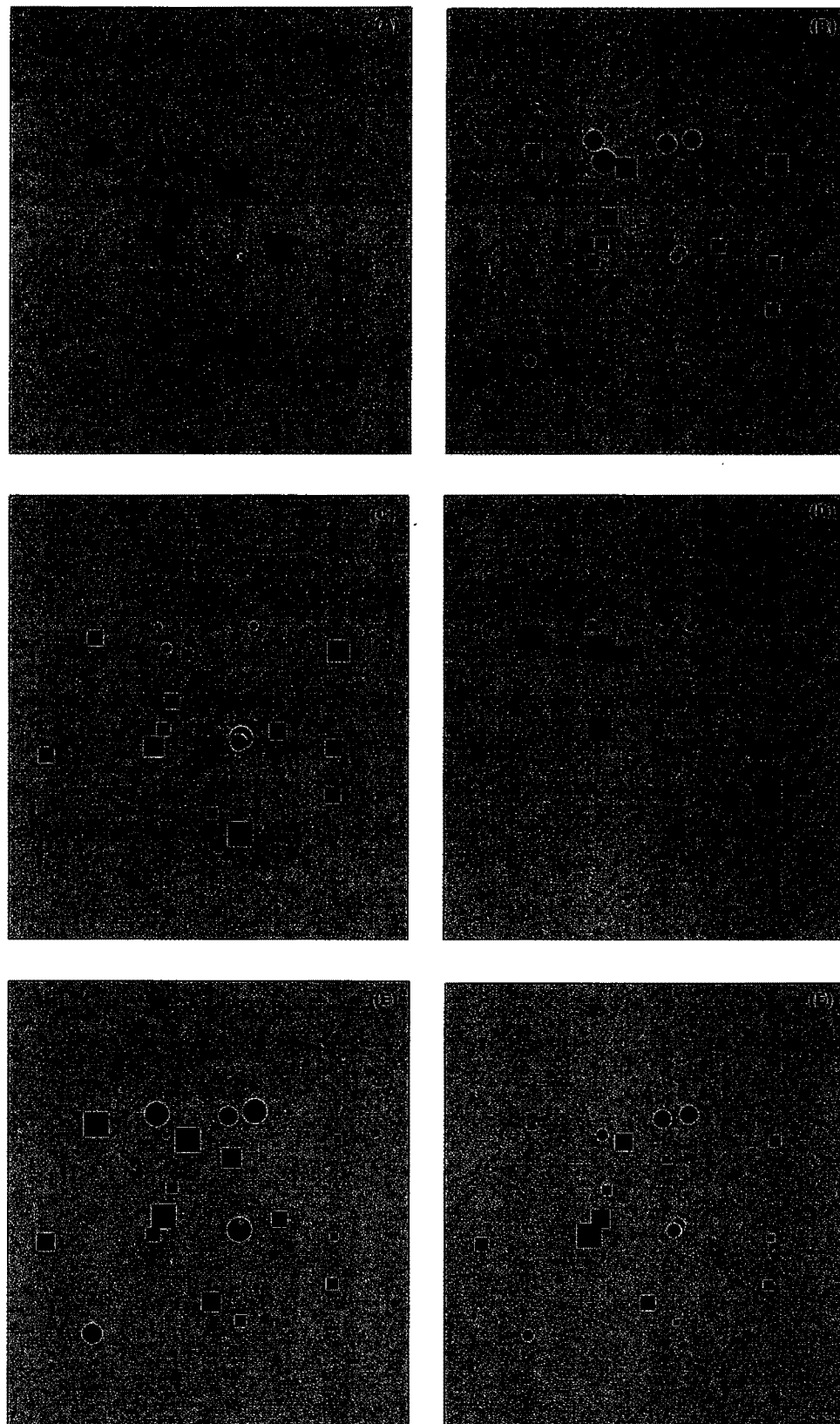


Fig. 3.12 Overlay plots for Urchins (A), Parrotfish (B), Damselfish (C), Surgeonfish (D), Triggerfish (E) and No. of Species (F), on juvenile coral community MDS plots. (Circles = Inside BIRNM, Squares = Outside BIRNM).

Overlays of the grazer densities on MDS plots of juvenile community structure did not generally show an obvious distribution patterns between communities inside and outside the Marine Park. However, there does seem to be a trend in the distribution of parrotfish and coral community structure, with a decreasing parrotfish abundance from the top to the bottom of the MDS plot.

Table 3.8 BIOENV correlation results showing which grazers/ association of grazers best explain the juvenile coral communities (only the highest multiple correlation's are shown).

n	r	Urchins	Parrotfish	Damselfish	Surgeonfish	Triggerfish
1	0.013	X				
1	0.003			X		
1	-0.049		X			
1	-0.065				X	
1	-0.085					X
2	0.043	X	X			
3	0.071	X		X	X	
4	0.082	X	X	X	X	
5	0.049	X	X	X	X	X

Table 3.8 shows that urchin densities have the single best correlation with the juvenile communities, and that a combination of all the grazers has the highest overall correlation. However, the correlations show no significant relationship between grazer densities and multivariate community structure.

4. Discussion

4.1 Mean Density and Percentage composition of juvenile corals

The juvenile coral densities, at depths between 0.5 and 4m, around St. Croix and BIRNM coral reefs is found at the lower range of juvenile coral densities recorded else where (Table 4.1).

Table 4.1 Previous results of juvenile coral surveys (* recruitment under enhanced environmental conditions).

Location	Paper	Abundance of juveniles (mean)	Sample size (m ⁻²)
Florida Keys	Chiappone and Sullivan (1996)	2.03	450
Curaçao (Netherlands Antilles)	Bak and Engel (1979)	15.3	60
Bonaire (Netherlands Antilles)	Bak and Engel (1979)	17.6	15
Rio Bueno (Jamaica)	Hughes (1985)	19.4*	36*
Heron Island (GBR)	Connell (1973)	15	--
BIRNM (around sites B1-B2)	Bythell (1999)	17.2	48
BIRNM and St. Croix	Wright (1999)	4.4	185

This could be an indication that St. Croix and BIRNM generally have a low level of recruitment compared to the other areas studied. However, as the sample sizes indicate, this could also be explained by studies with a smaller sampling size not sampling widely enough to encompass a range of different reef habitats. This is supported by Hughes et al. (1999) and Fig 3.7, which shows that there is a large degree of variability within the geographical scale of a reef.

The density of juvenile corals in the BIRNM (Bythell 1999) was recorded as an area of specific interest and not as an area typical of the BIRNM system, and thus this value should be regarded as at the higher range of recruitment within the system. However, 17.2 juvenile corals m⁻² (in 1996) compares well with values of 14.5 juvenile corals m⁻² (a mean for B1-B2) and 16.8 juvenile corals m⁻² for B2 (the closer of the two sites to the transects) recorded in this study, suggesting that rates of recruitment in this area have been high over a number years. The size class data also supports this, showing that this area generally has relatively high densities of recruits in all size categories.

Porites asteroides, *Porites porites* and *Agaricites agaricites* were the most abundant juvenile coral species around St. Croix and BIRNM. These findings are very similar to those of Chiappone and Sullivan (1996) and Bak and Engel (1979). Who both found that *Agaricites agaricites* and *Porites asteroides* were the most common species, together accounting for 76-86% (Chiappone and Sullivan, 1996) and 69% (Bak and Engel 1979) of the juvenile corals found. Thus *A. agaricites* seems to invest a large amount of its resources in producing high numbers of juveniles. Other coral species which have low numbers of juveniles, but equally large percent cover, must invest in other strategies, such as regeneration

of damaged areas, or faster growth rates and higher survivorship, to maintain their high percentage cover. This finding supports Bak and Luckhurst (1980) and Jackson and Hughes (1985), indicating that although *A. agaricites* produces more juveniles and they grow faster than other foliaceous or massive corals, they are killed and injured more often and rarely reach a large size.

4.2 The effects of different reef zones on juvenile coral distributions

In this study juvenile coral communities were not significantly affected by the reef zone that they were found in. Chiappone and Sullivan (1996) showed that there was a difference in juvenile coral communities when spur and groove, and relict reef flats were compared with relict spur and groove sites (i.e. sites which had high levels of sediment deposition and movement). Chiappone and Sullivan (1996) explained this as being a direct result of the harsher conditions in these areas. However there have been few juvenile coral studies replicated on such a large scale (Hughes et al. (1999) being the major exception), to compare this finding with.

It is widely expected that different species of coral tend to grow in different areas on the reef, forming distinct zones (e.g. Antonius 1980; Aronson and Precht 1997). This then raises the question why don't the juvenile corals show this same distribution? As Hughes (1985) illustrates, juvenile corals have a high rate of mortality, with fewer than 5% of all corals surviving longer than 3 years. However these pressures might not be similar in all the reef zones, and the lack of a significant difference between the communities could be due to the juvenile corals being too 'young' to show this trend. As it takes time for the individual mortality rates of each species, in a specific zone, to be converted into a significantly different community. These findings also contradict Richmond (1997) who suggested, that differences in species distribution patterns are more likely the result of larvae selection than colony survivorship.

4.3 Effect of the Marine Garden on Juvenile coral densities

As Fig. 3.3 shows there was no significant difference between the density of juvenile corals inside and outside the BIRNM Marine Garden. This could be due to a number of different factors. It could be that trophic cascade effects, if occurring at all, might have been too subtle for this survey to show. Thus although the project suggests that high triggerfish densities reduce urchin densities there is no evidence that reducing urchin densities has an effect on juvenile coral densities.

As Table 3.1 and Fig. 3.4 also show, the sites inside the Marine Garden did not have a significantly different substrate composition to those outside. Indicating that there is no significant difference in the space available for the juvenile corals to settle in. This could mean that the density of settlement would thus be similar.

Although coral larvae are able to swim to potentially suitable habitats, this only occurs on a small scale as their propulsion comes from tiny flagella. Instead larvae rely on currents to carry them close to a suitable habitat. Which means that settlement of larvae at a specific reef could be patchy. Settlement success will depend not only on the arbitrariness of the currents and predation, but also on the actual source of the larvae, as some larvae will settle close to their parents whereas other larvae can get caught in local currents. There is also the potential for juvenile corals being affected by large scale events like hurricanes. A number of other studies e.g. Hughes (1985) also show that recruitment can be very variable temporally as well as spatially.

4.4 Differences in substrate characteristics

It is interesting that there were no significant differences in the relative percentage cover of any of the substrate characteristics inside and outside the Marine Garden, or in the topography. As this contradicts McClanahan and Shafir (1990) who found significantly different levels of percentage cover of hard coral, algal turf, and sand inside and outside marine protected areas. This could be due to the relative scale of the areas studied, as McClanahan and Shafir (1990) studied several protected and unprotected areas along a 150 km coastline whereas this project compared one small protected area which is spatially very close to the unprotected areas. Thus the BIRNM Marine Garden is exposed to many of the same environmental conditions (e.g. hurricane impacts in 1989, 1995 and 1998) as the areas around St. Croix.

McClanahan and Shafir (1990) concluded that substrate differences outside the marine park may be attributable to (i) reduction in finfish, (ii) an increase in sea urchins or (iii) a combination of both changes. Results of this study showed that although there were more urchins grazing outside the Marine Garden compared to inside, there was not a significant difference in the number of grazing fish (a different finding to McClanahan and Shafir 1990). Thus McClanahan and Shafir's (1990) conclusions could be tested. As there was no significant difference in the substrate variables, but still a significant difference in urchin densities, this could suggest that finfish abundance is the more important factor in determining the substrate community.

4.5 Differences in Grazer densities

One of the major findings of the project was that there was a significant difference in the density of urchins inside and outside the marine park. One explanation could be the significant relationship between triggerfish and urchin abundances. This supports McClanahan and Shafir's (1990) findings, that predation acts as a strong controlling force on urchin community structure. This was supported by results inside and outside the Marine Garden, however, due to the small sample size the results should be viewed with caution.

Another factor, which should be taken into consideration, is that the urchin distribution was very patchy, with over 50 urchins found in some extended quadrates where as none were found in nearby extended quadrats. The higher densities of triggerfish could therefore be having an indirect effect on the grazing pressure, by reducing urchin densities. Thus if fishing were to be reduced, for example through fisheries management, then increases in triggerfish densities and thus reduced urchin densities, could actually reduce the grazing pressure.

The high significant difference in urchin abundance however, raises the question, why is this not reflected in low algae cover or high rock cover? There could be two explanations to this, the first could be that, the urchin densities are much lower than before the mass die-off in 1983 (Jackson 1997), and thus densities might be at such low levels, even at the sites with the highest density, that their affect on algae could at present be minimal. The second explanation could be that the fish grazing pressures (which are not significantly different) could be the significant factor in determining algae percentage cover, especially when urchin grazing pressures are historically low (McClanahan and Shafir's 1990).

Unfortunately due to the small sample size within the Marine Garden it is hard to say conclusively whether the Marine Garden has higher densities of fish than the unprotected areas outside. The fish surveys indicated that there was a significant difference in the number of different fish species and the density of triggerfish, however there was no significant difference in the other fish species studied. Thus although the Marine Garden might have a net positive effect on the fish populations as a whole, the abundance of grazing fish is not significantly higher, suggesting that restricting fishing might not have an appreciable effect in increasing the grazer populations. This is surprising as Beets (1987) suggests that catches in the USVI, are now dominated by parrotfish and surgeonfish. However, a lack of significant differences in the grazer densities could be due to the remoteness of some of the non-protected sites studied, which meant that the sites were rarely fished (Table 1.1), thus making an unequal comparison. Another explanation could be that due to the recent lack of a Park Ranger, illegal fishing has occurred inside the Marine Garden and thus reduced the density of grazing fish.

Higher fish diversity has been shown by Tilman (1996) to help stabilise community and ecosystem processes, although not necessarily population levels. Thus the higher diversity of fish species found within the park suggests that the fish community as a whole is more stable inside than outside the Marine Garden. Hence although there might not be any difference in grazing fish densities, the fish community as a whole is generally more robust and thus less likely to suffer from changing environmental conditions.

4.6 Identifying factors which affect juvenile coral distribution

The best predictor of juvenile density was a combination of the amount of rock and algae >5cm. Cover of rock had a positive relationship with the density of juvenile coral, whereas the amount of large algae (>5cm) had a negative relationship, indicating that the large algae could be potentially inhibiting either the settlement or the growth of juvenile corals. This is supported by Rodgers et al. (1984) who found that low rates of recruitment were associated with high algae biomass.

Best sub-sets regression also showed that the percentage cover of rock had the best single-predictor association with juvenile coral density. Thus the results may be showing that for corals to survive and grow after they have settled, they need a certain amount of free space (rock), allowing them to spread horizontally secreting a strong basal plate, whilst not being out-competed for light and other resources by larger algae. This finding also supports the findings of Hughes (1985) where areas of exposed bare rock were created, and compared to control areas. This showed that larval recruitment in cleared areas was significantly different and that there was a significant negative correlation between rates of larval recruitment and the percentage cover of previously established macro-organisms (mainly corals and algae). Thus indicating that coral and algae utilising space on the reef, has a significant inhibitory effect on net larval recruitment.

As the amount of bare rock is important, this then asks the question, what controls the amount of rock that is available for the coral larvae to settle on? The answer comes back to the amount of grazing that takes place on the reef. Thus although the experimental results did not show that grazers had a direct relationship on the density of juvenile corals the fact that 'grazed space' was identified as the single most important factor suggests that they must be playing an important role.

Another factor that could be affecting coral larva densities, is that coral larvae might aggregate together when they settle on the substrate, thus if one larva settles in a desirable place, other larvae will settle near-by because of it. Although this has not been proved to occur in coral larva, and work with barnacle larva (a similar sedentary benthic organism) suggests that recruitment of an initial larva has minor effects on the subsequent settlement of other larvae (Keough 1998).

From (Table 3.6), the results suggest that there is little or no relationship between the densities of different types of grazers and the density of juvenile corals. Which disagrees with Rogers et al. (1984), who found that high rates of coral recruitment tend to be associated with relatively high grazing pressure, by urchins and fishes. However the Rogers et al. (1984) study observed a relationship with depth rather than spatially. Thus the lack of any relationship could be due to the mobility of some of the grazers and the fact that they do not have a direct relationship with juvenile corals but can move about and feed at a number of

different sites. This could also be a reflection on the limited sampling of the project, only taking a snap-shot of the densities rather than a longer term, more realistic, estimation of the actual population densities. The results could also be indicating that factors which are concerned with larvae settlement (like the amount of rock available), could be more important in determining juvenile coral densities than grazing pressures.

4.7 Juvenile coral community distribution

There was a lack of a significant difference in juvenile coral communities inside and outside the Marine Garden although MDS analysis indicates that there may be some differences in the juvenile coral communities. Thus the no fishing policy in the Marine Garden could be creating subtle pressures on the survival of certain juvenile coral species, which although not significant could be important.

Although there were no significant differences in grazing fish populations inside and outside the park, MDS analysis showed a trend relating parrotfish densities with community structure. This could be an indication that parrotfish are having an active role in determining the coral community. This could occur because parrotfish can bite and remove relatively large amounts of coral, and large parrotfish can remove small juveniles in one mouthful. Hence if parrotfish family or an abundant parrotfish species was to show a preference for a specific species or range of juvenile coral species it could potentially affect the coral community composition. If this proved to be a significant trend then removing certain parrotfish species via fishing, could have a potential impact on coral communities. Another option could be that parrotfish graze in a pattern, or on a specific microhabitat, that would encourage settlement or promote early survival of certain corals, thus selecting out some coral juvenile species.

4.8 Spatial distribution of juvenile corals

One reason for the high density of juvenile corals around sites C9-C12 and B1 and B2 could be that this area was hit by Hurricane Hugo in 1989. Due to the currents and eddies created, the northeast part of the island was severely affected and the south shore of St. Croix was totally obliterated with only bare rock remaining. Thus one explanation of the high abundance of juvenile corals could be that this huge natural disaster created large areas of substrate that could be colonised by juvenile corals. This also supports the findings of the best sub-sets analysis and Hughes (1985), which suggested that large expanses of rock could potentially have high densities of juvenile corals. Another factor which could also have played a role in the relatively high abundance of juvenile corals could be that the prevailing current generally moves in an east to west direction, thus these sites could be exposed to the greatest influx of coral larvae.

The variation of juvenile coral densities within BIRNM show some of the same trends as seen by Hughes et al. (1999), in that there seems to be large amounts of variation in the densities of juvenile corals on the scale of hundreds of meters. There does however, seem to be a trend of low juvenile densities throughout some reefs whilst other reefs tend to have a far wider range of densities. This variation might be due to random distribution patterns caused by a wide range of environmental variables currents, spawning site and the random influx in juveniles each year. The variations could however, be more to do with the availability of suitable substrate for juvenile corals to settle on.

The northeast coast and southern shore of BIRNM seem to have relatively large abundance's in all of the size categories studied. This suggests that this site has continually been recruiting well, rather than just recruiting well in one or two year spurt. The trend of juvenile corals tending to be dominated by the larger juveniles could be due to larger juveniles being easier to see, or it could be reflecting a particularly strong recruitment event in the past few years.

4.9 Implications for reef management

The results show that the present management practices do not seem to be having a direct effect on the density of juvenile corals, and as Fig. 3.7 shows there is a large amount of variation within reefs as well as between them. Thus if active management practices can not control what is coming into the park they should concentrate more on protecting the corals that are already present in the park as well as the new recruits which do settle within the park boundaries. The present management measures are relatively simple but seem to be effective in maintaining as pristine a habitat as possible.

BIRNM and its location seem to be quite fortunate, in the fact that a lot of the normal human pressures on coral reefs (e.g. high nutrient levels from land run-off or sewage) are not important as BIRNM is far enough from the mainland not to be affected. There are three main areas in which an influx of high densities of people (usually tourists) to the park can affect the health of the coral reefs. One of the biggest potential impacts could come from boats crashing into the reef. For this reason there is one specific route and entrance and exit to the Marine Garden, which is marked with buoys, thus limiting the chance of any groundings. The second potential impact could be from people removing and damaging pieces of coral. This is generally tightly regulated as most tourists are taken to the underwater trail (Fig. 1.6) which has numerous signs reminding people not to touch the coral. As well as this, most of the tour operators have a vested interest in maintaining the health of the reef, and thus strongly discourage any contact with the reef. The third way that people could impact the reef is by throwing their trash over board. This again is strongly discouraged by the tour

operators, who carry the bulk of the people to BIRNM, and there are bins on Buck Island for people to leave their trash in.

The fourth major impact that people can have on the health of the reef community as a whole, is through fishing. As the study shows densities of certain types of fish (triggerfish and parrotfish) are important not only in terms of the structure of the fish community, but also in terms of urchin abundance and juvenile coral community structure. Thus it is important to maintain densities of these fish, otherwise the wider coral reef community could be affected, not only by increased urchin grazing, or by changes in juvenile community structure but also by the knock on effects of these changes.

As already stated, there is a complete ban on fishing within the Marine Garden. Although this is true in law, at present there is no Park Ranger to enforce the laws, thus a good first step would be to reinstate a Park Ranger as soon as possible (which is currently being arranged). Other possible improvements in regulating the fishing in the marine park are listed below.

- To establish the exact boundaries of the BIRNM and the Marine Garden (to see whether the patch reefs are legally inside or outside the Marine Garden).
- To have more BIRNM boundary markers (to put in and maintain more buoys around the marine parks boundaries).
- To educate fishermen on the boundaries of the BIRNM and the Marine Garden, as well as the benefits of the Marine Garden.
- To try and increase the area of no fishing, (to at least extend the boundaries of the Marine Garden out to the BIRNM boundaries in the eastern end of the park).
- To increase the confiscation time of boats which are found fishing in restricted areas. At present fines for illegal fishing are very low compared to the amount of money that can be made by fishing, and the fines would have to increase dramatically to be more of a deterrent. There is however an indirect fine associated with being caught, the confiscation of the boat and fishing equipment. Thus a fisherman actually suffers a double fine of not earning money from fishing as well as paying a fine. If the confiscation period was extended then this could thus act as more of a deterrent.

5. Conclusions

1) The study shows that the creation of a marine protected area even if it has been relatively well protected for a long time does not necessarily affect the density of juvenile corals. As it was proved that there was no significant difference in juvenile coral densities inside or outside the BIRNM Marine Garden.

2a) There were no significant differences in the substrate cover, or the topography inside or outside the BIRNM Marine Garden. This contradicts McClanahan and Shafir (1990) who found significantly different levels of percentage cover of hard coral, algal turf, and sand inside and outside marine protected areas.

2b) The densities of urchins were found to be significantly higher outside the BIRNM Marine Garden than inside, showing a similar trend to those seen by McClanahan and Shafir (1990). There is evidence of triggerfish density have a negative effect on urchin densities supporting McClanahan and Shafir (1990).

2c) The densities of grazing fish were not significantly different inside or outside the BIRNM Marine Garden. This contradicts McClanahan and Shafir (1994) who found significantly different abundances of parrotfish and surgeonfish inside and outside marine protected areas.

3a) The percentage cover of rock is the single best predictor of juvenile coral density, agreeing with Hughes (1985). A combination of rock and algae >5cm are the best combination of factors which are the best predictors of juvenile coral density, with algae having a negative effect on juvenile coral abundance, supporting findings by Rogers et al. (1984).

3b) The density of grazers does not seem to have a direct relationship on the density of juvenile corals, disagreeing with Rogers et al. (1984).

4a) There was no significant difference in juvenile coral communities inside or outside the BIRNM Marine Garden.

4b) There was no significant difference between the juvenile coral communities in any of the different reef zones studied.

4c) Only Parrotfish densities seem to affect juvenile coral communities.

5a) The northeast coast and southern shore of BIRNM seem to have relatively large abundance's in all of the categories studied.

5b) There was substantial variation within reef systems (e.g. the BIRNM system), however there was also variation between reefs (e.g. C1-C3 and B1-B2).

6. References

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