An examination of a degraded coral reef system and the biological processes that may lead it to recovery: Castle Harbour, Bermuda.

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An examination of a degraded coral reef system and the biological processes that may lead it to recovery: Castle Harbour, Bermuda

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Summary

Coral reefs of a semi-enclosed basin, Castle Harbour, Bermuda, have been subjected to over a century of anthropogenic disturbance, the most detrimental being dredge and land-fill operations during the 1940's, creating 3 km^2 of land. This produced vast amounts of sediment and caused catastrophic coral mortalities. Sixty years on, response and recovery of the coral populations were re-assessed with a view to defining current status and future trajectory of these reef systems. Video surveys of benthic cover showed coral communities of Castle Harbour were depauperate compared to other reefs around Bermuda, and to observations made by early naturalists. Nevertheless, the dominant reef-building species of Bermuda were all found within the harbour. Hard coral coverage ranged from 4 -10 % and was greatest at locations closest to the open ocean, decreasing with distance into the harbour. Turf algae covered much of the remaining space (~56 %). Coral condition within the harbour was good compared to external reefs, with intermediate levels of partial mortality, and virtually no incidence of disease. Adult coral populations were relatively stable with ~2 % mortality over four years. Settlement appeared to be compromised within Castle Harbour and permanent quadrat studies showed larger juvenile populations and greater recruitment closer to oceanic water influx, compared to locations deep within the harbour. This could be a result of fine sediment build-up on the reef surface preventing settlement and recruitment. Size demographics of *Diploria* spp. showed *D. strigosa* were nearly eliminated from the harbour by the dredging, while *D. labyrinthiformis* survived. The demographic study showed some recovery by these species, with the majority of the populations having recruited post-dredging. This study illustrates the detrimental impacts coastal development has on near-shore coral reef environments, and the value of studying all life history stages to determine how best to aid coral reef recovery.

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Acknowledgements

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Chapter 1: General introduction and objectives of thesis

1.1 Study location

It is considered by many that coral reefs are on a downward spiral of degradation and decline (Wilkinson 1998, 1999, 2000, 2002, 2004; Gardner *et al.* 2003; Hughes *et al.* 2003; Pandolfi *et al.* 2003; Bellwood *et al.* 2004). This decline is both directly and indirectly caused by human activities (Goreau 1992; Sebens 1994; Wilkinson and Buddemeier 1994; Hughes *et al.* 2003). Global climate change has resulted in increasing sea temperatures and acidification, which in turn have caused increases in incidence of coral disease (Harvell *et al.* 2002; Ward *et al.* 2007), bleaching (Cook *et al.* 1990; Fitt *et al.* 1993; Hoegh-Guldberg and Salvat 1995; Brown 1997), and decreased rates of calcification (Clausen and Roth 1975; Kleypas *et al.* 1999). Locally, over-fishing, pollution, land development, and tourism are taking their toll on already stressed coral reefs (Hughes *et al.* 2003; Pandolfi *et al.* 2003; Wilkinson 2004; Davenport and Davenport 2006). Coral reefs are inherently valuable ecosystems because of their high biodiversity, and are economically important to humans for a number of reasons, including: (1) recreational, commercial, and subsistence fishing, which provide a valuable protein source to tens of millions of people, (2) in the production of pharmaceuticals with anti-cancer, AIDS-inhibiting, anti-coagulating properties from various reef organisms, (3) functioning as break waters, and (4) attracting huge numbers of tourists every year (Moberg and Folke 1999). These are just a few examples among many. As a result, there has been increasing pressure to document coral reef decline and to understand the processes behind it (Wilkinson 1999), in an attempt to preserve these diverse and valuable ecosystems.

High latitude coral reefs, such as those in Bermuda, exist at the extreme limits of hermatypic reef growth. At high latitudes, corals live close to their lower thermal tolerances and experience lower annual levels of photosynthetically active radiation (PAR) because of the low sun angle during the winter months (Wilkinson 1999). These factors lead to reduced species diversity and to coral populations that are slower growing than conspecifics of lower latitudes (Logan and Tomascik 1991; Wilkinson 1999). Consequently, high latitude coral reefs are thought to be slower to recover from physiological damage (Cook *et al.* 1994). This causes high latitude reefs to be more vulnerable to environmental change making them particularly important to study, especially regarding their responses to environmental and anthropogenic impacts (Hughes *et al.* 2002; Glassom *et al.* 2006).

The high latitude coral reefs of Bermuda (32°20' N, 064°40' W) lie at the northern limits of hermatypic coral growth in the Atlantic Ocean. Currents and eddies from the Gulf Stream bring warm waters north from the tropics, allowing corals to survive here (Wilkinson 1999). Bermuda's corals are a subset of those found in the Caribbean (Dryer and Logan 1978), with 34 hard coral species and 23 gorgonian species known to the reefs (Sterrer 1986). Most notably, Bermuda's reefs lack the branching hard coral *Acropora* spp., distinctive of lower latitude reef systems. The dominant coral species on Bermuda's reefs are the massive and encrusting species *Diploria labyrinthiformis*, *Diploria strigosa*, *Montastraea cavernosa* and *Montastraea franksi* (Jones 2004). These species combined comprise over 80 % of hard coral cover on the reefs of Bermuda (Jones 2004, 2005, 2006; this study). The Bermuda reef platform is approximately 18 km wide, roughly circular, and can be divided into four physiographic reef zones (Morris *et al.* 1977): (1) the outer-most terrace reefs, (2) the rim reefs, lying shoreward

of the terrace reefs, (3) the lagoonal reefs, comprised of numerous isolated patch reefs, (4) and the reefs of the in-shore basins (Fig. 1).

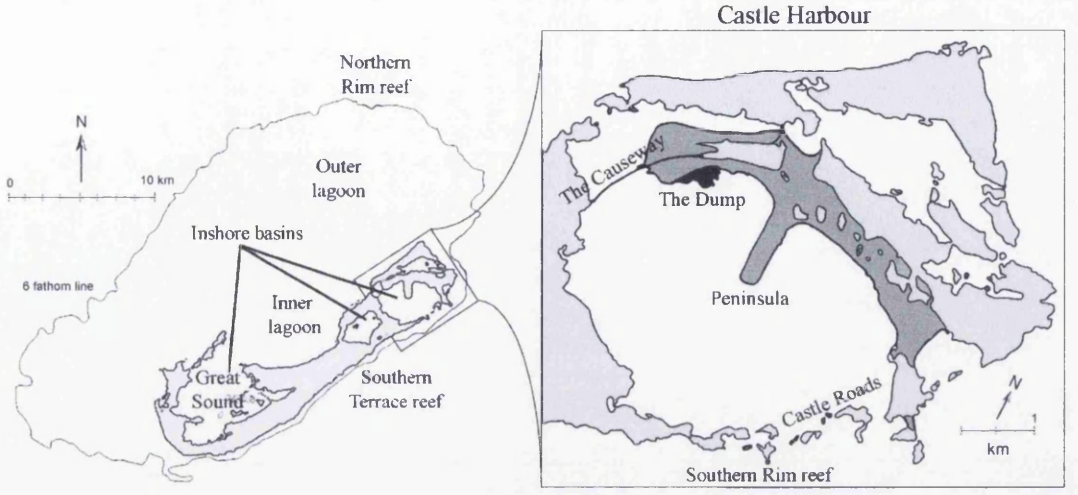


Fig. 1. Map showing the position of Bermuda's four major reef zones, and a close up of Castle Harbour (inset). Light grey indicates natural land mass' existing prior to the 1940's dredging activities, dark grey indicates area of landfill created by the dredge and fill activities, black indicates the dump. Image provided by the Marine Environmental Program (MEP), at the Bermuda Institute for Ocean Sciences (BIOS). Image modified by Helen Brylewska.

Conditions at each of these reef zones vary (Table 1), shaping the coral communities found there. Turbidity increases closer to shore (thus reducing visibility), with terrace and rim reefs experiencing ~25 m visibility during summer months, whilst lagoonal reefs generally have ~7-10 m visibility and Castle Harbour (in-shore waters) has 5-6 m visibility during summer months (de Putron 2003) (Table 1). There is a gradation in annual seawater temperature variation across the reef platform, with terrace and rim reefs showing least annual variation in seawater temperatures because they are more buffered by oceanic waters (Jones 2006). The lagoonal reefs experience slightly greater variation in annual seawater temperatures than rim and terrace reef locations because the lagoon is less influenced by oceanic waters. In-shore waters experience greatest annual seawater temperature fluctuations (Jones 2006), because of their relative distance from the open ocean, and sometimes enclosed nature (Table 1). Nutrient concentrations

(NO_2 , NO_3 and PO_4) vary little in waters surrounding the reefs of Castle Harbour, and other inshore reefs of the Bermuda reef platform (Table 1).

Table 1 Environmental parameters of the five major reef zones found around the Bermuda reef platform. Visibility data are provided by de Putron (2003), remaining data are provided by the Marine Environmental Program at the Bermuda Institute for Ocean Sciences, and were collected during 2005. Nutrient concentrations are the average of readings taken monthly between March and December 2005.

	Summer visability	Mean coral cover	Minimum annual temp. (degrees c)	Maximum annual temp. (degrees c)	Dissolved oxygen (ml/L)	Nitrate (NO_3) (µM)	Nitrite (NO_2) (µM)	Phosphate (PO_4) (µM)
Terrace reef	~25 m	55 %	17.6	28.9	-	-	-	-
Rim reef	~25 m	25 %	17.6	29.6	-	-	-	-
Outer lagoonal patch reef	7-10 m	25 %	17.1	29.8	-	-	-	-
Inner lagoonal patch reef	7-10 m	15 %	15.6	30.2	4.800	0.072	0.019	0.037
Castle Harbour	~5 m	5-10 %	15.6	29.8	4.892	0.099	0.023	0.038

The outer-most terrace reefs are the deepest of the Bermuda reefs (10-15 m to the reef). Coral cover is greatest at the terrace reefs (~55 %) and is dominated by (in descending order) *Diploria strigosa*, *Diploria labyrinthiformis*, *Montastraea franksi*, *Montastraea cavernosa* and *Porites astreoides* (Jones 2006). The rim reefs are similar in coral composition but they are shallower (2-10 m to the reef), and coral cover is lower at ~25 % (Jones 2006). Coral cover at lagoonal locations is ~18 % and dominated by *M. franksi*, *D. labyrinthiformis* and *D. strigosa.* In-shore reefs have low coral cover (5-10 %) and are dominated by *D. labyrinthiformis* (Jones 2006).

The inshore basins of Bermuda are broken into three types; Great Sound, which is fairly open to the waters of the north lagoon, Harrington Sound, which is closed apart from one small opening in the south-western corner, and Castle Harbour, which is semi-enclosed with a small opening to the north and some channels to the south opening onto oceanic waters (Fig. 1). The semi-enclosed, in-shore basin of Castle Harbour has an area of 10.5 km^2 (Morris *et al.* 1977) and is located at the northeastern end of the island (Fig. 1). Within the harbour there is a man-made peninsula (constructed as an airport

runway), running approximately north/south. To the west of this is a landfill site for bulk waste and incinerator ash disposal (The Dumpsite) (Barnes and Sterrer 1981). A low causeway linking Saint David's Island to the main island encloses the western-most edge of the harbour. The southeastern edge of the harbour is protected by a chain of small islands, with channels between them. This area is called Castle Roads (Fig. 1). These channels connect the waters of Castle Harbour to the clear waters of the southern rim and terrace reef zones and the Atlantic Ocean. Numerous pinnacle and knoll-like reefs dot the waters of Castle Harbour (as defined by Dryer and Logan 1978), while rim reefs are found along the southwestern perimeter of the harbour. The reefs of Castle Harbour are of particular interest because they are surrounded by land and have been heavily influenced by humans over the years, making their environment historically more subject to change than other reef locations around Bermuda.

Castle Harbour was once noted by early naturalists for its clear waters (Verrill 1902) and numerous patch reefs, with an abundance of large brain coral colonies (*Diploria* spp.) (Agassiz 1895). However, for over a century Castle Harbour has been affected by a succession of anthropogenic activities (Flood *et al.* 2005). In 1871 the construction of a causeway altered the hydrodynamics of the harbour, though appeared to have little affect on the coral communities within (Heilprin 1889; Agassiz 1895; Verrill 1902). Between 1941 and 1943 there were major dredge and landfill operations within the harbour, for the construction of a wartime airbase and runway (what is now Bermuda International Airport) (Block 1969). This resulted in the creation of an additional 3 km^2 of land (Dryer and Logan 1978) and the loss of approximately 5.6 hectares of mangroves, 18.2 hectares of seagrass beds, and 24.4 hectares of coral reef within the harbour (Sterrer and Wingate 1981; Smith 1999). The construction of the runway peninsula additionally altered the hydrology of the harbour basin (Sterrer and Wingate

1981). The changes to the land surrounding Castle Harbour can be seen in Figs. 1. and 2.

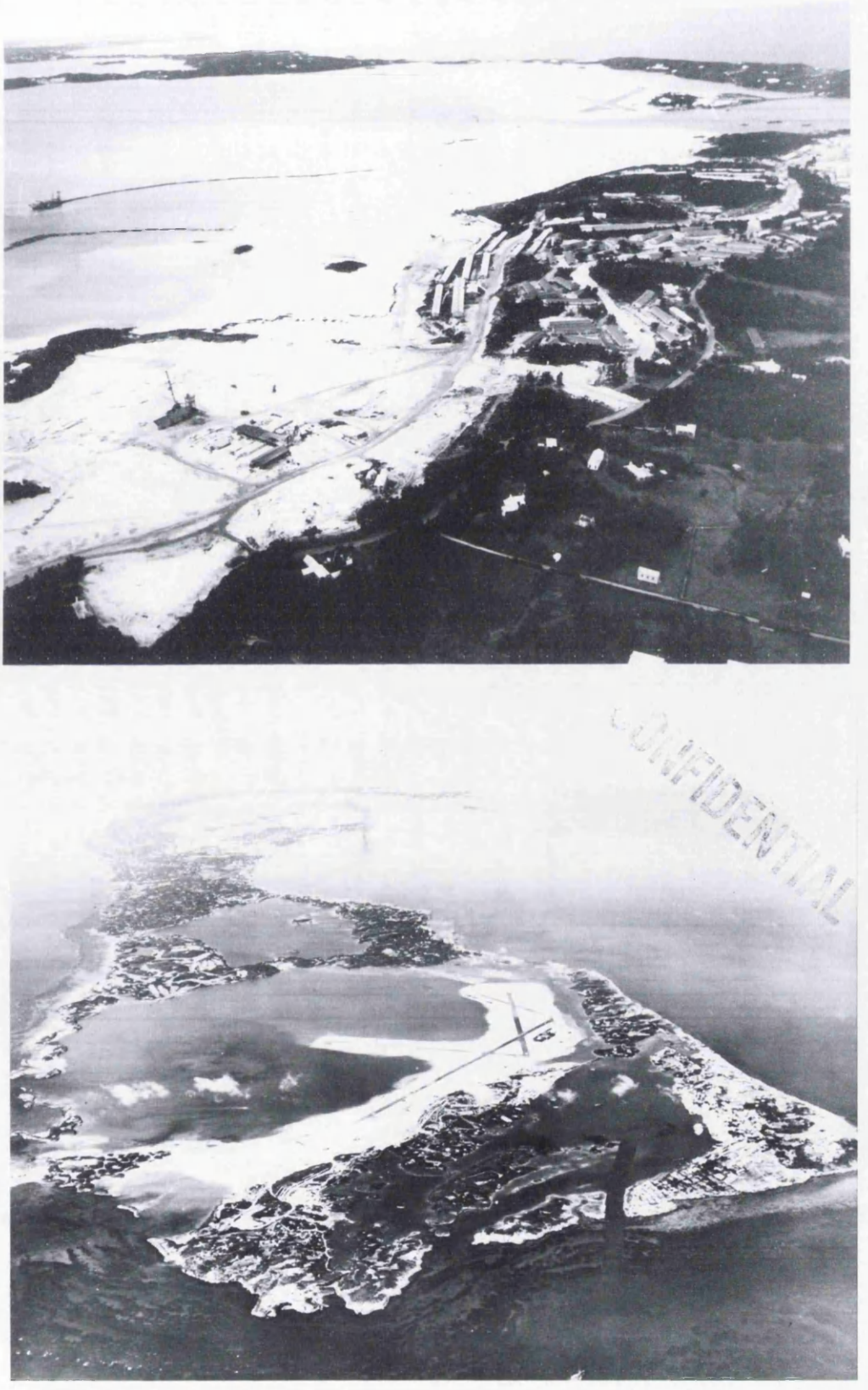


Fig. 2. Photographs of the 1940's dredging operation in Castle Harbour to create 3 km^2 of land for an air force base (now the Bermuda International Airport). Images provided by the Bermuda Maritime Museum.

In 1971 a stretch of land adjacent to the airport was designated as a landfill site for bulk waste; constituting motor vehicles, used tyres, household appliances and construction waste (Barnes and Sterrer 1981). Furthermore, in the mid 1990's the Bermuda Government began disposing of cement-stabilised ash (from a municipal solid waste incinerator) at the airport landfill site.

The dredge and landfill activities in particular were catastrophic for the coral communities in Castle Harbour, drastically altering the marine environment of the harbour (Figs.1 and 2), and causing mass coral mortalities (Dryer and Logan 1978). One of the first studies to document the demise of Castle Harbour's post-dredging coral reef populations was that of Dodge and Vaisnys (1977) who noted reduced coral cover within the harbour when compared to similar reefs outside. They also studied the growth history of dead coral colonies from within the harbour, by examining density growth bands of their skeletons. This showed a period of reduced growth around the time of the airport construction, subsequently followed by total colony death; a common direct response to high turbidity and increased sediment load (Rogers 1990, and references therein). Through their studies on the growth of coral populations within Castle Harbour, Dodge and Vaisnys (1977) suspected that these coral communities were in a phase of repopulation and recovery, and attributed the low coral cover and growth rates to elevated sedimentation and turbidity brought on by the past dredging activities.

A more recent study focusing on the coral reef populations of Castle Harbour was conducted by Flood *et al.* (2005), based on data collected in 2003. They noted that coral cover has remained low in Castle Harbour, not changing significantly since studies by Dodge and Vaisnys (1977) and Dryer and Logan (1978). However, species composition was seen to have changed somewhat since Dryer and Logan's (1978) study; once

composed mainly of *Madracis* spp., the coral communities are now composed mainly of *Diploria labyrinthiformis* (Flood *et al.* 2005). The coral species that have managed to persist in Castle Harbour are mostly those considered to be more sediment tolerant (Hubbard and Pocock 1972; Flood *et al.* 2005), indicating that turbidity and sedimentation may still be shaping the coral reef communities of Castle Harbour more than 60 years after the dredge and landfill activities ceased.

Sedimentation and turbidity can be caused by natural processes such as river outflows and land run-off, but it is the anthropogenic activities of dredging and land-filling that have the most detrimental local impacts on coral reef ecosystems world wide (Rogers 1990; Hughes *et al.* 2003; Wilkinson 2004; Dikou and Van Woesik 2006). Therefore, sedimentation and turbidity are common problems encountered by in-shore reefs worldwide, such as those of Castle Harbour. Dredging and land filling can be responsible for localized coral reef decline, both directly through reef destruction and burial, and indirectly through increases in sedimentation and turbidity (Rogers 1990). Sedimentation and turbidity can reduce coral growth and negatively impact life processes such as coral fecundity, larval metamorphosis and growth (Gilmour 1999), and larval settlement (Babcock and Davies 1991). The impacts of sedimentation and turbidity can be alleviated by strong currents, which flush sediments from an area (Rogers 1982). However, in a semi-enclosed basin, such as Castle Harbour, flow rates are low (Morris *et al.* 1977; Flood *et al.* 2005) meaning that sediment related problems can persist for extended time periods.

Increased sedimentation has been shown to be detrimental to coral health in a variety of ways. In the most extreme situations, direct smothering and burial can cause total coral colony mortality (Bak 1978; Rogers *et al.* 1983; Rogers 1990; Brown 1997). In the long

term, sedimentation and turbidity can have negative effects on coral growth rates by reducing light levels (Bak 1978; Tomascik and Sander 1985; Rogers 1990), which causes decreased rates of zooxanthellae photosynthesis (Dodge and Vaisnys 1977), while energy is expended on cleaning behaviour (Dodge *et al.* 1974). Elevated sediment levels have also been shown to reduce coral fecundity, larval metamorphosis and growth (Gilmour 1999), larval settlement (Babcock and Davies 1991), and juvenile recruitment and ultimate survival (Hunte and Wittenberg 1992). All these factors often result in coral populations that are depauperate, with recovery taking anywhere from 15-100 years, and with the likelihood that the resulting coral population may differ from the original in a number of ways including species composition, and reef-building ability (Done 1999).

In habitats under the influence of adverse environmental conditions, variations in an organism's ability to tolerate these unfavourable conditions and to use available resources play vital roles in structuring community composition (Chesson and Huntly 1997; Emery *et al.* 2001). In such environments, species often live close to thresholds of growth and survival (Anthony and Connolly 2004). However, corals can, and do, occur in a wide range of environmental conditions, *including* near-shore environments characterised by high turbidity and sedimentation rates (Anthony and Connolly 2004). It has been hypothesised that coral species which perform well in high-turbidity areas have greater heterotrophic plasticity, with an ability to adjust their feeding rates to moderate increases in suspended particulate matter, gaining supplementary energy from increases in organic suspended material (Anthony and Fabricius 2000). Coupled with an ability of both zooxanthellae and coral host to photo-acclimate to lower light levels (Falkowski and Dubinsky 1981; Anthony and Hoegh-Guldberg 2003; Anthony and Connolly 2004), allows certain coral species to overcome the metabolic shortfalls

resulting from high sediment, low light environments. Coral species have also been shown to have varying abilities to shed sediment using a variety of methods including use of their tentacles and cilia, stomodeal distension, and mucus production (Hubbard and Pocock 1972). This explains how some species can be sediment tolerant whilst others will quickly perish in similar conditions.

1.2 Characterisation of coral reef substrata

Knowledge of current coral population structure and dynamics allows for a greater understanding of the initial and subsequent impacts past anthropogenic activities have had on a coral reef community (Smith *et al.* 2005). Certain species are better adapted to withstanding various anthropogenic stresses, while some species are more able to recover post-stress (Ginsberg *et al.* 2001; Jones 2004; Garzon-Ferreira *et al.* 2005). Coral species and their abundances can be surveyed *in situ*, but more commonly digital video is used to record known areas of reef, allowing a more detailed and thorough examination of community composition back in the laboratory, using still images and random point count techniques (Aronson *et al.* 1994). Coral Point Count with Excel extensions (CPCe) is a standalone Visual Basic programme which was created to increase the efficiency of such video processing; automating, facilitating, and speeding up the random point count process (Kohler and Gill 2006). This is a great benefit when considering the larges areas of reef that must be surveyed to gain statistically meaningful data.

1.3 Assessing coral condition

Coral condition surveys are conducted to quantify and qualify the health of adult colonies by assessing disease prevalence and lesion formation (partial mortality). These factors (disease and lesion formation) are known to contribute to coral reef declines (Garzon-Ferriera *et al.* 2005). Information on the health of coral communities can be gathered from video surveys or from *in situ* reef surveys. The latter allow for more accurate identification of disease, and better quantification of the proportion of the colony affected, providing more detailed data on the extent of damage to the reef.

During the 1990's a number of publications noted an increase in reports of coral disease (Santavy and Peters 1997; Goreau *et al.* 1998; Hayes and Goreau 1998; Richardson 1998). The Caribbean, in particular, has experienced notable increases in the occurrence of coral disease over the past 20 years (Green and Bruckner 2000), as well as a rapid emergence of 'new' coral diseases (Harvell *et al.* 1999). The cause for this increase is still unclear (Harvell *et al.* 1999; Green and Bruckner 2000). Harvell *et al.* (2002) hypothesised that human activities, global warming trends, and extreme El Niño Southern Oscillation (ENSO) events might be contributing factors with regards to the emergence of new marine diseases. It has been shown that in both marine and terrestrial environments, elevated temperatures can increase pathogen development, transmission and growth rates, while decreasing host resistance, which can have direct impacts on abundance and geographic range of pathogens (Harvell *et al.* 2002). Other studies have also implicated coral bleaching as cause for increased disease prevalence, through a weakening of the coral's defenses (Harvell *et al.* 2001). Current research is focusing on the microbial communities associated with corals, and the roles these play in the manifestation of coral diseases (Ainsworth *et al.* 2007; Klaus *et al.* 2007; Rosenberg *et al.* 2007).

There are presently about 30 names for the various coral diseases. However, in some instances names have been allocated based on few observations, leading to uncertainty over whether differently named diseases are in fact the same (Green and Bruckner 2000). Generally accepted major hard coral diseases include black band disease (BBD, Antonius 1973), white plague (Dustan 1977), white plague type II (Zorpette 1995) and type III (Richardson and Aronson 2001), yellow blotch/band disease (Reeves 1994) and white pox (Patterson *et al.* 2002). Status of the 'new' coral diseases is currently uncertain (Richardson 1998).

Several studies have examined coral disease in Bermuda, describing black band disease, white plague (mainly white plague type II; Weil *et al.* 2000), yellow blotch/band disease on hard corals, and aspergillosis in sea fans (Garrett and Ducklow 1975; Rutzler and Santavy 1983; McKinney 1998; Rohwer *et al.* 2002), all at relatively low levels (i.e. ~1% prevalence, Weil *et al.* 2000). For these coral diseases there is evidence to suggest a close relationship between prevalence and elevated seawater temperatures (Antonius 1981; Kuta and Richardson 1996; Richardson 1998; Alker *et al.* 2001; Harvell *et al.* 2002, Ward *et al.* 2007), and increased sedimentation (Antonius 1988; Bruckner *et al.* 1997). In Bermuda, summer surface seawater temperatures have the tendency to be higher near-shore compared to off-shore (Jones 2005, 2006), while sedimentation and turbidity have been suspected problems for the corals in Castle Harbour ever since the dredging activities of the 1940's (Dodge and Vaisnys 1977; Dryer and Logan 1978; Flood *et al.* 2005). Therefore, it would be reasonable to assume that coral disease has the potential to be highly detrimental to the already devastated coral populations within Castle Harbour. The diseases most frequently seen on the major reef-building coral species in Bermuda are white plague disease and black band disease (Jones 2004, 2005,

2006). As such, the current study will pay particular attention to the prevalence of these diseases on Bermuda's reefs.

Lesion formation is another aspect of coral health to consider. Corals are colonial organisms, and can thus survive the loss of portions of their tissue; this attribute is termed partial mortality (Hughes and Jackson 1980; Babcock and Davies 1991; Nugues and Roberts 2003a). Partial coral colony mortality can be caused by a variety of factors including disease, bio-erosion, physical disturbance and sedimentation (Bak 1978; Rogers 1990; Nugues and Roberts 2003a; Wielgus *et al.* 2004; Garzon-Ferreira *et al.* 2005). Past studies have shown different Caribbean coral species to have varying abilities to resist or recover from damage to their tissues that can result in partial mortality; *Diploria* spp. and *Montastraea cavernosa* being least susceptible to partial colony mortality (Ginsberg *et al.* 2001; Garzon-Ferreira *et al.* 2005). The longer a coral colony exists, and therefore the larger it grows, the more likely a colony is to experience one or more of the above mentioned traumas (Ginsberg *et al.* 2001). Thus, larger colonies are more susceptible to partial mortality than smaller ones. This trend has been shown to be much less pronounced for *Diploria* spp., possibly because of an enhanced ability to overcome such disturbances with increasing colony size (Meesters *et al.* 1996). *Diploria* spp. are the dominant coral species in Bermuda's reefs, therefore the current study will pay particular attention to them with regards to partial mortality.

1.4 Quantification and qualification of hard coral settlement

Along with documenting coral population structures, another factor to address is population dynamics; the ability of corals to sexually reproduce and recruit to the reefs effectively, thus ensuring continuation of the population. Coral larval settlement,

recruitment and survival of juvenile corals are the end products of reproduction, and these processes play key roles in shaping coral community structure especially following periods of disturbance (Connell 1985; Hughes 1996; Glassom *et al.* 2006; Vermeij 2006). Coral settlement is one step of these vital processes and refers to the settlement of coral larvae to the reef substrate after a planktonic period. These stages of settlement and recruitment tell us most about the success or failure of sexual coral reproduction, with any disruption to these processes, or those prior, leading to unsuccessful recruitment to the reefs, and dwindling coral populations.

Coral larvae do not settle randomly (Lewis 1974a; Morse *et al.* 1988; Resing and Best 1988; Harrison and Wallace 1990; Babcock and Mundy 1996), with settlement studies demonstrating the high variability in settlement rates between reef areas and even within the same reef (Glassom *et al.* 2004). Factors such as illumination (Birkeland *et al.* 1981; Wallace 1985; Harriott and Fisk 1987), substrate type and orientation (Birkeland *et al.* 1981; Neudecker 1981; Harriott 1985; Van Moorsel 1985; Carleton and Sammarco 1987; Harriott and Fisk 1987), algal type and abundance (Birkeland 1977; Van Moorsel 1985; Birrell *et al.* 2005; Kuffner *et al.* 2006), and sedimentation and grazing pressure (Dart 1972; Brock 1979; Sammarco and Carleton 1981; Gleason 1996) all have significant effects on larval settlement and subsequent survival, making coral settlement location dependent (Birkeland 1977; Harriott 1992; Babcock and Mundy 1996; Smith 1997; Edmunds *et al.* 2004). Coral larval settlement and metamorphosis are optimised on biologically conditioned surfaces, which provide important chemical and physical cues for coral larval settlement and metamorphosis (Morse *et al.* 1988; Harrington *et al.* 2004; Webster *et al.* 2004).

Quantifying coral larval settlement in the field can be difficult since it is often hard to detect newly settled larvae because of their small size and often cryptic settlement (Babcock 1985; Fitzhardinge 1988). Mortality rates of newly settled corals are high (Babcock and Mundy 1996), making visible patterns of recruitment to reef substrata asymptomatic of settlement rates (Babcock *et al.* 2003). In these cases, only recruitment can be measured (rather than settlement), which Connell (1985) defines as "...the recently settled juveniles that have survived a period of time after settling...". Removable artificial settlement substrates, as used in this study, overcome this problem since as long as a coral is not overgrown or abraded then its skeleton provides a catalogue of its settlement, regardless of whether it survived. A number of settlement studies, using a variety of substrates, have been conducted on reefs throughout the world's oceans. These include the use of unglazed tiles (Harriott and Fisk 1987; Gleason 1996; Glassom *et al.* 2006), glazed tiles (Harriott and Fisk 1987), dead coral (Harriott and Fisk 1987; Sammarco 1991; Birrell *et al.* 2005), Petri dishes (Harriott and Fisk 1987) concrete blocks (Lam 2003), clay blocks and tiles (Petersen *et al.* 2005), and Formica plates (Vermeij 2006). Past comparisons of artificial settlement substrates have shown ceramic tiles to attract the largest number of spat (Harriott and Fisk 1987). Other important benefits of using ceramic tiles include the ease with which they can be searched for recruits (likelihood of recruits being seen on first inspection under low power magnification) and that settled colonies on ceramic tiles tend to grow larger than recruits on other artificial surfaces over the same period of time, again making searching and identification easier (Harriott and Fisk 1987).

Past studies of coral spawning and coral larval settlement around Bermuda have provided baseline information on these processes on the reefs of the Bermuda platform. Studies by Wyers *et al.* (1991) and de Putron (2003) indicate coral spawning in

Bermuda occurs during the months of July, August and September, while two previous settlement studies in Bermuda, located at the northern rim reef zone, showed that settlement to this reef environment occurred on both horizontal and vertical ceramic tile surfaces, and was dominated by brooding species (Smith 1985, 1988). This settlement study is a pilot study to test the tile array design, and to document the rates of coral larval settlement across all of Bermuda's reef zones. Such data can provide essential information on where coral settlement is occurring, and whether this important process of the coral's life cycle is compromised. Information on identification of newly settled corals are few (Baird and Babcock 2000; Babcock *et al.* 2003), however, studies on settlement and corallite development of hard coral species found in Bermuda are currently being conducted by S. de Putron (pers. comm.) of the Bermuda Institute of Ocean Sciences.

1.5 Quantification and qualification of hard coral growth and survival within Castle Harbour

Survival of settled corals is vital to coral reef survival and recovery (Harriott and Fisk 1987; Harrington *et al.* 2004), as such juvenile coral recruitment to the reefs is the next of the life history stages to be monitored. This follow up monitoring of growth and survival of corals on areas of reef substrata is best done *in situ*, rather than through video or photography techniques, as again, juvenile corals can be very difficult to locate because of their small size and often cryptic nature (Babcock 1985; Fitzhardinge 1988). Permanent quadrats provide a means to manually survey the same small area of reef year to year, allowing recruitment to be quantified and qualified, and growth or mortality of individuals to be recorded (Hughes and Jackson 1985; Smith 1992; Smith 1997; Miller *et al.* 2000).

Permanent quadrat studies have shown that juvenile coral species composition and relative abundance often do not reflect that of adult populations (Smith 1997). On Atlantic reefs studies have shown that brooding corals, such as poritiids and agariciids, often dominate juvenile coral populations. However, these brooding coral species are found to contribute only a small proportion to adult cover, whilst broadcast spawning species, that often dominate the adult reef framework (e.g. *Diploria* and *Montastraea* spp.), show much lower levels of recruitment (Smith 1997). This relationship between reproductive mode and subsequent dominance of the recruit populations has been seen in a number of studies (Bak and Engel 1979; Rogers *et al.* 1984; Hunte and Wittenberg 1992; Smith 1992, 1997; Vermeij 2006).

Permanent quadrats can also be used to gain information on adult coral colony growth, partial mortality and death. High-resolution photography of quadrats allows two-dimensional calculations of surface area (of either living or dead colony areas) to be made, using computer based software.

1.6 *Diploria* spp. demographics determined by size

Coral's life history processes are affected by their environment and this is represented in the size structure of the population (Meesters *et al.* 2001). Looking at coral size frequency distributions can provide valuable information about ecological processes at various life history stages, and the effects of these on the population as a whole (Bak and Meesters 1998). Frequency parameters such as skewness and kurtosis are valuable indicators of the effects of ecological processes on populations (Underwood 1997a; Meesters *et al.* 2001), where values can indicate dominance or a lack of size groups

within the population. A healthy reef will probably have high coral cover, with a high proportion of small size classes, which includes new recruits and juveniles, and relatively few representatives in the larger size classes (Bak and Meesters 1998; Meesters *et al.* 2001). This population would typically be skewed slightly to the left as a result. Recruits and juvenile corals are vital to population maintenance but contribute little to percentage cover. Therefore, their importance is often overlooked when only assessments of coral cover are used to asses reef health (Smith *et al.* 2005).

Breaking down present day coral populations into size groups puts equal weighting on all colony sizes, allowing a clearer picture of the population to emerge. These kind of data can provide insight into long-term consequences of environmentally sensitive life history processes (Meesters *et al.* 2001), which may be correlated to known events. To enable size frequency data to be meaningfully correlated to past events, it is necessary to have sufficient coral species subjects and to be able to age them. *Diploria* spp. are the dominant massive coral species on the reefs of Bermuda, and within Castle Harbour. Although the reefs inside Castle Harbour are now considered depauperate (Flood *et al.* 2005), *Diploria* spp. were once considered abundant within the harbour (Agassiz 1895). In addition, these species have been the subject of coral growth studies in Bermuda for a number of years (Dodge and Vaisnys 1977; Logan *et al.* 1994; Cohen *et al.* 2004; Goodkin *et al.* 2005; A. Cohen pers. comm.). This means that reasonable estimates of colony age can be made. Previous studies have also shown interesting differences in the ratio of these two congeners inside Castle Harbour when compared to the rest of the Bermuda reef platform (Dodge and Vaisnys 1977; Dryer and Logan 1978; Flood *et al.* 2005), which makes them an interesting subject to study. These factors combined make *Diploria strigosa* and *Diploria labyrinthiformis* appropriate species subjects for the demographic study.

Using data gathered on growth and survival at each life history stage of Castle Harbour's coral populations, a basic model of coral population change at two contrasting locations within Castle Harbour, over time will be constructed. Models can be used to project, rather than predict, future community changes under a variety of biotic and abiotic conditions (Caswell 1989; Bierzychudek 1999; Ebert 1999).

1.7 Objectives of thesis

Coral reefs are one of the most diverse environments in the world (Connell 1978), and they have proved themselves to be commercially valuable ecosystems in a number of ways (Moberg and Folke 1999). It has been well established that coral reefs are on a downward spiral of degradation and decline (Wilkinson 1998, 1999, 2000, 2002, 2004; Gardner *et al.* 2003; Hughes *et al.* 2003; Pandolfi *et al.* 2003; Bellwood *et al.* 2004), with human activities often to blame (Goreau 1992; Sebens 1994; Wilkinson and Buddemeier 1994; Hughes *et al.* 2003). There is increasing pressure to understand the interplay of the processes involved in this global coral reef decline (Wilkinson 1999). Dredging and land-filling have been shown to have the most detrimental local impacts on coral reef ecosystems world wide (Rogers 1990; Hughes *et al.* 2003; Wilkinson 2004; Dikou and Van Woesik 2006), and are therefore a global problem that needs to be tackled on the local scale.

The aim of this thesis was to document some of the long-term effects of a catastrophic dredge and landfill event on the high latitude coral reefs of a semi-enclosed body of water. This study used multiple survey techniques to examine a variety of hard coral life history stages, including larval settlement, and juvenile and adult survival, and to

investigate the size and age demographics of the dominant coral species populations found within Castle Harbour. The objectives of this thesis were as follows:

- It was hypothesised that coral cover and species diversity would be lower within the harbour when compared to similar reefs outside the harbour so the first objective was to quantify and qualify these parameters.
- In addition, coral health inside Castle Harbour was expected to be poor in comparison to reefs unaffected by the dredging activities, so quantification and qualification of this was done, and comparisons to locations unaffected by the dredging activities were made.
- To identify if, and at which life history stage the coral populations of Castle Harbour are compromised, biological processes of larval settlement, coral growth, partial colony mortality, and total colony mortality at juvenile and adult life history were documented.
- To identify any recovery the coral reefs of Castle Harbour may have undergone since the dredging activities through comparisons with past studies.
- Plot the demographics according to size/age of the dominant reef building species in an attempt to better understand what happened to these communities as a result of the dredging activities.
- To start the process of modelling projected futures for these reefs through processing of initial data gathered on coral community dynamics.
- Through recognition of which coral life history stages are compromised recommendations for future research and restoration studies will be made.

By providing data on this snapshot in time it will enable future studies to make detailed comparisons, and better follow the potential recovery of all life stages of the coral populations of Castle Harbour.

Chapter 2: Materials and methods

2.1 Study location

Seven locations within Castle Harbour were chosen to represent variation in conditions across the harbour (Fig. 3). Five additional locations, distributed north and south across the Bermuda reef platform, were used for comparison (NR, OL, ST Fig. 3, and IL, SR, inset Fig. 3). A 'location' is the general area (e.g. 1), and the 'sites' refer to the two study reefs within that location (e.g. 1a and 1b). Site names and details can be seen in Tables 1 and 2. All fieldwork for this study was conducted using SCUBA.

2.2 Characterisation of coral reef substrata

Adult coral cover and composition were determined using standard video monitoring techniques (Aronson *et al.* 1994). Ten × 30 m transects were surveyed at each of the seven locations inside Castle Harbour, and the five locations outside the harbour (Fig. 3 and Table). Inside Castle Harbour, where reefs are smaller and pinnacle-like (Dryer and Logan, 1978), transects were laid from the reef base, spiralled up around the reef sides for ~15 m and then extended onto the reef top for the remaining ~15 m. Outside Castle Harbour, where reefs were larger and flatter, transects were laid parallel to each other along the reef (~ 5-10 m apart). A SCUBA diver slowly (~3 m min^{-1}) videotaped the reef to the left-hand side of the transect line using a DCR SONY TRV900 MiniDV (Sony corporation, Tokyo, Japan) digital video recorder mounted in an Amphibico Dive Buddy™ underwater video housing (for a DCR SONY TRV900) (Amphibico Inc., Quebec, Canada).

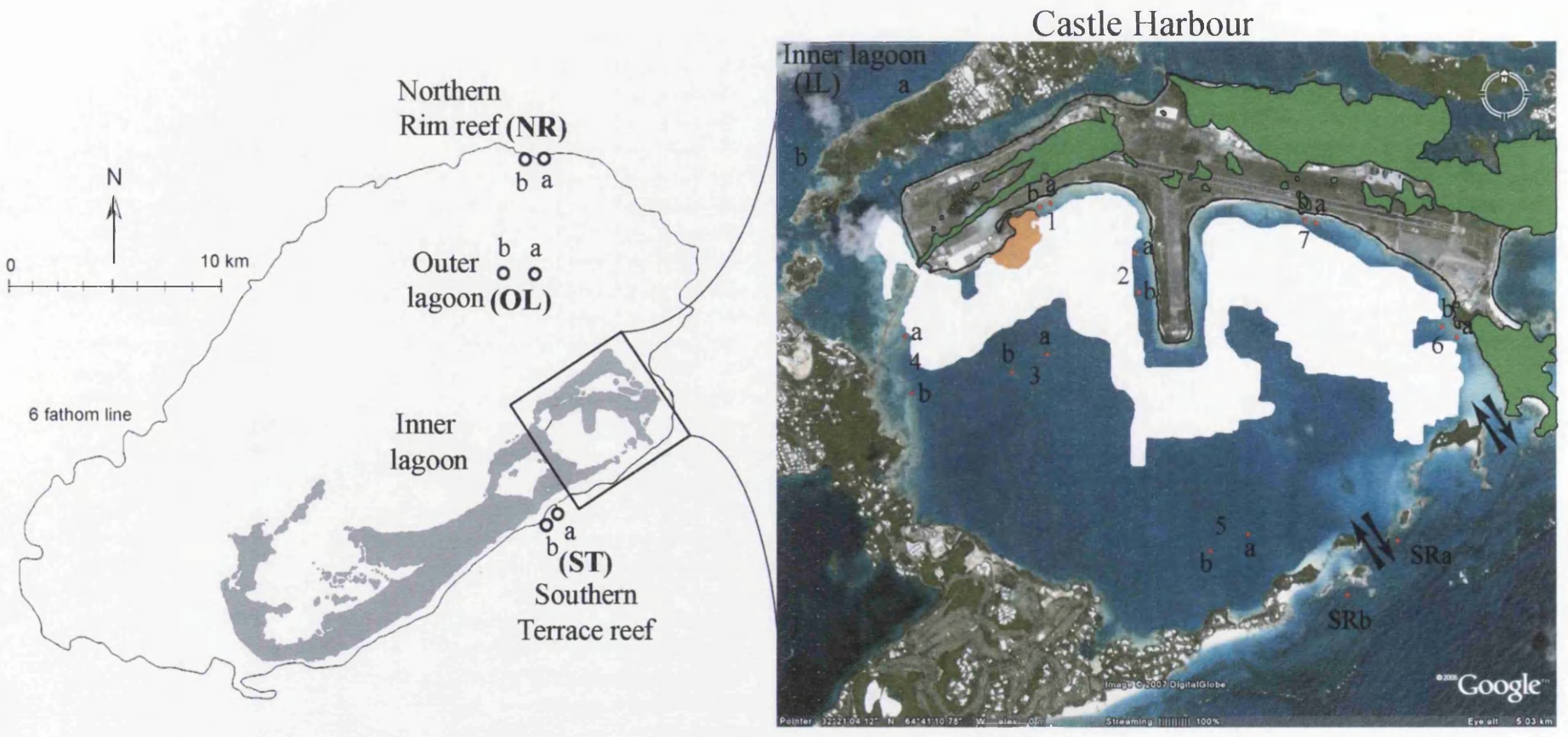


Fig. 3 Map showing the position of the study locations across the Bermuda reef platform and within Castle Harbour (inset). Each location is composed of two sites (a and b). Green areas indicate natural landmasses encompassed by landfill activities, white indicates the area dredged to provide landfill, orange indicates the dumpsite. Arrows indicate points and direction of major water exchange with the open ocean. Satellite image of Castle Harbour from Google Earth (http://earth.google.com/index.html), remainder of image provided by the Marine Environmental Program (MEP), at the Bermuda Institute for Ocean Sciences (BIOS). Image modified by Helen Brylewska.

Table 2 Site names, abbreviations, approximate reef depth, GPS coordinates and studies conducted at all sites within and outside Castle Harbour (marked with an X).

Full Site Name	Site Name	Reef Zone	Approximate Depth of Reef (m)	Latitude (N)	Longitude (W)	Video Surveys	Coral Condition Surveys	Permanent Quadrat Study	Settlement Study	*Diploria* spp. Demographic
Castle Harbour Dump East	1a	Castle Harbour	<6.0	32°21.768	064°41.700	X	X		X	X
Castle Harbour Dump West	1b	Castle Harbour	<6.0	32°21.748	064°41.763	X	X		X	X
Castle Harbour Peninsula East	2a	Castle Harbour	<6.0	32°21.576	064°41.320	X	X	X	X	X
Castle Harbour Peninsula West	2b	Castle Harbour	<6.0	32°21.429	064°41.304	X	X	X	X	X
Castle Harbour Middle East	3a	Castle Harbour	<6.0	32°21.170	064°41.738	X	X		X	X
Castle Harbour Middle West	3b	Castle Harbour	<6.0	32°21.113	064°41.899	X	X		X	X
Castle Harbour Fringing East	4a	Castle Harbour	<6.0	32°21.261	064°42.406	X	X		X	X
Castle Harbour Fringing West	4b	Castle Harbour	<6.0	32°21.024	064°42.361	X	X		X	X
Castle Harbour Tucker's East	5a	Castle Harbour	<6.0	32°20.455	064°40.787	X	X	X	X	X
Castle Harbour Tucker's West	5b	Castle Harbour	<6.0	32°20.404	064°40.946	X	X	X	X	X
Castle Harbour A West	6a	Castle Harbour	<6.0	32°21.293	064°39.893	X	X			X
Castle Harbour A East	6b	Castle Harbour	<6.0	32°21.238	064°39.790	X	X			X
Castle Harbour B West	7a	Castle Harbour	<6.0	32°21.702	064°40.518	X	X			X
Castle Harbour B East	7b	Castle Harbour	<6.0	32°21.682	064°40.445	X	X			X
North East Breakers East	NRa	Northern Rim	9.1	32°28.887	064°41.916	X	X		X	X
North East Breakers West	NRb	Northern Rim	6.4	32°28.808	064°42.251	X	X		X	X
Three Hill Shoals East	OLa	Outer Lagoon	7.3	32°25.511	064°42.316	X	X		X	X
Three Hill Shoals West	OLb	Outer Lagoon	7.0	32°25.583	064°43.574	X	X		X	X
Whalebone Bay East	ILa	Inner Lagoon	7.0	32°22.252	064°42.433	X	X		X	X
Whalebone Bay West	ILb	Inner Lagoon	4.5	32°21.968	064°42.886	X	X		X	X
Gurnet East	SRa	Southern Rim	6.0-11.0	32°20.426	064°40.021	X	X		X	X
Gurnet West	SRb	Southern Rim	6.0-11.0	32°20.203	064°40.314	X	X		X	X
John Smith's Bay East	STa	Southern Terrace	12.2	32°18.929	064°42.536	X	X		X	
John Smith's Bay West	STb	Southern Terrace	13.7	32°18.749	064°42.572	X	X		X	

Filming was conducted at an approximate distance of 40 cm from the reef. A thin, metal bar attached to and projecting forwards from the video housing, was held just above reef level during filming to ensure the camera was held a constant distance from the substratum (Aronson *et al.* 1994). With the camera set at its widest angle of view, a field of view 40 cm wide resulted. Filming was conducted perpendicular to, and following the contours of the substrata. In total, 120 square meters of reef were recorded per location.

In the laboratory, 50 non-overlapping, still frames were captured from each video transect using Premiere Video Editing Software (Adobe Systems, Inc., California, USA). On each image 10 randomly distributed points were overlain (producing 500 points per transect, 5000 points per location) using CPCe (Coral Point Count with Excel extensions (Kohler and Gill 2006), National Coral Reef Institute, Florida, USA). Coral species/substrate under-laying these points were then identified (Fig. 4). Eleven benthic categories specific to Bermuda were devised for CPCe analysis. These were 'corals', 'gorgonians', 'zoanthids', 'sponges', 'other live animals', 'macro-algae', 'turf algae' and 'coralline algae', as well as 'dead coral with algae', 'sand, rock or rubble' and 'indeterminate'. Organisms within each category were identified to the highest level of taxonomic certainty. During image processing, if the marker point overlaid a colony with bleached or diseased tissues this was also recorded.

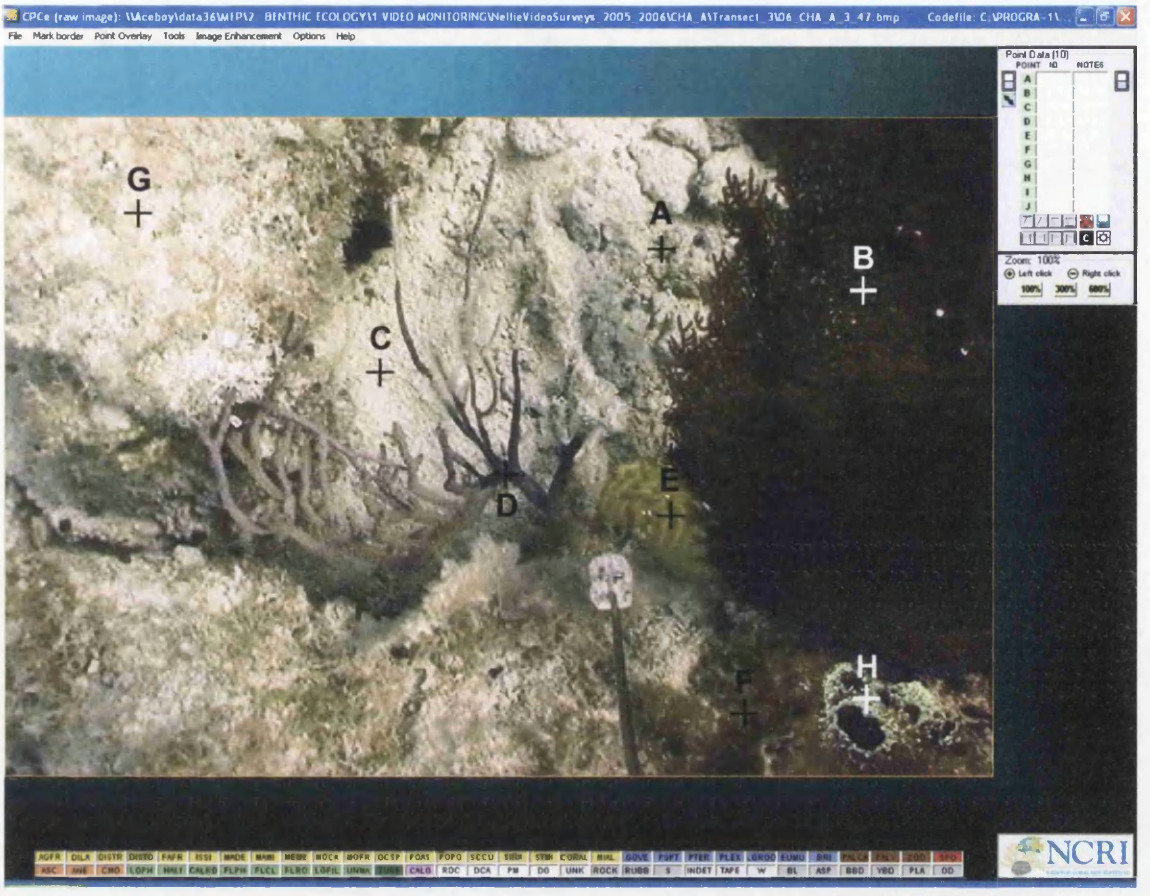


Fig. 4 Representative example of a CPCe still image for video analysis showing A) Rubble, B) Gorgonian (sea fan), C) Sand, D) Gorgonian (sea rod), E) Coral (*Diploria strigosa*), F) Macro-algae, G) Turf algae, H) Sponge. For simplification only eight of the eleven categories are illustrated here.

2.3 Assessing coral condition

An assessment of partial coral colony mortality, incidence and prevalence of coral disease, and extent and severity of any coral bleaching was made using the same locations and transects as those used for video surveys (Table). Survey sheets printed on underwater paper contained the major scleractinian and gorgonian coral species with categories for 'healthy', 'partial mortality of < 50 %', 'partial mortality of > 50 %' and 'diseased'. Partial mortality was defined as 'an area of recently dead coral overgrown by algae but with coral skeleton still clearly visible, or any old mortality completely surrounded by living tissue of one colony'. For the categories of 'partial mortality' and 'diseased' the size of the colony, and percentage of the colony affected were noted

along with the disease type (if applicable). Depending on the density of corals, the area surveyed consisted of either a 1 m band along the left side of the transect tape only (locations NR, ST and SR), resulting in a survey area of 300 square meters per location, or a 1 m band on both sides of the transect line (locations OL, IL, and all locations inside Castle Harbour), resulting in a survey area of 600 square meters per location.

2.4 Quantification and qualification of hard coral settlement

Data on hard coral settlement at five locations inside Castle Harbour and five locations outside were collected in this study. Unglazed, ceramic quarry tiles (American Olean, Quarry Naturals®, colour N01-Lava red) were chosen for this coral larval settlement study because past comparisons of artificial settlement substrates have shown them to be superior (Harriott and Fisk 1987). Tiles with dimensions 6"× 6"× ½" (approximately 450 cm^2 total surface area) were used for this study. This tile size is frequently used in settlement studies (Birkeland *et al.* 1981; Fisk and Harriott 1990; Gleason 1996; Smith 1997), and most importantly, has been used for previous studies in Bermuda (Smith 1985, 1988), which makes direct comparisons to past data far easier. The tiles were smooth on one side, with regular, shallow (~1 mm) grooves on the other (a common construction feature). To mount the tiles and provide a sturdy, low impact method of attachment to the reef, a rack/array system was used. A variety of methods can be used to attach tiles to the reef substrate (Harriott and Fisk 1987), however, a rack/array system is the method used in previous settlement studies on Bermuda's reefs (Smith 1985, 1988, 1992). Frames to hold the settlement tiles were constructed using unthreaded 1" (internal diameter) PVC piping and corresponding 'T' joints. The piping was cut to size (7" each arm) and glued into the joints using PVC cement. A ¾" hole was cut into the top, centre of the 'T' joint to allow the concrete-reinforcing-bar (rebar) to protrude, and a ¼" hole was drilled to either side of that to accommodate cable ties

for attachment (inset Fig. 5). The frame and attached tiles combined will subsequently be referred to as an array.

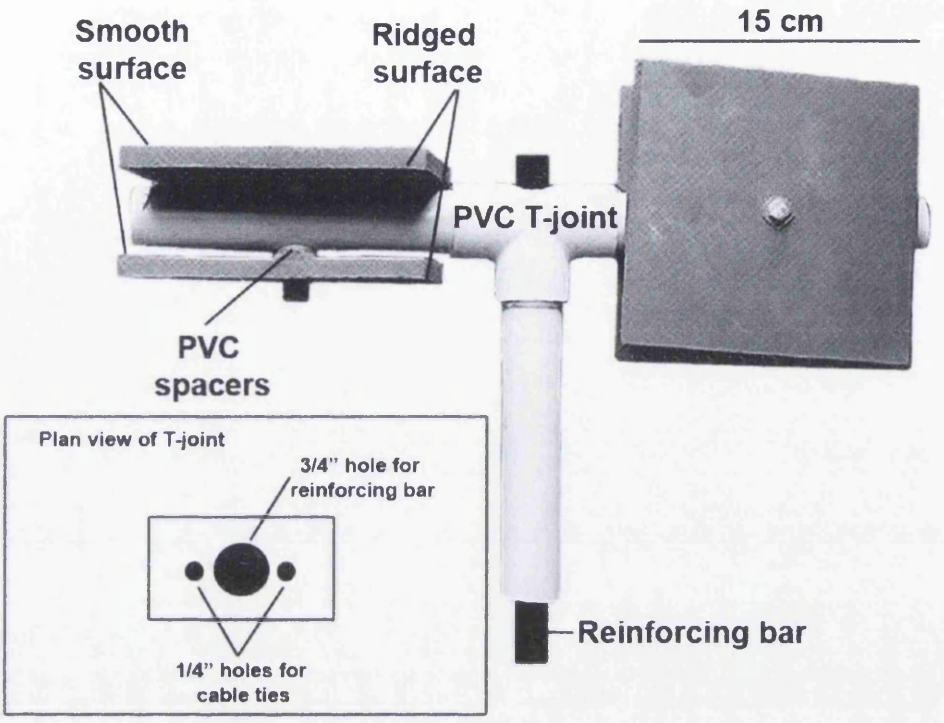


Fig. 5 Array design showing tile attachment and orientation. The insert to the bottom left illustrates the hole arrangement in the top of the PVC T-joint, allowing the frame to be placed over, and attached to the rebar bar. Figure created by Helen Brylewska.

Four tiles were mounted on each PVC frame using ¼"× 3½" stainless steel bolts, ¼" nylon insert lock-nuts, and ¼" washers. Each array consisted of one pair of horizontal tiles and one pair of vertical tiles sandwiched together around each PVC arm, using PVC washers as spacers. A ~4 cm gap resulted between the tiles. The vertical tiles were oriented such that one smooth and one grooved surface faced into the gap. The grooved surfaces of both the horizontal tiles were oriented downwards. This method of tile attachment provides variations in substrate orientation and conditions, vital when a variety of coral species are being targeted. In this study, settlement tiles are being deployed at locations representing all reef zones of the Bermuda platform, encompassing a variety of depth and environmental conditions, therefore it is important

for this study to offer a variety of surface conditions for settlement. If the results from this study indicate a distinct preference of substrate orientation, the frame design can be modified as necessary for future studies. To attach the frames to the reef, ¾" × 20" rebar stakes were hammered into bare patches of reef, and cemented at their base using a 7:1 ratio of builder's cement: plaster of Paris. The arrays were then placed over the rebar stakes (so the rebar emerged through the hole in the top of the 'T' joint) (Fig. 5 and Fig. 6) and secured using plastic cable ties; one looped around the rebar and another two looping through this then through the ¼" holes on the T-joint. This study was conducted at five locations within Castle Harbour and five locations outside the harbour (Table); in total 10 locations, with 10 arrays per location.

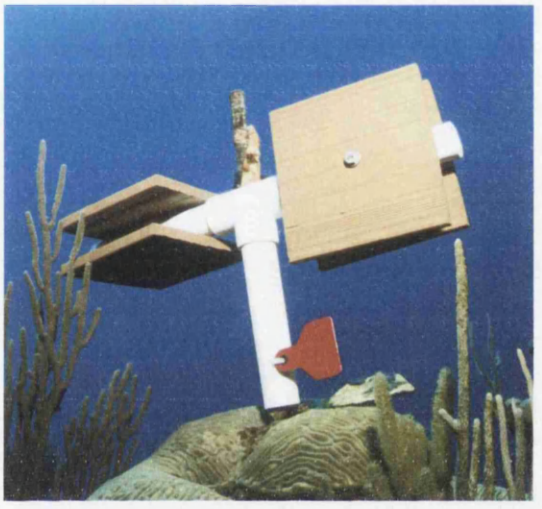


Fig. 6 *In situ* array at John Smith's Bay (ST). The rebar stake is cemented into a patch of partial mortality. Photograph by Alex Venn.

Tiles were deployed between the 12th to 18th May 2005, to allow a 'bio-film' (Morse *et al.* 1988; Harrington *et al.* 2004; Webster *et al.* 2004) to accumulate on the tiles surface prior to the spawning events. Tiles were retrieved between the 27th October and 8th November 2005, approximately 5-6 weeks after the last possible spawning event of Bermuda's corals (Wyers *et al.* 1991); in total, a 24-week deployment. Upon retrieval, the tiles were removed from the PVC frames and bleached in dilute (~10 %) hypochlorite solution for 48 hr to remove any algae and soft tissues (coral tissue, sponges, tunicates, worms, etc), rinsed in freshwater and dried outside on metal dish racks. Tiles were then examined under a dissecting microscope for coral skeletons,

which were often <1 mm in size. A scaled, digital photograph was taken of each individual, at a resolution of 500 pixels/inch. These images were later used to measure (using ImageJ software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2006.) and identify recruits to family-level or genus-level whenever possible. Only *Porites* spp. could be identified with any level of certainty. Other categories included '*Favia*-like' and *Siderastrea*-like'. The majority of spat went unidentified (Section 4.3). Studies on settlement and corallite development of hard coral species found in Bermuda are currently being conducted by S. de Putron (pers. comm.) of the Bermuda Institute of Ocean Sciences, and when complete, will allow further information to be drawn from this study. So far development of *Porites astreoides, Favia fragum* and *Siderastrea* spp. have been documented, though *Siderastrea* spp. have been found difficult to distinguish because of wide variations in their skeletal development. Studies on *Diploria* spp. and *Montastraea* spp. are ongoing. As such, identification to genus level is only possible at present for *P. astreoides* and *F. fragum.*

2.5 Quantification and qualification of hard coral growth and survival within Castle Harbour

Recruitment of hard corals to the reefs of Castle Harbour, and growth of juvenile hard coral colonies (those visible to the naked eye and up to 50 mm diameter) were determined with the use of permanent, 0.7 m^2 quadrats. A quadrat size of 0.7 m^2 was used since these permanent quadrats were already established as part of a long term monitoring programme on the reefs of Bermuda, first set up by S. R. Smith in 1999. This study was conducted at two locations within Castle Harbour (2 and 5) Fig. 3 and Table), representing a gradient of proximity to the potential effects of the dumpsite and

past dredging activities. In total, there were 48 quadrats at each location. Each quadrat was marked using a metal pin hammered into two corners, and identified with a numbered, plastic cattle tag (Universal Ear Tag, Ritchey Sales, Colorado, USA) and its position marked on a site map for easy location. The quadrats were surveyed by eye for juvenile corals, during 2004 (19th November to 2nd December), 2005 (11th August to 1st September) and 2006 (16th May to 19th May). All juvenile coral colonies within the quadrats were identified to species level, measured with callipers (longest linear dimension), and their location within the quadrat recorded on a printed and laminated photograph of the quadrat (see next paragraph) for easier location of the individual in subsequent years. Measurements of juvenile colonies were used to calculate two-dimensional surface area, which was in turn used to determine whether colonies increased in surface area (grew), or decreased in surface area through partial mortality (shrank) between years. Only massive or encrusting hard coral species were monitored since it was often difficult to distinguish a branching juvenile coral from an adult coral fragment.

Quadrats were photographed using a Nikonos V 35mm underwater camera (Nikon) with four Ikelite Substrobe DS-50 underwater strobes (Ikelite Underwater Systems, Indiana, USA), attached to a frame (Fig. 7). This ensured the camera

Fig. 7 Camera and strobe frame configuration for photographing the permanent quadrats. Image by the Marine Environmental Program (MEP) at the Bermuda Institute of Ocean Science (BIOS).

could be consistently oriented to the reef with a constant field of view, and repositioned exactly relative to the quadrat markers in subsequent years. The photographs were used to get a two-dimensional estimate of adult (> 50 mm diameter) colony surface area using ImageJ software (Rasband, W.S., ImageJ, U. S. National Institutes of Health, Bethesda, Maryland, USA, http://rsb.info.nih.gov/ij/, 1997-2006.). ImageJ allows scaling of a JPEG image from which you can then calculate 2-dimensional surface areas. Photographs were also used to mark the locations of juveniles recorded during the juvenile surveys.

Modelling simulations were performed using STELLA™ 7.0, a high-level visual-oriented software and simulation language (STELLA®, 2000). Observed rates of growth and mortality from each life history stage were used to construct the model. Settlement data were not included in the model, as rates of post-settlement mortality were not deduced in this study.

2.6 *Diploria* spp. demographics determined by size

At each of the seven locations inside Castle Harbour and four locations outside the harbour (Fig. 3 and Table), surveys were conducted of size class distributions of brain coral species, *Diploria strigosa* (Dana, 1848) and *Diploria labyrinthiformis* (Linnaeus, 1758). Ten transects of varying length were surveyed at each location. The length of transect was dependant on *Diploria* spp. density, with the aim being to survey ~200 corals at each location. Within Castle Harbour, where coral densities were low, 30 m × 2 m belt transects were surveyed (totalling 600 square meters per location). Outside the harbour at NR, OL and IL 30 m × 1 m belt transects were surveyed (totalling 300 m square meters per location), and at SR 10 m × 1 m belt transect were surveyed (totalling

100 square meters per location). Longest diameter (L), diameter perpendicular to this (W) and height (H) were measured for all *Diploria* spp. within the survey areas using a flexible tailor's tape measure. These measurements were used to calculate colony surface area using the following equation:

$$\text{Surface area} = 2\pi\left(\left(\sqrt{\frac{(r_A^2)+(r_B^2)}{2}}\right)h\right)$$

r_A = radius based on length

r_B = radius based on width

h = height

Once surface area had been calculated, a ln(+1) transformation was then applied to the surface area data to obtain 'normal' distributions (Bak and Meesters 1998). Data were divided into arbitrary groups of equal size so that size frequency distributions could be plotted. To approximately age, those colonies of roughly hemispherical shape were used (height to length ratio of 0.4 - 0.6) and their surface area calculated using the following equation:

$$\text{Curved surface area of a hemisphere} = 2\Pi r^2$$

From these surface area calculations age could be estimated through the use of annual linear extension rates of 4 mm per year (A. Cohen, pers. comm.).

All survey methods were non-destructive, although any larvae that recruited to the settlement tiles were, of necessity, sacrificed during the processing.

2.7 Statistical analyses

The statistical package BIOMstat version 3.3 (Exeter software, New York, U.S.A.) was used for data comparison. In most instances ANalyses Of VAriance (ANOVA) were

used. With the use of ANOVAs, independence of the sample data is more important than homogeneous variances, which are both more important than normality of the data (Underwood 1997b). Normality of data were not tested in this study as failures to conform to this assumption has little impact on the outcome of the ANOVA (Underwood 1997b). In some instances, variances amongst the samples could not be homogenised, however, the robustness of the ANOVA means that it will not be compromised by many conditions of heterogeneity of variance that can cause Bartlett's (1937) test (the test chosen to assess homogeneity of variances in this study) to fail (Underwood 1997b), especially when the sample sizes are the same among treatments, and there are more than about five treatments (Underwood 1997b), as was most often the case in this study. When variance could not be homogenised through transformation, the transformation that produced closest to 'normal' variance (a P-value closest to 0.05) was used. Results of subsequent ANOVAs, although fairly robust to non-normality (Sokal and Rohlf 1995; Underwood 1997b), must be viewed with caution. Under some circumstances, when variances could not be normalised and when post-hoc testing was not necessary, non-parametric analyses were used. Prior to grouping sites into locations, site pairs were post-hoc tested to check their similarity. Post-hoc testing was done using the T′ (Tukey 1949), Tukey-Kramer (Tukey 1949; Kramer 1956; Kramer 1957) and GT2 (Hochberg 1974; Hochberg 1975; Hochberg 1976) methods. Any sites that were too dissimilar to pair were considered as separate locations.

The statistical package PRIMER was used to create non-metric, multi-dimensional scaling (MDS) plots (Shepard 1962) and cluster analyses, based on Bray-Curtis similarities from square root transformations of the abundance data. MDS is a multivariate analysis ordination technique. In this case it was used to produce a map of the study sites reflecting their biological similarity (in terms of species, benthic class or

species group) rather than reflecting their geographic location (therefore, sites located closest to each other on the MDS map are most similar in terms of their community composition). To identify the causes of differences between sites and locations a SIMilarity PERcentage analysis (SIMPER; (Clark 1993) was used. A SIMPER analysis breaks down the average dissimilarity between two sites into the contribution from each benthic group.

The skew and kurtosis values of the *Diploria* spp. populations were calculated and compared to critical values (S-crit. (*ses*) and K-crit. (*sek*)) for each location. The critical values were calculated using methods outlined in Shiken (1997).

3.1 Characterisation of coral reef substrata

Mean hard coral (C: Anthozoa, O: Scleractinia) cover inside Castle Harbour was 4.9 ± 0.7 % (mean ± SE), whilst outside the harbour it was 28.1 ± 7.4 % (Fig. 8). Outside Castle Harbour coral cover was greatest at the southern terrace (STa and STb), and lowest at ILb ($F_{6, 43}$ = 135.61, P <0.0001, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 1). Coral cover also varied significantly among locations within the harbour ($F_{6, 63}$ = 9.37, P <0.0001, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 2). Post-hoc tests revealed that with a mean (± SE) of 8.5 ± 0.8 %, location 5 had significantly greater hard coral cover than all other Castle Harbour locations (Fig. 8), whereas there was no significant difference in hard coral cover among all other locations.

Diploria spp. were in the top six hard coral species both inside and outside Castle Harbour (Fig. 9). Within the harbour (all sites combined), *Diploria labyrinthiformis* constituted 37.7 ± 5.6 % (mean ± SE) of all hard coral cover, followed by *Diploria strigosa* (18.6 ± 8.8 %), *Madracis decactis* (10.3 ± 3.3 %), *Madracis mirabilis* (8.5 ± 2.5 %) and *Porites astreoides* (5.1 ± 1.8 %) (Fig. 9). Locations 6 and 7 (found in the north-eastern portion of the harbour, (Fig. 3) did not follow this general trend. These locations were dominated by *D. strigosa* (comprising 62.2 ± 1.4 % and 47.3 ± 1.7 % (mean ± SE) of hard coral cover, respectively), whilst *Madracis* spp. were not within the top six (Fig. 9). Outside the harbour, hard coral cover was dominated by *D. strigosa* (39.8 ± 9.7 %), *Montastraea franksi* (24.4 ± 9.9 %), *D. labyrinthiformis* (16.4 ± 4.3 %), *Montastraea cavernosa* (9.0 ± 4.2 %) and *Porites astreoides* (6.6 ± 1.7 %) (Fig. 9).

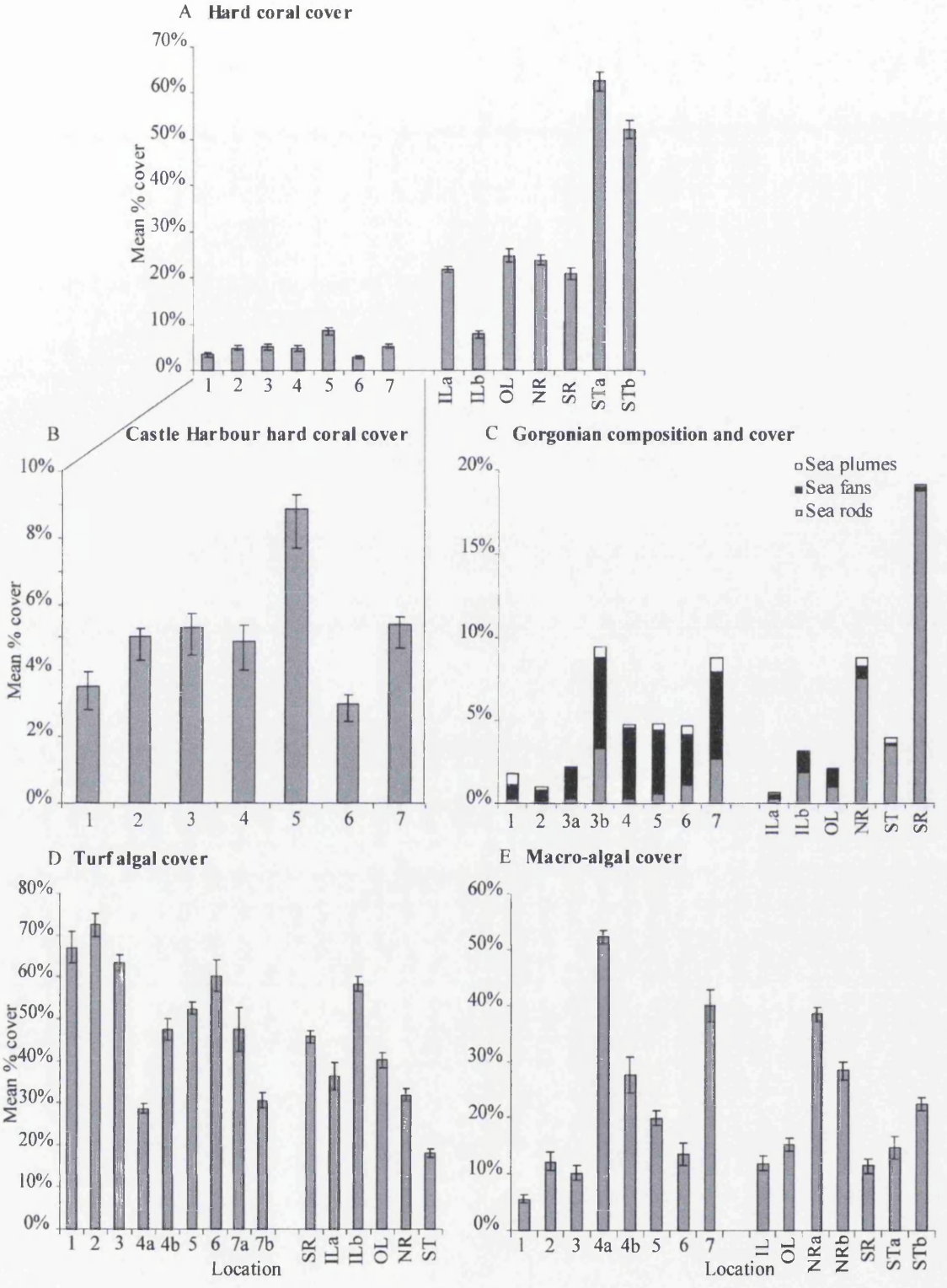


Fig. 8 Video survey and Coral Point Count with Excel extensions data showing mean (± standard error) proportion of the substratum covered by **A.** Hard corals (including hydrocoral *Millepora alcicornis*), at all locations **B.** Hard corals (including hydrocoral *Millepora alcicornis*), within Castle Harbour **C.** Gorgonians, broken down by morphological group **D**. Turf algae **E**. Macro-algae. N = 10 video transects for those locations where site pairs are grouped, and n = 5 video transects for those sites that were too different to pair (distinguished by a/b suffix).

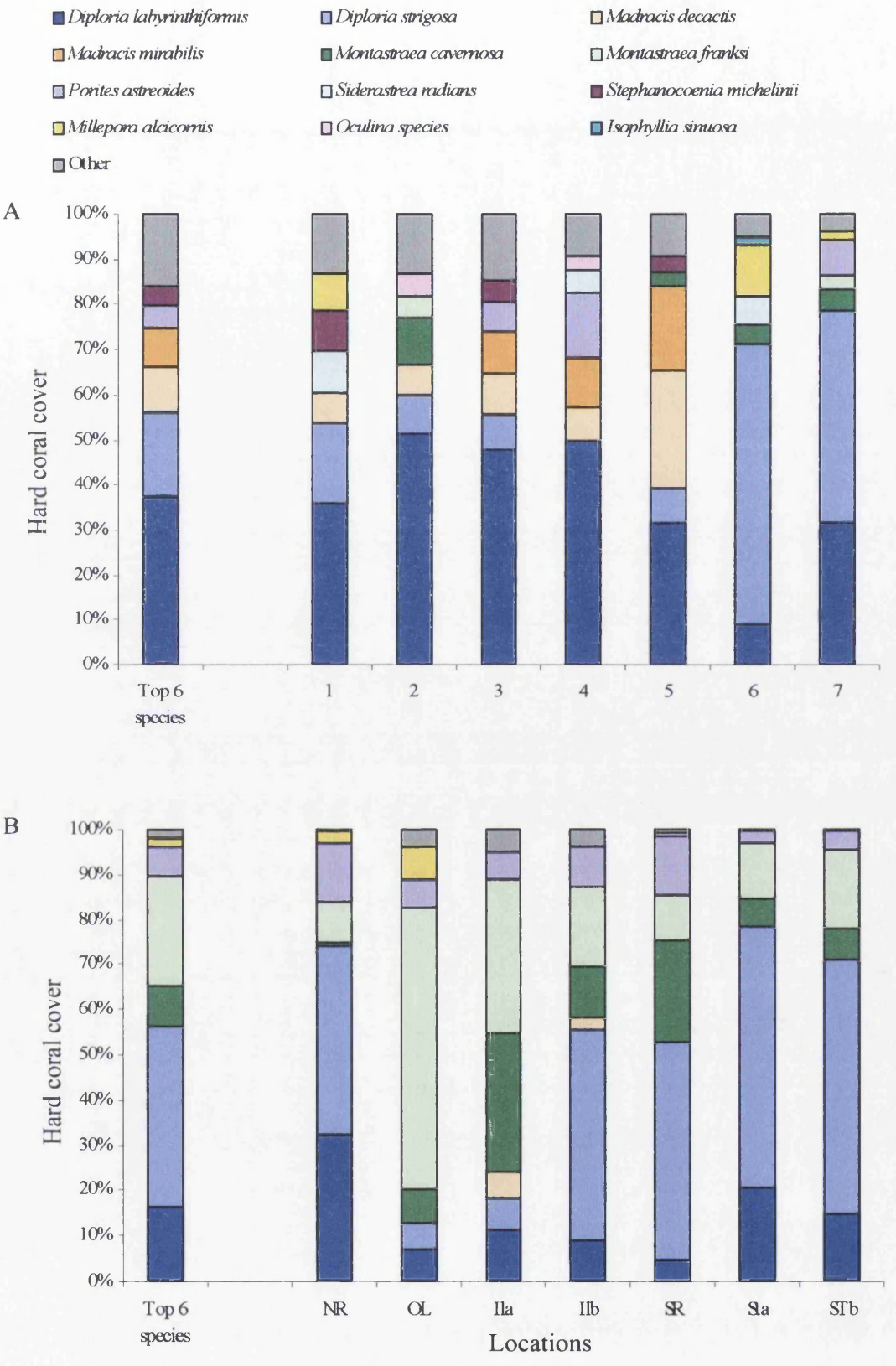


Fig. 9 Data from video surveys and Coral Point Count with Excel extensions showing top six hard coral species (including hydrocoral *Millepora alcicornis*), **A**. inside Castle Harbour and broken down by location, **B**. outside Castle Harbour, and broken down by location.

Mean gorgonian (C: Anthozoa, O: Alcyonacea) cover varied significantly among reef zones ($F_{4,\ 115} = 10.30$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus

multiple comparison of means, Appendix 3). Outside Castle Harbour gorgonians were significantly more abundant on the rim and terrace reefs (NR, SR, ST, (Fig. 3) than at other reef zones (Fig. 8). With a mean (± SE) cover of 19.1 ± 6.6 %, total gorgonian cover was significantly higher at SR ($F_{5, 44} = 66.95$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 4) than at other locations outside Castle Harbour (Fig. 8). Examining gorgonian composition at these locations (NR, SR, ST, (Fig. 3), sea rods comprised the majority (89.7 ± 3.7 %) of the gorgonian community (Fig. 8).

Inside Castle Harbour, gorgonian cover also varied significantly among locations ($F_{7, 62} = 15.31$, $P < 0.0001$, one-way ANOVA with one level of nesting, Appendix 5) (Fig. 8). Post-hoc testing showed that with <3 % cover, locations 1 and 2 had significantly less gorgonian coverage than all other Castle Harbour locations ($F_{7, 62} = 15.31$, $P < 0.0001$, one-way ANOVA with one level of nesting, Appendix 5) (Fig. 8). At all locations within Castle Harbour, sea fans were the most abundant gorgonian, comprising 69.1 ± 4.0 % of total gorgonian cover (mean ± SE) (Fig. 8). Sea plumes made up <2 % of gorgonian cover at all locations inside and outside the harbour (Fig. 8).

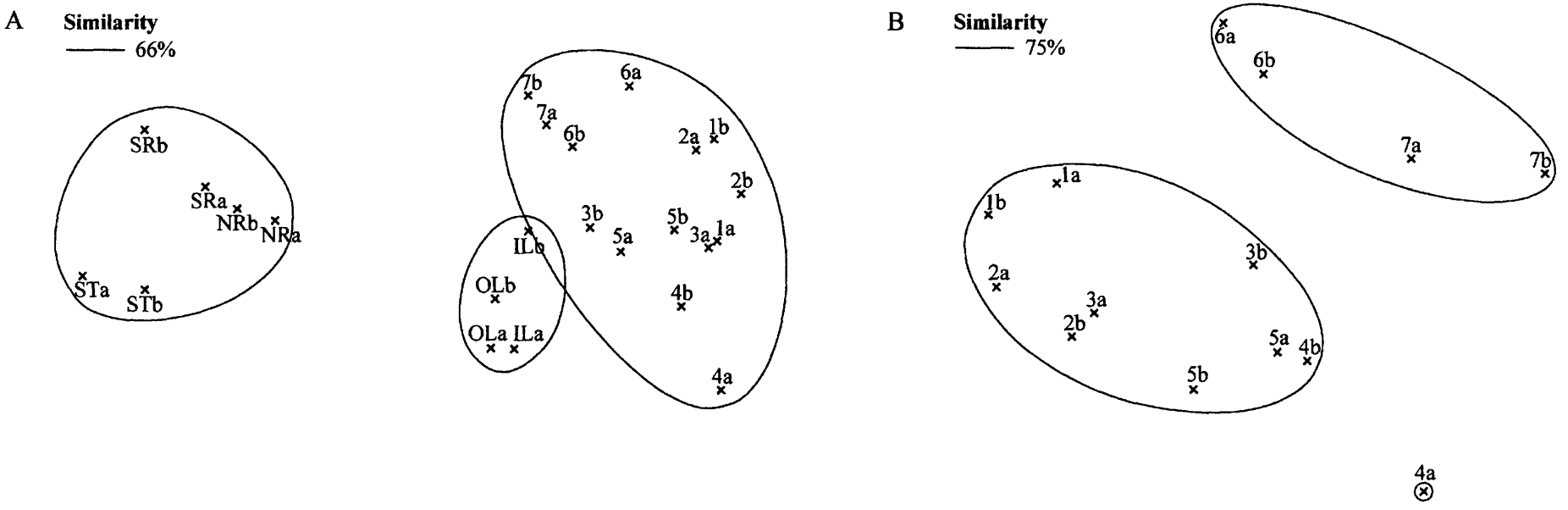
On average (mean ± SE), turf algae covered significantly more of the substrata at all locations within Castle Harbour combined (56.0 ± 5.1 %) compared to locations outside the harbour combined (36.5 ± 5.4 %) ($F_{1, 118} = 58.74$, $P < 0.0001$, one-way ANOVA with one level of nesting, Appendix 6, Fig. 8). Statistical analysis showed that locations within Castle Harbour differed significantly in their turf algal cover ($F_{8, 61} = 28.69$, $P < 0.0001$, one-way ANOVA with one level of nesting, Appendix 7), with post-hoc tests showing that while locations 1 and 2 did not have significantly different mean levels of turf algal cover to each other, they both had significantly more turf algae than

location 5 (Fig. 8). All locations had significantly greater mean turf algal cover than 7b and 4a (Fig. 8). Outside the harbour, turf algal cover also varied significantly ($F_{5, 44}$ = 59.10, P <0.0001, one-way ANOVA with one level of nesting, Appendix 8, Fig. 8), with greatest mean turf alga cover in-shore at ILb and lowest mean cover off-shore at ST. Mean (± SE) macro-algal cover within Castle Harbour was 20.2 ± 5.3 %, whilst outside the harbour it was 18.1 ± 4.0 % (Fig. 8). This was not a significant difference (P[ChiSq>=H] = 0.7313, Kruskal-Wallis, Appendix 9).

3.2 Multi-dimensional scaling (MDS)

Using the video and Coral Point Count with Excel extensions (CPCe) data, a multi-dimensional scaling (MDS) plot of community composition at all locations was constructed (Fig. 10). This showed that at 66 % similarity the communities of Castle Harbour clustered distinctly together when compared to communities from outside the harbour (Fig. 10). An 'across platform' gradation could be seen, from terrace (ST), to rim (SR, NR), to lagoonal patch reefs (OL, IL), to the in-shore reefs of Castle Harbour (Fig. 10). Within Castle Harbour, at 75 % total community similarity, MDS analysis identified one primary cluster containing the majority of sites. Sites 6a, 6b, 7a and 7b formed their own distinct cluster, as did 4a, at this level of similarity (Fig. 10). A similarity percentage (SIMPER) analysis of the Castle Harbour data indicated that variations in relative abundance of macro-algae caused 62 % of the differences between sites (Appendix 10). The next largest cause of difference was the abundance of the sea fan, *Gorgonia ventalina*. This was the main cause of differences between sites 8.8 % of the time. The remaining groups causing differences between sites were in the following order: sea rods (7 %), turf algae (6 %), *Diploria labyrinthiformis* (6 %), *Madracis decactis* (6 %), *D. strigosa* (2 %) and other invertebrates (4 %) (Appendix 10).

Fig. 10 Multi-dimensional scaling plots of video survey and Coral Point Count with Excel extensions data created using the statistical package PRIMER, based on a Bray Curtis similarity matrix of square root transformed abundance data for all benthic groups. **A.** Community structure similarity at all study sites, with a stress value of 0.1. Cluster markers indicate 66 % or less total community similarity. **B**. Community structure similarity at study sites within Castle Harbour, with a stress value of 0.12. Cluster markers indicate 75 % or less total community similarity.



Looking at only hard coral (scleractinian) communities at each site within Castle Harbour, at 65 % similarity, cluster analysis showed sites 6a, 6b, 7a and 7b grouped distinctly together and separate from the rest of the Castle Harbour sites (Fig. 11). A SIMPER analysis (Appendix 11) showed that the top three coral species responsible for differences between sites (through their relative presence/absence) were *Diploria strigosa* (the main cause of difference between sites 29 % of the time), *D. labyrinthiformis* (26 %), and *Madracis decactis* (21 %). All other species were the major cause for difference between sites <10 % of the time.

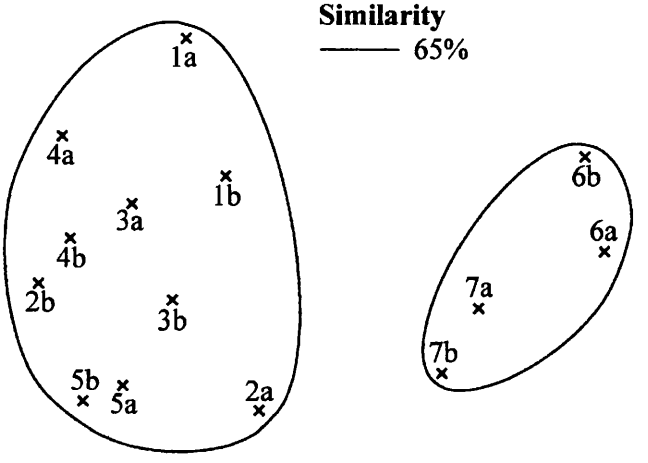


Fig. 11 Multi-dimensional scaling (MDS) plot showing coral community similarity at study sites within Castle Harbour. Cluster markers indicate those sites with 65% or less coral community similarity. MDS plot based on Bray Curtis similarity matrix of square root transformed hard coral abundance data obtained from video surveys and Coral Point Count with Excel extensions data. MDS plot created using the statistical package PRIMER.

3.3 Assessing coral condition

Of 11,524 coral colonies (both hard corals and gorgonians) surveyed outside Castle Harbour, a total of 342 (3.0 % occurrence) were affected by disease in some way. Inside the harbour, of 7546 colonies surveyed only 16 (0.21 %) coral colonies were affected (Table 3). Outside the harbour 39 (0.3 %) colonies had black band disease (BBD), and 76 (0.7 %) colonies had white plague type II (WP) (Table 3). Of those colonies outside Castle Harbour with BBD, 24 (62 %) were *Diploria strigosa*, whilst

there were no incidences of *Diploria labyrinthiformis* with BBD. Inside the harbour there were only two incidences of BBD (Table 3). Outside the harbour, 172 (18.4 %) *Montastraea franksi* colonies had Yellow Blotch/Band Disease (YBBD), whilst this disease was not recorded at all inside the harbour (Table 3).

Outside Castle Harbour

	Black band disease	White plague disease	Yellow blotch /band disease	Skeletal abnormalities	Aspergillosis disease	Total incidences	Colonies examined
Diploria labryinthiformis	0	10 (0.63%)	0	22 (1.39%)	-	32 (2.02%)	1582
Diplora strigosa	24 (0.63%)	54 (1.41%)	0	19 (0.50%)	-	97 (2.54%)	3826
Montastraea franksi	9 (0.96%)	6 (0.64%)	172 (18.42%)	0	-	187 (20.02%)	934
Montastraea cavernosa	1 (0.12%)	6 (0.71%)	0	0	-	7 (0.82%)	850
Millepora alcicornis	5 (0.87%)	0	0	0	-	5 (0.87%)	577
Gorgonia ventalina	-	-	-	1 (0.14%)	9 (1.29%)	10 (1.43%)	697
Pseudoplexaura porosa	-	-	-	3 (0.10%)	0	3 (0.10%)	2929
Pseudopterogorgia spp.	-	-	-	1 (0.78%)	0	1 (0.78%)	129
TOTAL	39	76	172	46	9	342	11524

Inside Castle Harbour

	Black band disease	White plague disease	Yellow blotch /band disease	Skeletal abnormalities	Aspergillosis disease	Total incidences	Colonies examined
Diploria labryinthiformis	1 (0.08%)	0	0	0	-	1 (0.08%)	1193
Diplora strigosa	1 (0.11%)	0	0	0	-	1 (0.11%)	947
Montastraea franksi	0	0	0	0	-	0	69
Montastraea cavernosa	0	0	0	0	-	0	39
Millepora alcicornis	0	0	0	0	-	0	37
Gorgonia ventalina	-	-	-	0	4 (0.09%)	4 (0.09%)	4402
Pseudoplexaura porosa	-	-	-	1 (0.17%)	0	1 (0.17%)	588
Pseudopterogorgia spp.	-	-	-	9 (3.32%)	0	9 (3.32%)	271
TOTAL	2	0		10	4	16	7546

Table 3 Coral condition data on total prevalence of black band disease (BBD), white plague (WP), yellow blotch/band disease (YBBD), skeletal abnormalities, and aspergillosis recorded during coral condition surveys. Zeros indicate none of that disease recorded; dashed line indicates none of that species recorded.

Gorgonians were affected by aspergillosis (on *Gorgonia ventalina*) and by skeletal abnormalities (on sea rods and sea plumes) (Table 3). Outside Castle Harbour, of 697 *G. ventalina* colonies surveyed 1.29 % suffered from aspergillosis. Inside the harbour, aspergillosis affected only 4 of 4402 sea fans surveyed (Table 3). With regards to sea rods and sea plumes, of 3058 individuals surveyed outside Castle Harbour, only 0.13 % had visible skeletal abnormalities. Inside the harbour 1.2 % of the 859 sea rod and sea plume colonies surveyed had visible skeletal abnormalities (Table 3).

Partial mortality of hard coral colonies was seen at all sites (Fig. 12 and Table 4 – 6). Total mean percent occurrence (± SE) of hard coral partial mortality inside Castle Harbour was recorded at 28.1 ± 1.9 % of all coral colonies surveyed, compared with 36.3 ± 1.4 % at the lagoonal patch reefs (OL, IL) and 10.4 ± 1.4 % at the terrace and rim reefs (SR, NR and ST) (Fig. 12 and Table 4 and 5). Data on partial mortality by zone could not be normalised through transformation. The lagoonal locations had significantly more partial mortality of hard coral species than all other reef zones, whilst the rim/terrace reef locations had the least partial mortality ($F_{2, 117} = 88.10$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 12) (Fig. 12).

Of *Diploria* spp., *D. labyrinthiformis* colonies suffered significantly greater incidence of partial mortality than did *D. strigosa* ($F_{1, 37} = 5.25$, $P < 0.05$, one-way ANOVA with one level of nesting, Appendix 13) (Fig. 12 and Tables 3 and 4). Data on *Diploria* spp. partial mortality by zone could not be normalised through transformation. There was significantly less partial mortality of *D. labyrinthiformis* at the rim/terrace reef locations, with no significant difference between Castle Harbour and lagoonal locations ($F_{2, 117} = 34.75$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 14) (Fig. 12). Partial mortality of *D. strigosa* was greatest at the lagoonal sites, whilst there was no significant difference between the rim/terrace locations and Castle Harbour ($F_{2, 116} = 17.15$, $P < 0.0001$, one-way ANOVA with one level of nesting, with multiple comparison of means, Appendix 15) (Fig. 12). Within Castle Harbour, location 6 had significantly less *D. labyrinthiformis* partial mortality than all other locations, with the exception of location 7 ($F_{6, 63} = 7.39$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 16) (Fig. 12 and Table 5). The proportion of *D. strigosa* colonies with

partial mortality inside Castle Harbour could not be normalised. A one-way ANOVA with one level of nesting showed that there was no significant variation in partial mortality of *D. strigosa* within the harbour ($F_{13, 55} = 1.37$, $P > 0.05$, Appendix 17) (Fig. 12). In addition, non-parametric testing also showed no significant variation in partial mortality of *D. strigosa* within the harbour (P[ChiSq>=H] = 0.1395, Kruskal-Wallis test, Appendix 17). Data on *Montastraea franksi* partial mortality by zone could not be normalised. There was significantly less partial mortality of *M. franksi* at the rim/terrace reef locations (mean ± SE, 20.4 ± 3.7 %), with no significant difference between Castle Harbour (84.6 ± 7.2 %) and lagoonal locations (74.3 ± 3.2 %) ($F_{2, 70} = 54.71$, $P < 0.0001$, one-way ANOVA with one level of nesting, plus multiple comparison of means, Appendix 18). Numbers of *M. franksi* colonies inside Castle Harbour were too few to perform further statistical analysis.

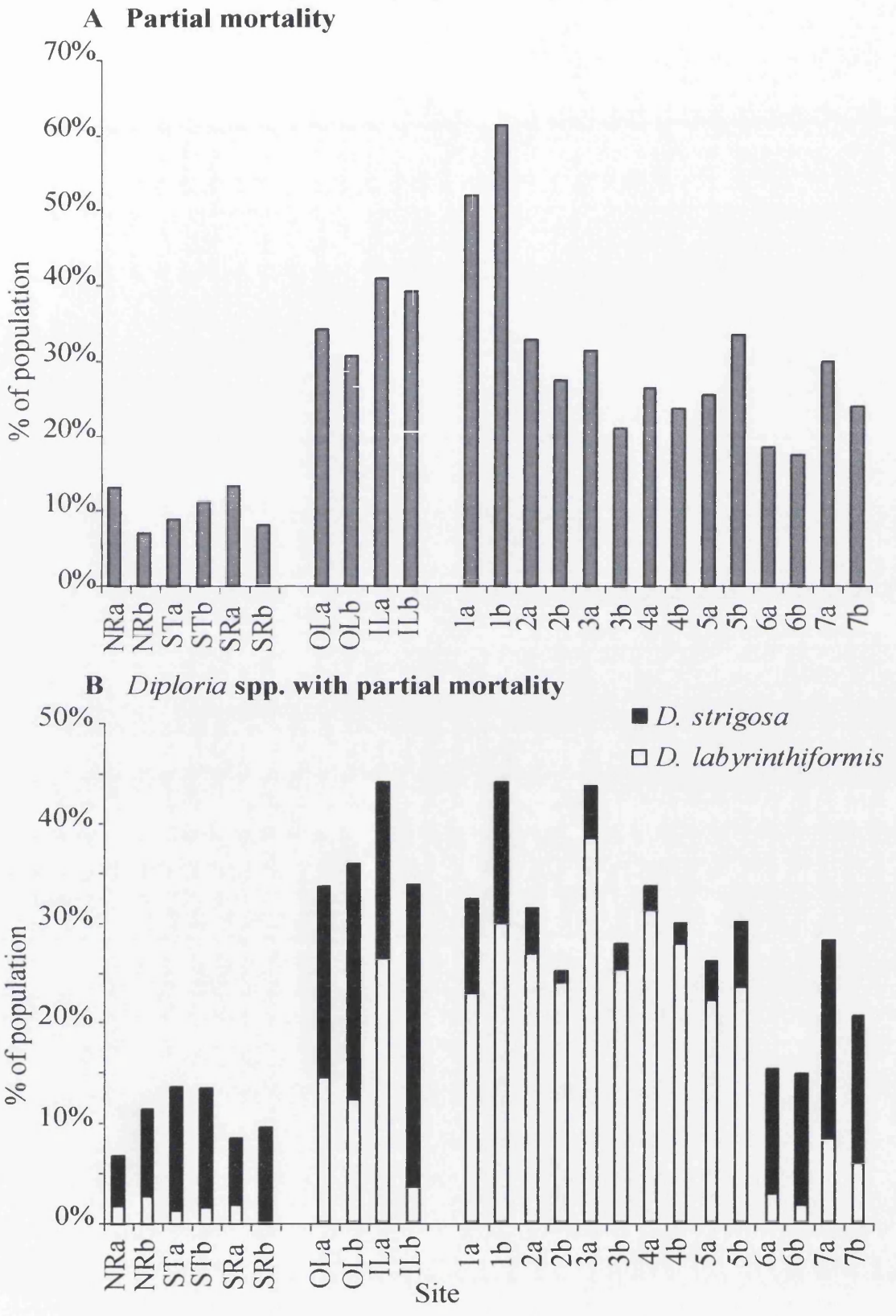


Fig. 12 Coral condition data showing **A.** total percent of the hard coral and gorgonian populations combined, with evidence of partial colony mortality, **B.** the proportion of those colonies affected by partial mortality that were *Diploria strigosa or D. labyrinthiformis.*

Table 4 Data on proportion (± standard error) of apparently 'healthy' hard coral species (including hydrocoral *Millepora alcicornis*), and those with partial mortality (PM) of >50 or <50 % outside Castle Harbour (each location comprising two sites; a and b) assessed during coral condition surveys. N = 5 transects per site. '0' = no PM, '-' = none of that species recorded.

	Northern Rim Reef		Southern Terrace		Southern Rim Reef		Outer Lagoon		Inner Lagoon	
'location':	**NR**	**NR**	**ST**	**ST**	**SR**	**SR**	**OL**	**OL**	**IL**	**IL**
'site':	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
D. strigosa										
Healthy	86.9 ± 2.5	85.3 ± 2.5	79.1 ± 2.0	81.6 ± 2.2	89.7 ± 1.2	87.2 ± 2.2	66.9 ± 2.7	57.3 ± 7.8	56.7 ± 4.1	64.0 ± 2.6
>50% mortality	7.3 ± 1.9	11.2 ± 2.5	18.5 ± 1.9	16.2 ± 2.3	9.4 ± 1.3	10.8 ± 2.2	25.4 ± 2.4	27.1 ± 6.1	23.7 ± 5.5	25.7 ± 1.5
<50% mortality	0	0.4 ± 0.4	0	0.2 ± 0.2	0.7 ± 0.4	0	5.5 ± 1.1	14.5 ± 2.6	14.4 ± 3.3	6.5 ± 2.3
n:	435	448	601	593	440	499	162	167	123	358
D. labyrinthiformis										
Healthy	88.4 ± 3.3	82.0 ± 2.7	94.2 ± 1.3	92.9 ± 1.7	94.7 ± 0.9	97.1 ± 2.9	67.0 ± 6.8	63.3 ± 7.3	48.0 ± 6.1	67.1 ± 6.8
>50% mortality	4.7 ± 2.0	8.9 ± 2.0	4.0 ± 1.4	5.7 ± 1.8	5.3 ± 0.9	2.9 ± 2.9	25.7 ± 7.6	28.7 ± 6.7	40.2 ± 7.8	32.9 ± 6.8
<50% mortality	2.3 ± 1.6	0.6 ± 0.6	0	0	0	0	7.3 ± 1.9	4.4 ± 1.2	8.6 ± 4.5	0
n:	171	180	294	243	239	63	108	105	137	42
M. cavernosa										
Healthy	80.0 ± 16.2	100 ± 0	82.4 ± 5.6	87.7 ± 6.1	66.3 ± 9.2	90.1 ± 5.2	55.8 ± 2.6	58.7 ± 5.7	54.2 ± 2.9	55.7 ± 8.5
>50% mortality	20.0 ± 16.2	0	16.2 ± 4.7	12.3 ± 6.1	33.7 ± 9.2	9.9 ± 5.2	41.7 ± 2.6	41.3 ± 5.7	40.3 ± 3.3	40.6 ± 5.3
<50% mortality	0	0	0	0	0	0	2.5 ± 1.1	0	3.6 ± 1.2	1.3 ± 1.3
n:	22	10	89	81	40	61	121	57	303	66
M. franksi										
Healthy	18.1 ± 11.7	25.3 ± 12.7	25.8 ± 8.7	13.2 ± 4.1	39.3 ± 6.3	59.8 ± 9.2	22.5 ± 4.0	21.3 ± 4.7	20.7 ± 10.5	8.5 ± 5.9
>50% mortality	25.5 ± 12.4	13.0 ± 8.3	14.9 ± 7.3	8.0 ± 3.9	43.8 ± 7.4	12.9 ± 6.3	67.7 ± 5.9	69.1 ± 2.8	65.0 ± 7.8	80.5 ± 6.7
<50% mortality	0	1.8 ± 1.8	0	1.2 ± 1.2	0	0	6.4 ± 2.4	4.5 ± 1.4	5.3 ± 3.2	7.9 ± 5.0
n:	26	28	71	78	68	52	238	218	112	43
P. astreoides										
Healthy	98.1 ± 1.1	97.3 ± 1.0	94.1 ± 3.7	93.2 ± 4.5	94.7 ± 1.5	97.8 ± 1.5	89.8 ± 2.0	82.5 ± 2.4	72.6 ± 3.0	46.8 ± 2.3
>50% mortality	1.7 ± 0.9	2.5 ± 1.1	5.9 ± 3.7	6.8 ± 4.5	4.6 ± 1.2	2.2 ± 1.5	10.2 ± 2.0	15.4 ± 2.9	21.1 ± 2.5	49.7 ± 3.3
<50% mortality	0.2 ± 0.2	0.3 ± 0.3	0	0	0.8 ± 0.6	0	0	1.5 ± 0.6	2.8 ± 1.4	3.4 ± 1.6
n:	382	400	467	403	378	202	306	568	122	171
M. alcicornis										
Healthy	89.9 ± 3.7	90.0 ± 1.9	95.0 ± 5.0	100 ± 0	-	-	87.1 ± 4.1	93.8 ± 3.8	96.7 ± 3.3	82.2 ± 10.2
>50% mortality	0	0	0	0	-	-	12.2 ± 4.6	5.7 ± 3.6	3.3 ± 3.3	17.8 ± 10.2
<50% mortality	0	0.8 ± 0.8	5.0 ± 5.0	0	-	-	0	0	0	0
n:	67	90	13	8	-	-	184	144	38	33

Table 5 Data on proportion (± standard error) of apparently 'healthy' hard coral species (including hydrocoral *Millepora alcicornis*), and those with partial mortality (PM) of >50 or <50 % inside Castle Harbour (each location comprising two sites; a and b) assessed during coral condition surveys. N = 5 transects per site. '0' = no PM, '-' = none of that species recorded.

	Castle Harbour													
'location':	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**6**	**6**	**7**	**7**
'site':	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
D. strigosa														
Healthy	75.5 ± 14.0	72.7 ± 8.3	64.1 ± 5.1	90.0 ± 10.0	78.0 ± 8.8	94.9 ± 2.1	88.3 ± 5.0	83.6 ± 11.3	90.4 ± 6.3	84.4 ± 3.2	84 ± 3.0	84 ± 2.4	75.7 ± 2.2	68.1 ± 2.6
>50% mortality	19.5 ± 9.8	11.3 ± 7.9	27.3 ± 7.0	10.0 ± 10.0	22.0 ± 8.8	4.2 ± 1.8	8.3 ± 5.3	11.4 ± 11.4	8.3 ± 5.3	14.2 ± 3.6	0	0	0.7 ± 0.2	1.6 ± 0.4
<50% mortality	5.0 ± 5.0	16.0 ± 5.5	8.6 ± 4.5	0	0	0	3.3 ± 3.3	5.0 ± 5.0	1.3 ± 1.3	1.4 ± 1.4	16.0 ± 1.0	16.0 ± 1.2	23.6 ± 1.2	29.7 ± 1.2
	21	26	22	27	22	68	27	32	61	64	106	144	144	182
D. labyrinthiformis														
Healthy	56.0 ± 15.2	53.4 ± 8.2	71.0 ± 5.8	65.1 ± 9.8	48.1 ± 7.0	59.0 ± 3.0	59.4 ± 4.7	68.3 ± 4.8	66.9 ± 3.6	56.2 ± 7.3	87.9 ± 0.8	90.6 ± 0.7	85.4 ± 1.4	77.8 ± 3.5
>50% mortality	42.0 ± 16.1	36.9 ± 11.3	23.7 ± 5.0	28.4 ± 7.3	39.7 ± 4.3	36.4 ± 2.4	34.8 ± 5.4	29.7 ± 5.4	32.5 ± 3.2	34.9 ± 8.4	0	0	1.0 ± 0.2	0.9 ± 0.2
<50% mortality	2.0 ± 2.0	9.7 ± 6.1	5.3 ± 1.5	6.5 ± 4.2	11.2 ± 5.6	4.7 ± 2.1	5.8 ± 2.5	2.0 ± 0.8	0	9.0 ± 2.6	12.1 ± 0.4	9.4 ± 0.6	13.5 ± 0.9	21.3 ± 0.9
n:	32	38	132	57	54	100	102	217	125	73	33	32	96	108
M. cavernosa														
Healthy	-	-	45.8 ± 18.6	33.3 ± 21.1	50.0 ± 31.6	33.3 ± 21.1	-	-	70.0 ± 15.9	100 ± 0	100 ± 0.2	0	60.0 ± 0.4	62.5 ± 0.3
>50% mortality	-	-	54.2 ± 18.6	37.5 ± 21.4	50.0 ± 31.6	66.7 ± 21.1	-	-	30.0 ± 15.9	0	0	0	0	12.5 ± 0.2
<50% mortality	-	-	0	4.2 ± 3.7	0	0	-	-	0	0	0	100 ± 0.2	40.0 ± 0.2	25.0 ± 0.2
n:	-	-	16	13	4	4	-	-	15	2	1	1	5	8
M. franksi														
Healthy	-	-	0	0	0	0	-	0	72.4 ± 16.9	0	0	0	0	-
>50% mortality	-	-	100 ± 0	100 ± 0	100 ± 0	100 ± 0	-	100 ± 0	27.6 ± 16.9	100 ± 0	0	0	0	-
<50% mortality	-	-	0	0	0	0	-	0	0	0	100 ± 0.2	100 ± 0.4	100 ± 0.2	-
n:	-	-	7	4	2	4	-	1	13	2	1	3	1	-
P. astreoides														
Healthy	25.0 ± 19.4	77.8 ± 17.2	89.0 ± 6.8	100 ± 0	54.0 ± 9.8	84.8 ± 1.8	80.0 ± 4.3	80.5 ± 2.5	73.2 ± 4.1	64.9 ± 6.8	66.7 ± 0.7	70.6 ± 1.7	70.0 ± 1.7	33.3 ± 0.4
>50% mortality	65.0 ± 21.8	22.2 ± 17.2	9.0 ± 5.6	0	41.6 ± 11.4	15.2 ± 1.8	17.7 ± 3.7	17.3 ± 2.0	26.8 ± 4.1	33.9 ± 6.3	5.6 ± 0.2	0	0	0
<50% mortality	10.0 ± 10.0	0	2.0 ± 2.0	0	2.3 ± 1.5	0	2.3 ± 1.5	2.3 ± 1.1	0	1.2 ± 1.2	27.8 ± 0.4	29.4 ± 0.6	30.0 ± 0.9	66.7 ± 0.7
n:	10	6	24	4	70	187	299	218	101	57	18	17	40	12
M. alcicornis														
Healthy	50.0 ± 31.6	100	100 ± 0	-	100 ± 0	0	100 ± 0	100 ± 0	100 ± 0	100 ± 0	66.7 ± 0.2	85.7 ± 1.2	50.0 ± 0.4	-
>50% mortality	50.0 ± 31.6	0	0	-	0	100 ± 0	0	0	0	0	0	0	0	-
<50% mortality	0	0	0	-	0	0	0	0	0	0	33.3 ± 0.2	14.3 ± 0.2	50.0 ± 0.4	-
n:	4	1	1	-	4	2	3	3	3	2	3	7	4	-

Table 6 Data on proportion (± standard error) of apparently 'healthy' gorgonian coral species, and those with partial mortality (PM) of >50 or <50 % outside Castle Harbour (each location comprising two sites; a and b) assessed during coral condition monitoring surveys. N = 5 transects per site. '0' = no PM, '-' = none of that species recorded.

	Northern Rim Reef		Southern Terrace		Southern Rim Reef		Outer Lagoon		Inner Lagoon	
'location':	**NR**	**NR**	**ST**	**ST**	**SR**	**SR**	**OL**	**OL**	**IL**	**IL**
'site':	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
G. ventalina										
Healthy	94.0 ± 6.0	84.3 ± 12.5	100 ± 0	91.7 ± 7.5	100 ± 0	100 ± 0	98.6 ± 0.9	96.2 ± 2.1	93.6 ± 4.6	94.7 ± 2.5
>50% mortality	6.0 ± 6.0	5.7 ± 5.7	0	0	0	0	1.4 ± 0.9	3.0 ± 1.9	3.5 ± 3.5	2.8 ± 1.9
<50% mortality	0	7.1 ± 7.1	0	8.3 ± 7.5	0	0	0	0.4 ± 0.4	1.2 ± 1.2	0
n:	24	43	2	6	11	10	166	205	49	181
P. porosa										
Healthy	100 ± 0	95.7 ± 1.6	100 ± 0	100 ± 0	100 ± 0	99.5 ± 0.4	69.5 ± 7.0	80.4 ± 14.2	88.7 ± 7.9	93.2 ± 4.0
>50% mortality	0	4.3 ± 1.6	0	0	0	0.5 ± 0.4	25.9 ± 6.2	17.7 ± 14.6	10.0 ± 6.7	5.0 ± 2.6
<50% mortality	0	0	0	0	0	0	4.1 ± 1.3	0.9 ± 0.9	1.3 ± 1.3	1.1 ± 0.7
n:	287	259	243	200	502	834	142	55	74	333
Pseudopterogorgia spp.										
Healthy	100 ± 0	90.8 ± 6.5	87.1 ± 9.7	90.0 ± 10.0	87.5 ± 11.2	63.3 ± 18.6	66.7 ± 25.8	90.0 ± 10.0	100 ± 0	50.0 ± 31.6
>50% mortality	0	6.7 ± 6.7	10.0 ± 10.0	10.0 ± 10.0	12.5 ± 11.2	36.7 ± 18.6	33.3 ± 25.8	0	0	0
<50% mortality	0	2.5 ± 2.5	2.9 ± 2.9	0	0	0	0	0	0	50.0 ± 31.6
n:	22	22	26	17	6	14	6	10	3	3

	Castle Harbour													
'location':	**1**	**1**	**2**	**2**	**3**	**3**	**4**	**4**	**5**	**5**	**6**	**6**	**7**	**7**
'site':	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**	**a**	**b**
G. ventalina														
Healthy	97.5 ± 1.6	87.8 ± 5.6	100 ± 0	98.3 ± 1.7	85.9 ± 1.8	78.9 ± 1.6	93.7 ± 0.6	94.6 ± 1.1	84.2 ± 1.5	83.5 ± 4.3	90.3 ± 6.0	91.8 ± 5.2	75.1 ± 5.0	83.7 ± 10.0
>50% mortality	2.5 ± 1.6	2.2 ± 2.2	0	1.7 ± 1.7	9.6 ± 1.5	17.3 ± 1.7	4.5 ± 0.5	4.3 ± 1.1	14.0 ± 1.0	10.6 ± 3.2	1.3 ± 0.4	0.3 ± 0.2	4.6 ± 1.0	2.9 ± 0.9
<50% mortality	0	0	0	0	4.5 ± 1.6	3.6 ± 0.8	1.8 ± 0.5	1.1 ± 0.3	1.8 ± 1.1	5.9 ± 1.6	8.5 ± 1.7	8.0 ± 2.4	20.3 ± 1.1	13.4 ± 3.1
n:	71	36	63	81	218	506	440	693	365	282	318	377	571	381
P. porosa														
Healthy	-	100 ± 0	100 ± 0	-	88.3 ± 7.3	98.0 ± 1.0	76.4 ± 19.3	92.9 ± 3.7	95.1 ± 3.0	95.0 ± 5.0	100 ±1.2	76.0 ± 0.7	82.0 ± 1.1	84.6 ± 0.7
>50% mortality	-	0	0	-	11.7 ± 7.3	1.7 ± 1.1	3.6 ± 2.6	7.1 ± 3.7	4.9 ± 3.0	5.0 ± 5.0	0	0	0	0
<50% mortality	-	0	0	-	0	0	20.0 ± 20.0	0	0	0	0	20.0 ± 0.4	18.0 ± 1.0	15.4 ± 0.4
n:	-	3	1	-	17	214	60	64	68	22	13	25	61	39
Pseudopterogorgia spp.														
Healthy	78.8 ± 12.3	87.5 ± 11.2	50.0 ± 0.2	83.3 ± 12.9	55.5 ± 18.7	51.3 ± 10.5	53.3 ± 22.5	73.0 ± 3.3	56.7 ± 16.3	66.7 ± 21.1	58.3 ± 0.6	65.4 ± 1.4	62.2 ± 1.0	53.8 ± 0.5
>50% mortality	9.5 ± 6.6	12.5 ± 11.2	50.0 ± 0.2	16.7 ± 12.9	22.9 ± 11.4	32.5 ± 8.3	40.0 ± 23.7	18.2 ± 5.4	43.3 ± 16.3	0	8.3 ± 0.4	7.7 ± 0.2	8.1 ± 0.2	0
<50% mortality	11.7 ± 7.3	0	0	0	10.0 ± 10.0	16.2 ± 7.5	0	8.8 ± 7.0	0	33.3 ± 21.1	20.8 ± 0.3	19.2 ± 0.3	21.6 ± 0.4	46.2 ± 0.4
n:	21	10	2	10	18	40	9	41	14	7	24	26	37	13

3.4 Quantification and qualification of hard coral settlement

Coral recruits were found on the settlement tiles at all study sites (Fig. 13). Data on total number of recruits per tile could not be normalised through transformation. Mean numbers of recruits per tile were significantly greater on the rim and lagoonal patch reefs of the northern platform (3.6-5.8 recruits per tile) ($F_{3, 396} = 92.22$, $P < 0.0001$, one-way ANOVA, with one level of nesting, plus multiple comparison of means, Appendix 19) (Fig. 13). Inside Castle Harbour, recruitment ranged from 0.1-2.2 recruits per tile. Despite the relatively high coral cover at the south shore locations (Section 3.1), settlement was significantly lower here than on reefs of the north shore, and did not differ significantly from settlement rates within Castle Harbour. There were significant differences in number of recruits per tile seen among locations inside Castle Harbour ($F_{5, 194} = 17.74$, $P < 0.0001$, one-way ANOVA, with one level of nesting, plus multiple comparison of means, Appendix 20) (Fig. 13). Inside Castle Harbour, locations 1, 2 and 3a had significantly lower settlement than other locations, whilst 3b had significantly higher settlement than all other locations within the harbour (Fig. 13).

Examination of the genus composition of the recruits to the settlement tiles highlighted the dominance of brooding coral recruits within Castle Harbour (Fig. 13). *Porites* spp. and *Favia*-like recruits (both brooders), comprised >50 % of all settlement at all locations within Castle Harbour (Fig. 13). Size frequency distributions of *Porites astreoides* recruits showed that the largest recruits were seen at the terrace/rim zone (Fig. 14). This zone also had the greatest range of sizes. The lagoonal reef zone had the smallest size range (Fig. 14). The dominant size group of *Porites* spp. recruits within Castle Harbour was 2.2-2.4 mm, whilst at the lagoonal zone it was smaller at 1.9-2.1 mm and at the terrace/rim zone it was smaller still at 1.6-1.8 mm (Fig. 14). Size-

frequency distributions of *Favia*-like recruits indicate that there was no clear trend between recruit size and reef zone (Fig. 14).

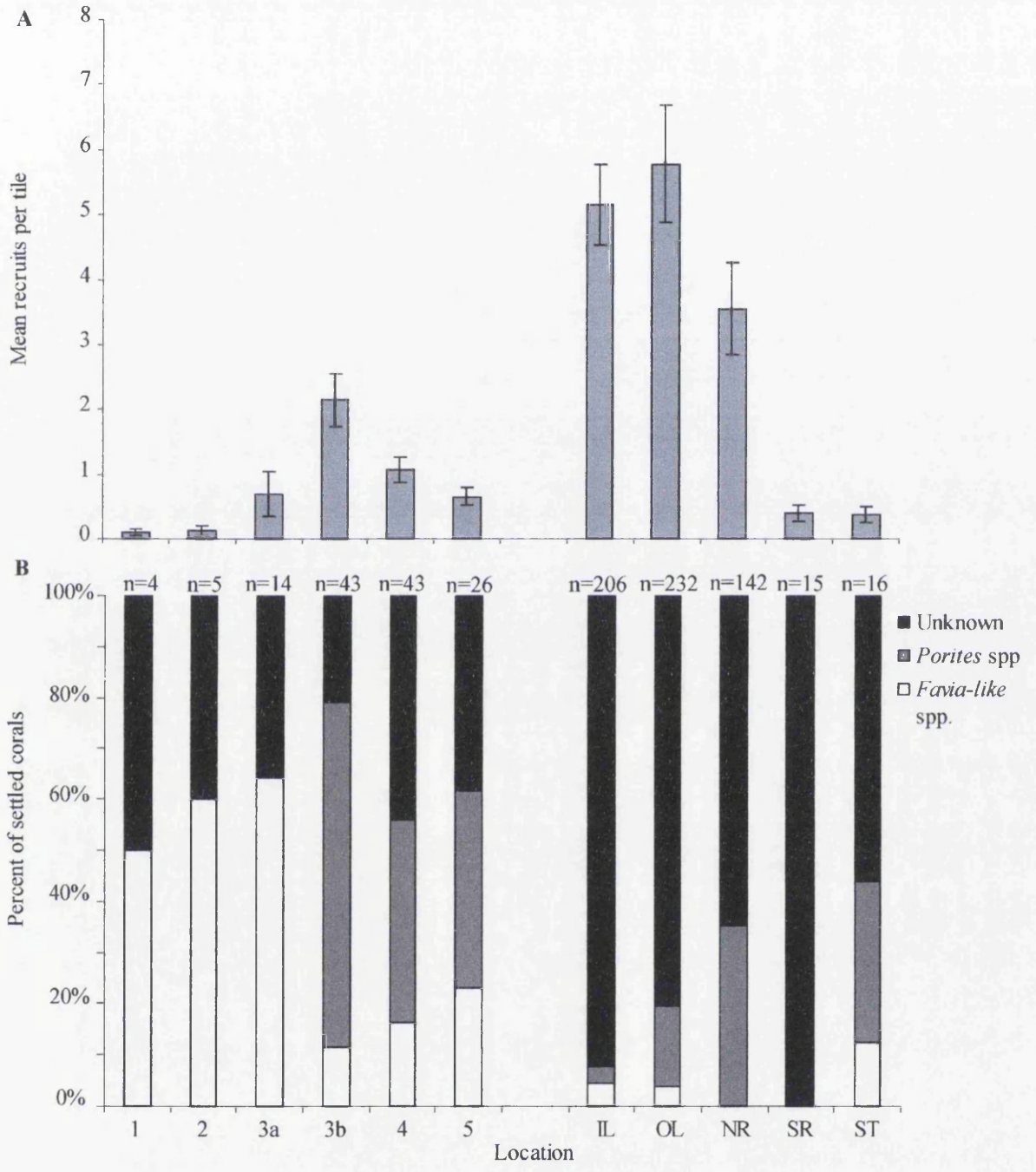


Fig. 13 Hard coral settlement data showing **A**. mean (± standard error) number of settled recruits per tile at each location (40 tiles per location except at 3a and 3b where there were 20 tiles), **B.** genus composition of settled corals. N values indicate total number of settled recruits seen at that location

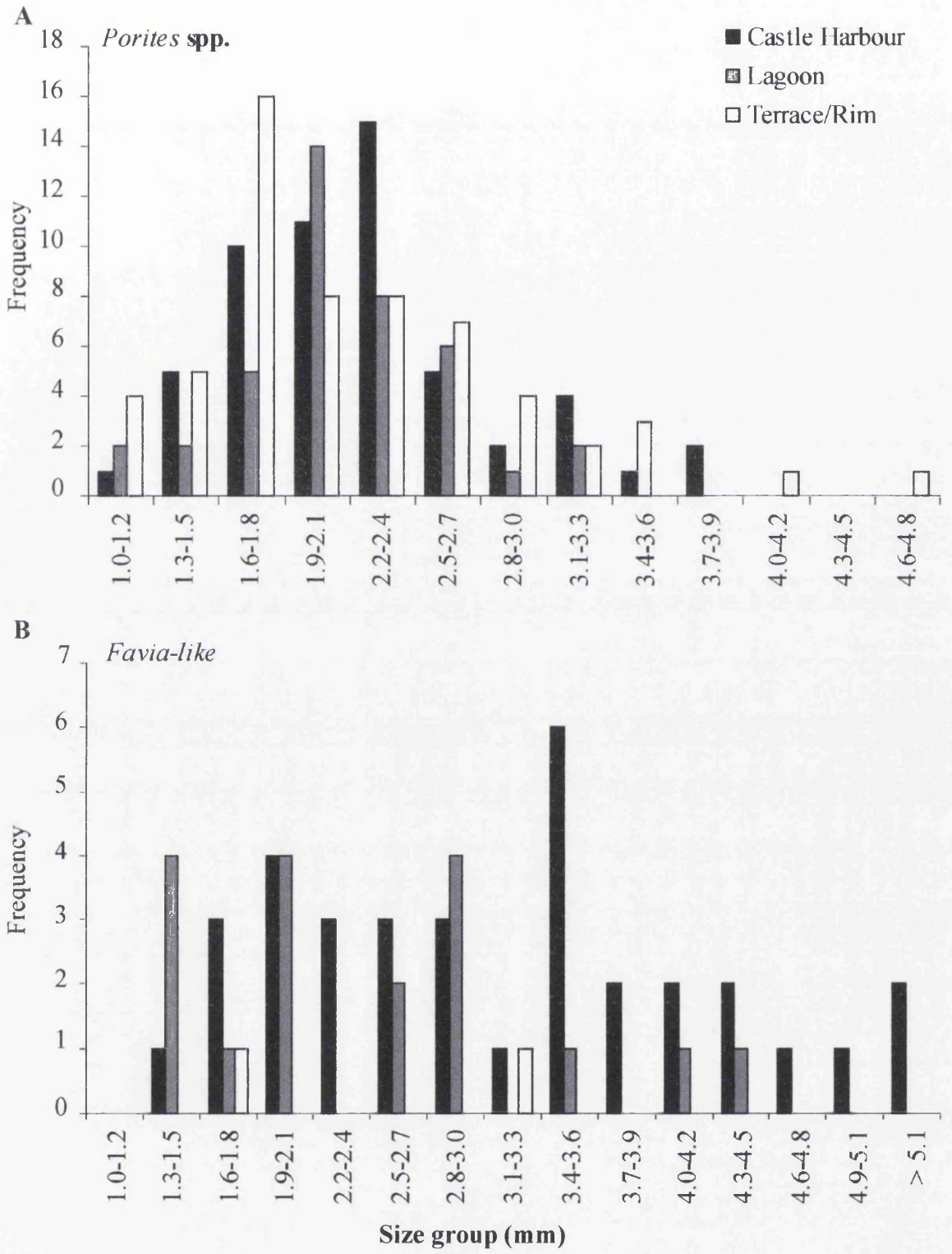


Fig. 14 Hard coral settlement data showing size frequency distributions of **A**. *Porites* spp. recruits and, **B**. *Favia*-like recruits, at the different reef zones. Castle Harbour = locations 1-5, Lagoon = locations IL and OL, Terrace/Rim = locations NR, SR, ST.

3.5 Quantification and qualification of hard coral growth and survival within Castle Harbour – juveniles

This study provided data on recruitment, survival and growth of juvenile massive and encrusting hard coral species. Over the four-year study period, the mean number of juvenile corals (<50 mm diameter only) per square meter was significantly higher at location 5 (9.1 ± 0.6) than at location 2 (2.9 ± 0.2) ($F_{3, 358} = 31.98$, $P < 0.0001$, one-way ANOVA with two levels of nesting, Appendix 21) (Fig. 15). Data on number of new recruits per square meter could not be normalised through transformation. A one-way ANOVA with two levels of nesting of the transformed data showed that there was a significant difference in recruitment between locations 2 and 5 ($F_{3, 272} = 36.09$, $P < 0.0001$, Appendix 22) but no significant difference in recruitment among the four years of study ($F_{8, 272} = 1.13$, $P > 0.05$, ANOVA, Appendix 22) (Fig. 15). Non-parametric Kruskal-Wallis tests also showed that there was a significant difference between locations (P = [ChiSq>=H] = 0, Kruskal-Wallis, Appendix 22), but not between years (P[ChiSq>=H] = 0.316, Kruskal-Wallis, Appendix 22) (Fig. 15).

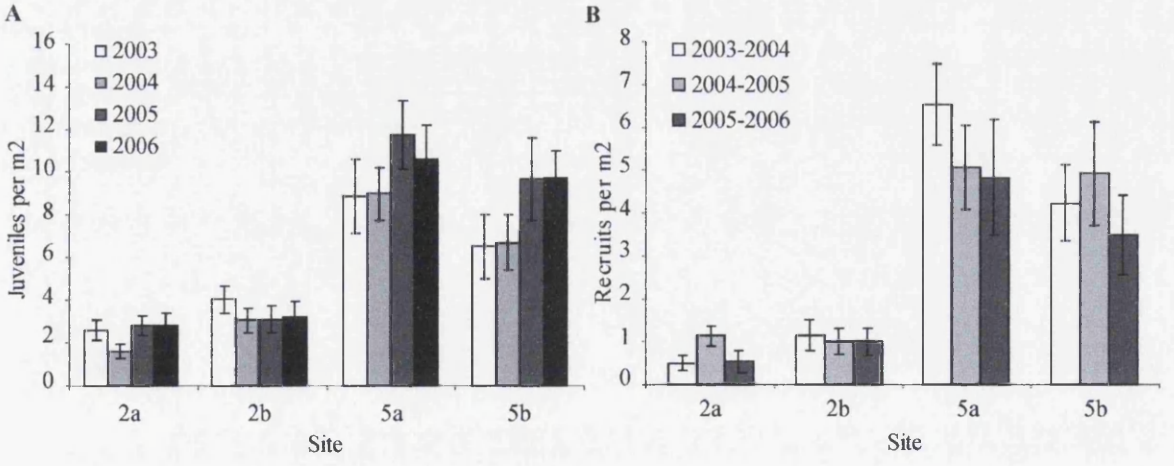


Fig. 15 Permanent quadrat data showing **A.** mean (± standard error) number of juvenile (<50 mm) hard corals per m^2 at all sites, over all study years, **B.** mean (± standard error) number of hard coral recruits per m^2 at all sites, over all study years.

Hard coral recruitment to reefs of location 5 (Fig. 3) by *Agaricia* spp., *Siderastrea* spp., and *Porites astreoides* contributed to over 75% of all hard coral recruitment (Fig. 16). At location 2, *Agaricia* spp. and *Siderastrea* spp. dominated along with *Favia fragum* (Fig. 16). The maximum number of either *Diploria labyrinthiformis* or *Diploria strigosa* recruited to a single location in one year was seen at site 5b in 2005, where seven individual *D. labyrinthiformis* colonies were found within the quadrats (Fig. 16). No recruitment of *Montastraea cavernosa* and *Montastraea franksi* was observed over the study.

A one-way ANOVA with two levels of nesting of juvenile coral growth data plus post-hoc testing showed that there was a significantly greater proportion of the juvenile coral population that grew at location 5, when compared to location 2 ($F_{1, 261} = 8.65$, $P < 0.05$, Appendix 23), but no difference in proportion of the juvenile coral population that grew between years ($F_{10, 261} = 1.43$, $P > 0.05$, Appendix 23) (Fig. 17). A one-way ANOVA with one level of nesting of data on juvenile colonies that reduced in size between surveys showed that there were significant differences in proportion of the juvenile population that reduced in size between sites, but a multiple comparison of means showed there were no differences between replicate sites ($F_{3, 269} = 3.15$, $P < 0.05$, Appendix 24). A one-way ANOVA with two levels of nesting showed that there were no significant differences in proportion of the juvenile population that reduced in size between locations ($F_{1, 261} = 0.60$, $P > 0.05$, Appendix 24), however, there was a significant difference over time ($F_{10, 261} = 5.41$, $P < 0.0001$, Appendix 24) (Fig. 17). A multiple comparison of means showed that there was a significant difference between all years (Appendix 24) (Fig. 17). A one-way ANOVA with three levels of nesting showed that the proportion of juvenile corals that died did not differ significantly between sites ($F_{2, 263} = 2.68$, $P > 0.05$, Appendix 25), or locations ($F_{1, 263} = 1.40$, $P > 0.05$,

Appendix 25), however the proportion dying did decrease significantly from 2004 to 2006 ($F_{8, 263} = 2.57$, $P < 0.05$, Appendix 25) (Fig. 17).

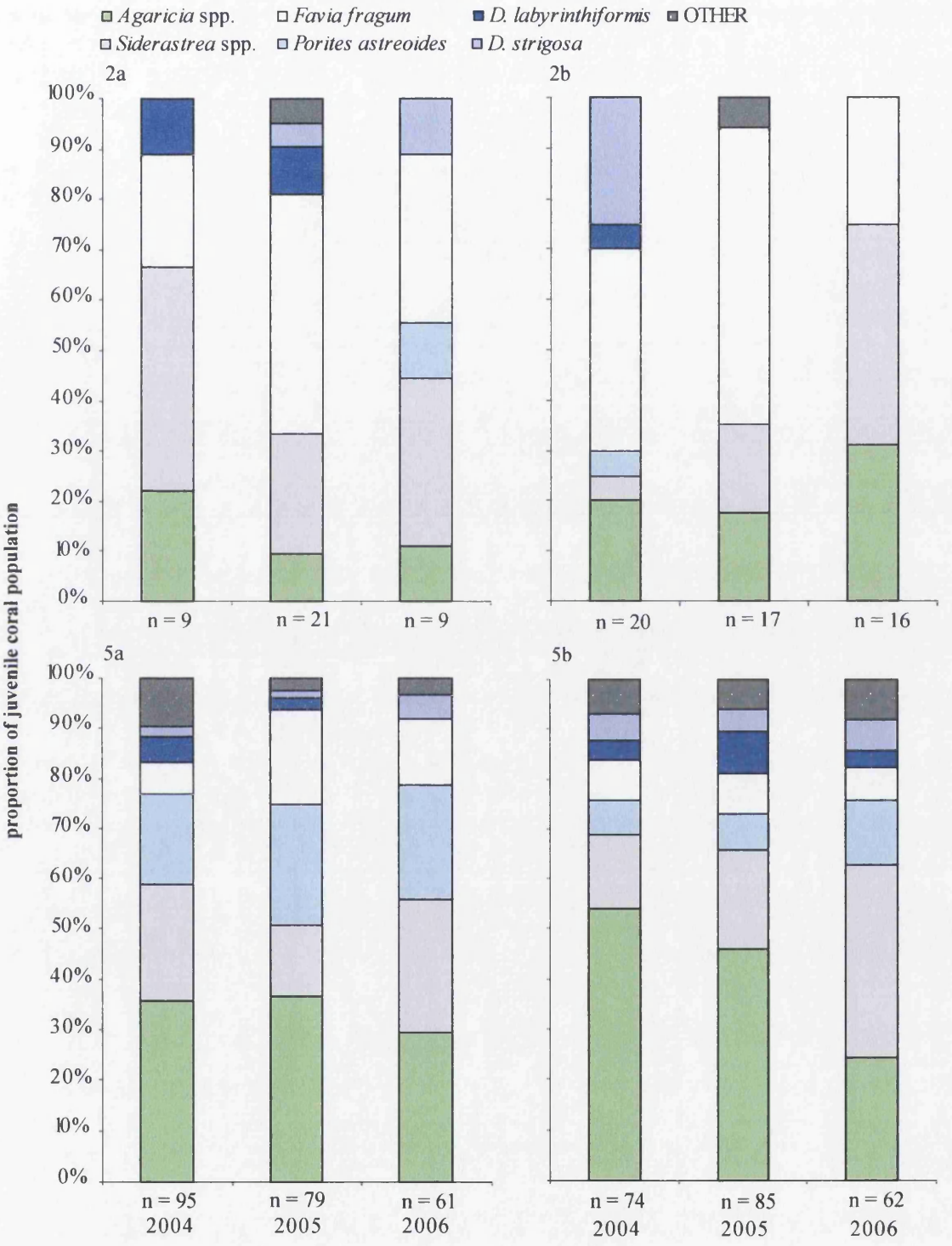


Fig. 16 Permanent quadrat data showing hard coral species composition of corals recruiting to Castle Harbour quadrats over all survey years. N values indicate the total number of hard coral recruits recorded from all quadrats at each site/time point.

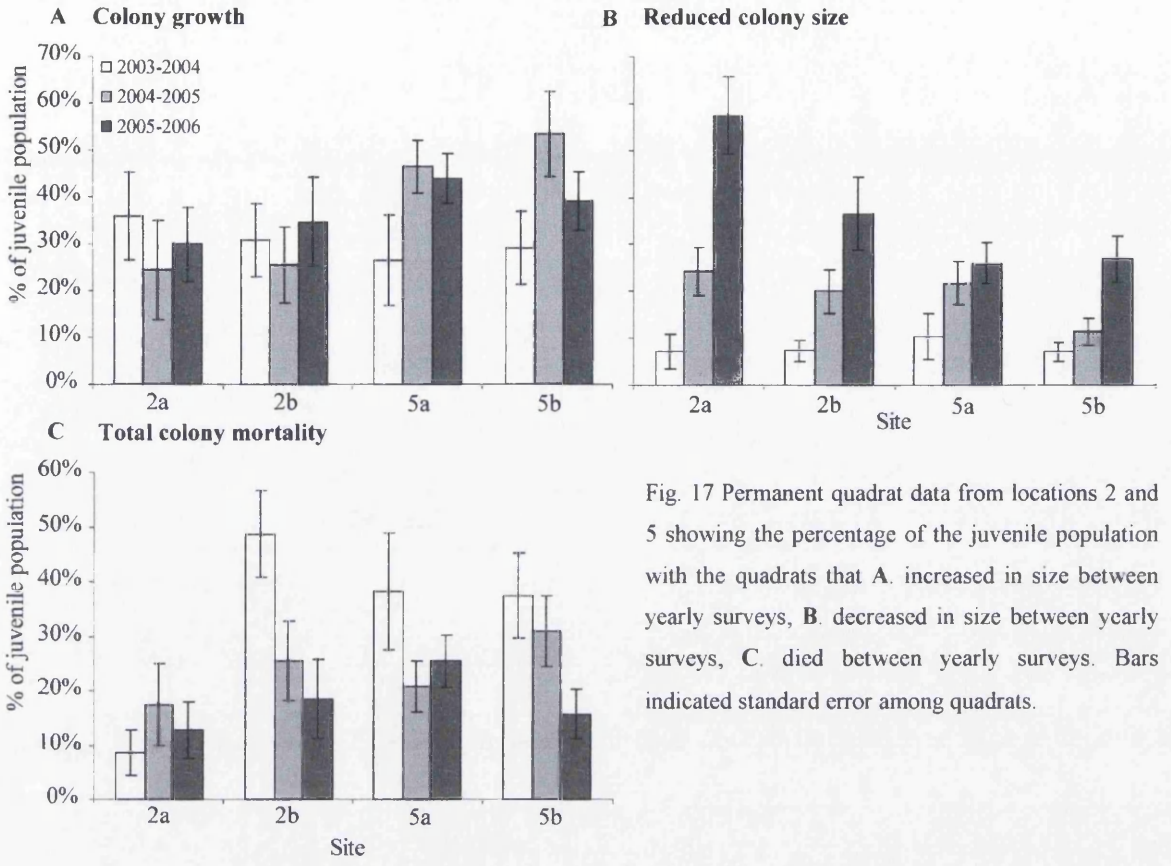


Fig. 17 Permanent quadrat data from locations 2 and 5 showing the percentage of the juvenile population with the quadrats that **A**. increased in size between yearly surveys, **B**. decreased in size between yearly surveys, **C**. died between yearly surveys. Bars indicated standard error among quadrats.

Looking at the juvenile populations from 2006 it can be seen that the greatest proportion of juveniles at sites 5a and 5b were one year old (36.4 % and 37.4 % respectively) (Fig. 18). At sites 5a and 5b there were fewest individuals in the 4+ age category. At sites 2a and 2b there was no clear pattern to age and number of juvenile corals (Fig. 18). Looking at the juvenile corals that died during the study periods and by breaking them down into age groups, it can be seen that at all sites studied, the youngest individuals (1 year age category) suffer higher mortality than older ones (Fig. 18).

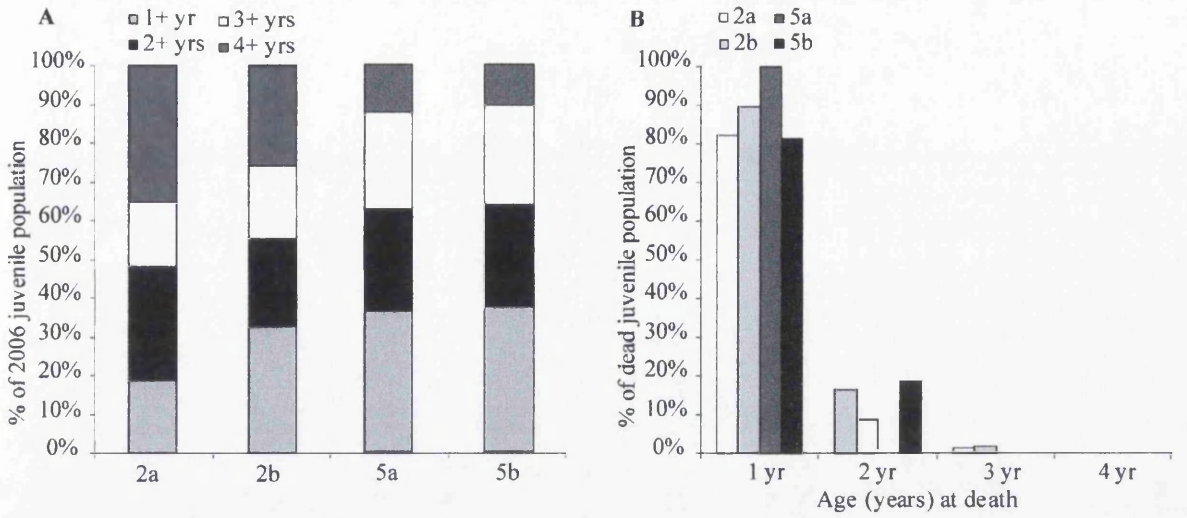


Fig. 18 Permanent quadrat data on juvenile corals showing **A.** juvenile coral age classes and their relative proportions within the total juvenile population present in 2006, **B.** age at death and relative proportion of dead juvenile corals.

3.6 Quantification and qualification of hard coral growth and survival within Castle Harbour – adults

This study provided data on survival and growth of adult massive and encrusting hard coral species. At all sites (2a, 2b, 5a and 5b) over the four study years (2003-2006), the majority of adult (>50 mm) coral colonies grew (Fig. 19). There was no significant difference in the proportion of the adult coral populations that grew between sites ($F_{2, 8}$ = 0.45, P >0.05, one-way ANOVA with two levels of nesting, Appendix 26) (Fig. 19). The amount of growth (percent size increase) by individual colonies was also comparable among sites ($F_{3, 283}$ = 0.18, P >0.05, one-way ANOVA with two levels of nesting, Appendix 27) (Fig. 19). Over the study period, adult coral colonies within the quadrats at sites 5a and 5b increased in size from the previous years surface area an average (mean ± SE) of 24.0 ± 2.3 % and 22.3 ± 4.3 %, respectively, whilst sites 2a and 2b averaged 24.3 ± 6.8 % and 20.3 ± 5.0 % increases in size from the previous year's surface area, respectively (Fig. 19). Amount of growth was significantly greater from 2003 to 2004 than between other years ($F_{8, 283}$ = 2.92, P <0.05, one-way ANOVA with two levels of nesting, Appendix 27) (Fig. 19). Throughout this study period, there was

little adult death witnessed in the photoquadrats, with a mean (± SE) of 3.2 ± 0.01 % of colonies dying at location 2 in comparison to 0.6 ± 0.01 % colonies at location 5 (Fig. 19).

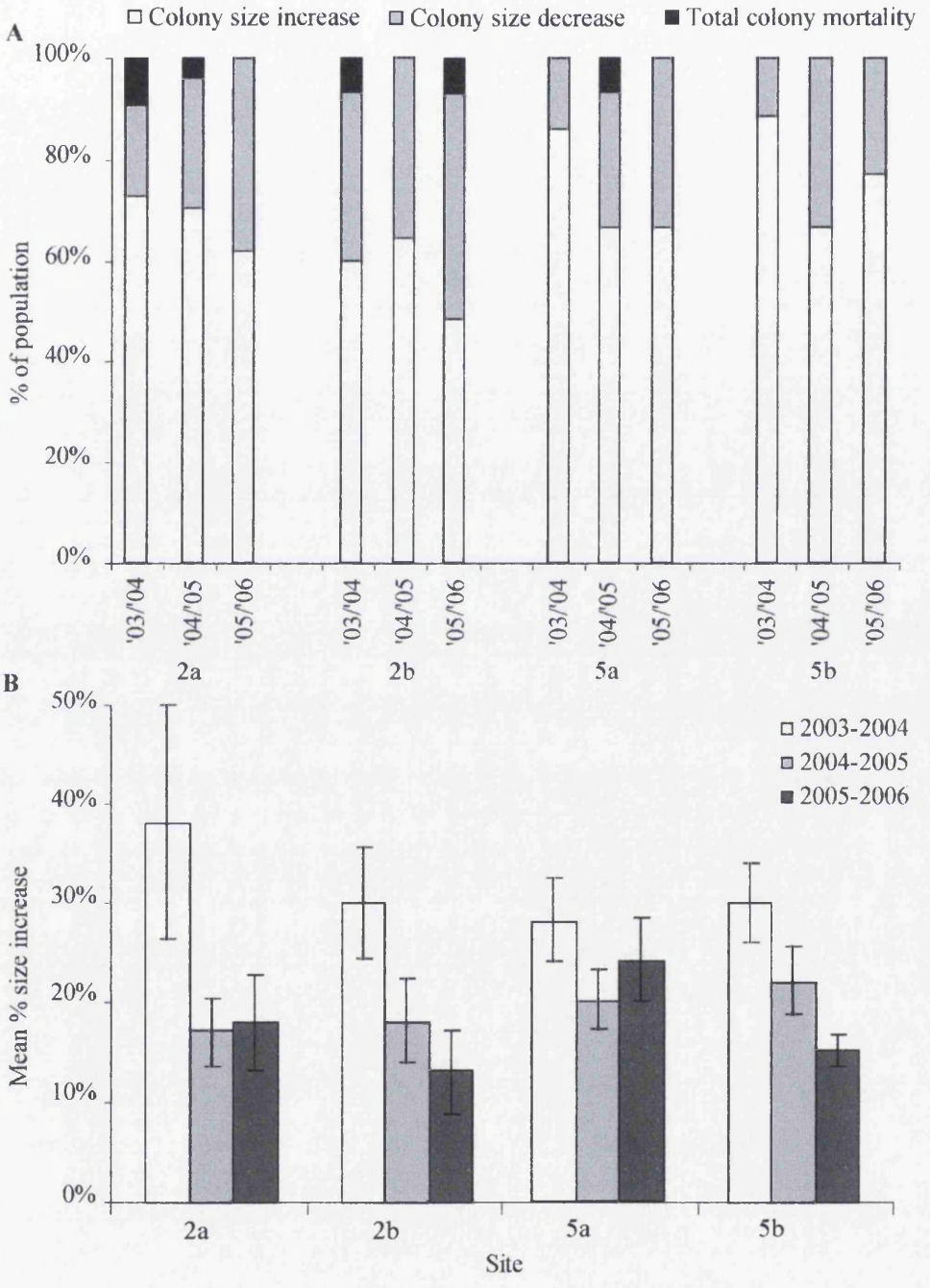


Fig. 19 Permanent quadrat data on adult coral colonies (>50 mm) showing **A**. total proportion of the adult hard coral population within the quadrats that grew, reduced in colony size, or died, **B**. mean (± standard error) percentage size increase of colonies that grew between yearly surveys. Growth based on 2- dimensional increase in surface area calculated using ImageJ software analysis of photographs.

3.7 *Diploria* spp. demographics determined by size

Diploria spp. demographic surveys showed the proportional dominance of one species over the other varied depending on location (Fig. 20). *Diploria strigosa* were proportionally dominant at all locations outside Castle Harbour whilst inside the harbour *Diploria labyrinthiformis* tended to dominate.

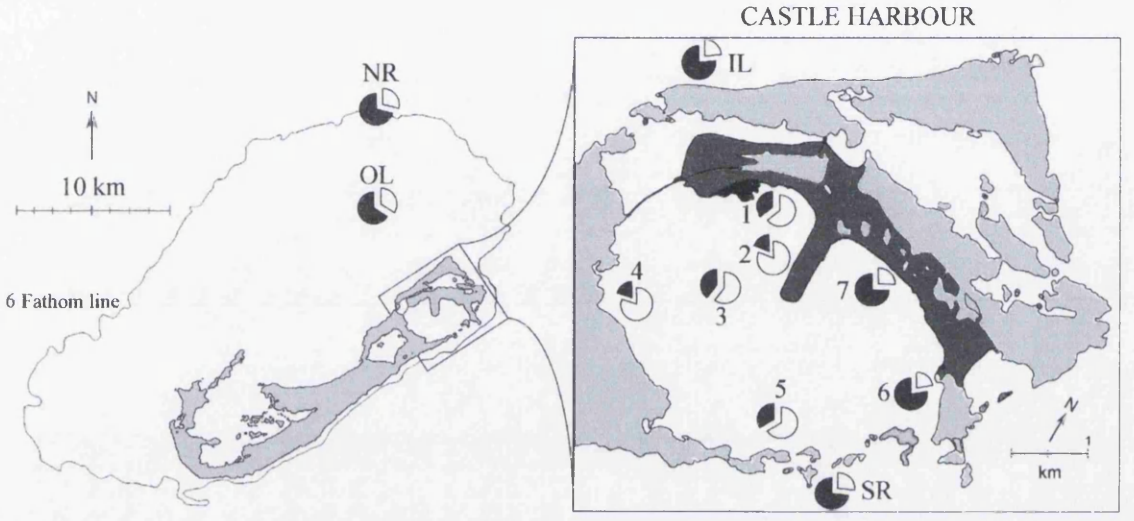


Fig. 20 *Diploria* spp. size demographics data showing relative abundance of *Diploria* spp. (pie charts) at locations surveyed during the demographics study. White portions represent *Diploria labyrinthiformis*, black portions represent *Diploria strigosa*. Original landmass' in light grey, land created by dredge and fill operations in dark grey and the dumpsite in black.

Size-frequency distributions of ln (+1) transformed surface area data showed that *Diploria* spp. populations at OL had closest to normal distributions (a normal distribution being one with a bell-shaped curve, where the mean, median and mode coincide), with no significant skew or kurtosis (skew describes the asymmetry of the distribution about the mean, while kurtosis describes the relative 'peaked-ness' of the distribution near the central mode) (Table and Fig. 22). *D. strigosa* populations at SR and IL were significantly skewed to the left, but neither population showed significant kurtosis (Table and Fig. 22). The *D. strigosa* population at NR was significantly platykurtic (relatively few values about the mean), but showed no significant skewness

(Table and Fig. 22). *D. labyrinthiformis* populations at three of the four locations outside Castle Harbour showed significant skewness to the left (OL is not significantly skewed) (Table and Fig. 22). No *D. labyrinthiformis* populations outside the harbour showed significant kurtosis (Table and Fig. 22).

Table 7 Descriptive statistics for size frequency distributions of *Diploria labyrinthiformis* and *Diploria strigosa* populations at each location surveyed, and for locations inside and outside Castle Harbour combined. Data are based on ln (surface area +1) transformed data of colony surface area. * indicates significant skew or kurtosis values.

Location	Mean	Median	Mode	Standard Error	Standard Deviation	Sample Variance	K-crit	Kurtosis	S-crit	Skewness	Count
Diploria labyrinthiformis											
1	5.93	5.98	2.34	0.20	1.75	3.08	1.13	-0.10	0.57	-0.16	75
2	5.37	4.90	2.42	0.17	2.27	5.17	0.73	-1.41*	0.36	0.14	182
3	6.88	7.66	2.20	0.15	1.84	3.38	0.79	1.17*	0.40	-1.44*	152
4	5.63	5.44	5.61	0.12	1.86	3.45	0.63	-0.46	0.32	-0.21	240
5	5.76	5.70	2.34	0.12	1.95	3.80	0.62	-0.76*	0.31	-0.21	246
6	4.61	4.73	1.10	0.24	1.87	3.49	1.28	-0.40	0.64	-0.22	59
7	5.76	5.87	4.74	0.16	1.45	2.10	1.06	0.06	0.53	-0.61*	86
In	**5.77**	**5.74**	**2.34**	**0.06**	**1.99**	**3.96**	**0.30**	**-0.82***	**0.15**	**-0.29***	**1040**
IL	5.79	6.03	1.88	0.18	1.68	2.83	1.08	0.51	0.54	-0.82*	83
OL	5.82	5.87	4.79	0.12	1.33	1.76	0.87	0.00	0.43	-0.16	127
NR	6.49	6.78	#N/A	0.13	1.64	2.67	0.81	-0.03	0.40	-0.65*	147
SR	5.59	5.75	2.49	0.13	1.28	1.65	0.96	-0.08	0.48	-0.72*	104
Out	**5.97**	**6.14**	**1.88**	**0.07**	**1.53**	**2.34**	**0.46**	**0.09**	**0.23**	**-0.45***	**461**
Diploria strigosa											
1	5.92	6.25	4.71	0.19	1.22	1.49	1.51	0.62	0.76	-0.36	42
2	4.66	4.85	#N/A	0.32	2.02	4.09	1.53	-1.29	0.77	-0.06	41
3	4.18	3.59	2.61	0.23	2.28	5.21	0.98	-1.32*	0.49	0.35	100
4	4.37	4.97	1.88	0.23	1.71	2.94	1.30	-1.37*	0.65	-0.19	57
5	5.01	5.34	2.20	0.12	1.34	1.80	0.87	-0.74	0.43	-0.43	128
6	5.12	5.58	1.21	0.12	1.64	2.69	0.69	0.23	0.34	-1.07*	203
7	6.12	6.49	2.72	0.08	1.23	1.52	0.62	1.73*	0.31	-1.32*	251
In	**5.26**	**5.77**	**1.88**	**0.06**	**1.73**	**2.98**	**0.34**	**-0.40***	**0.17**	**-0.73***	**822**
IL	5.44	5.73	2.09	0.10	1.69	2.85	0.59	-0.25	0.30	-0.42*	274
OL	5.18	5.15	3.57	0.09	1.40	1.97	0.62	-0.31	0.31	0.14	246
NR	5.18	5.09	2.72	0.09	1.76	3.10	0.52	-0.59*	0.26	0.23	359
SR	5.78	5.94	3.94	0.07	1.25	1.55	0.58	-0.23	0.29	-0.52*	281
Out	**5.39**	**5.48**	**3.57**	**0.05**	**1.58**	**2.48**	**0.29**	**-0.41***	**0.14**	**-0.14**	**1160**

Inside Castle Harbour, location 1 had such low numbers of *Diploria* spp. that no clear patterns were immediately evident and skew and kurtosis values proved insignificant for both species (Table and Fig. 21). *D. strigosa* populations at locations 3 and 4 were significantly platykurtic but showed no significant skewness (Table and Fig. 21). *D. strigosa* populations at locations 6 and 7 showed significant skewness to the left. In addition, the population at location 7 was also significantly leptokurtic (Table and Fig.

22). Locations 2 and 5 had significantly platykurtic *D. labyrinthiformis* populations, but neither population showed significant skewness (Table 7 and Fig. 21). Location 3 had a significantly leptokurtic (many values about the mean) *D. labyrinthiformis* population which was also significantly skewed to the left (Table and Fig. 21). Location 7 had a significantly left skewed *D. labyrinthiformis* population that showed no significant kurtosis (Table and Fig. 22).

At all locations within Castle Harbour *D. labyrinthiformis* dominated the larger size classes, whilst the smaller size classes showed a more even representation of *Diploria* spp. (Fig. 21 and Fig. 22). The intermediate size classes at locations 3 and 5 were fairly evenly represented by both *Diploria* spp., and at location 3 *D. strigosa* dominated the smaller size classes (Fig. 21). At all locations outside Castle Harbour *D. strigosa* dominated all size classes (Fig. 22). This was also the case inside the harbour at locations 6 and 7 (Fig. 22).

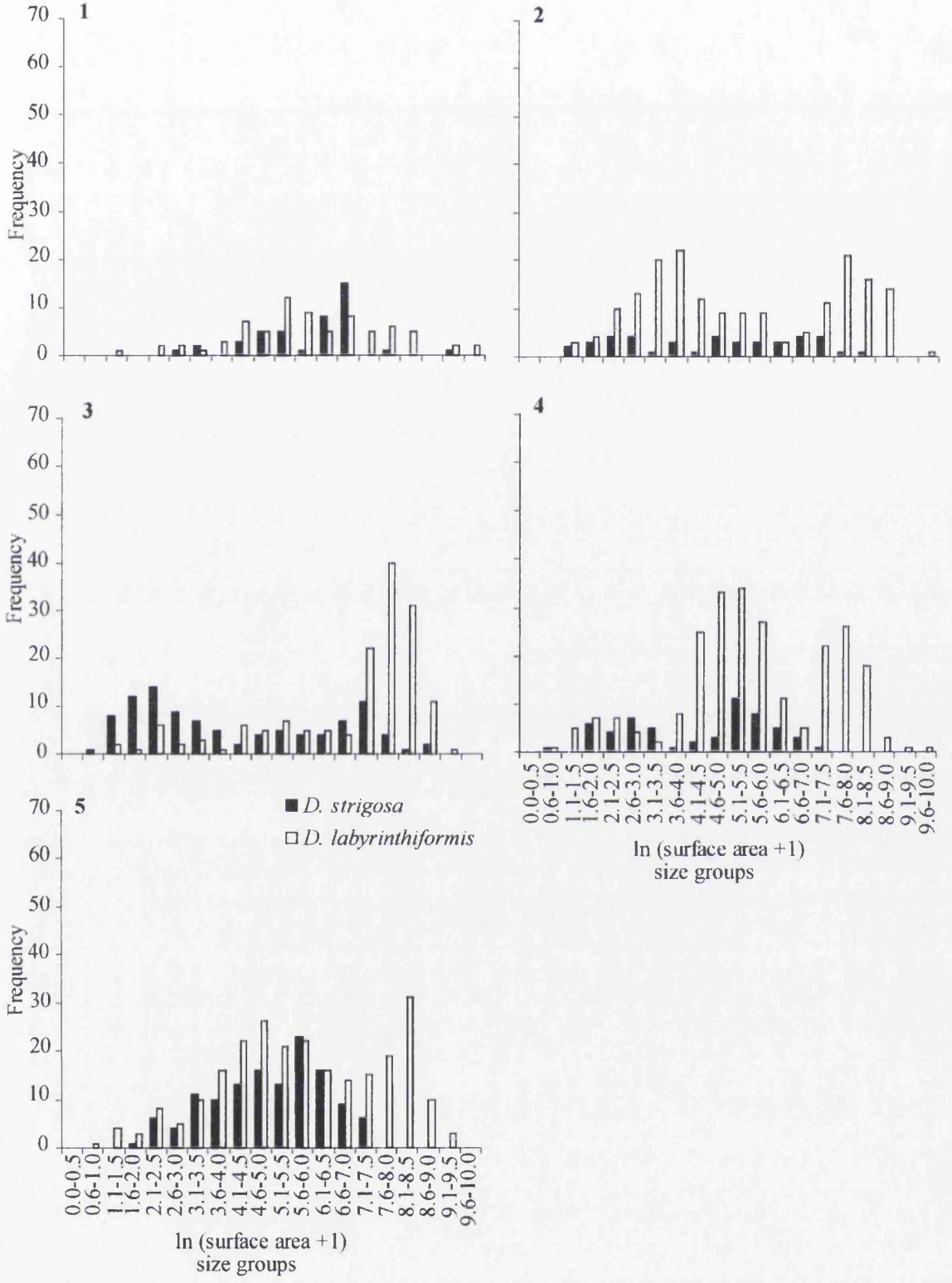


Fig. 21 *Diploria* spp. size demographics data showing size-frequency distributions of ln (+ 1) transformed surface area data of *Diploria labyrinthiformis* and *Diploria strigosa* colonies from locations 1-5 inside Castle Harbour.

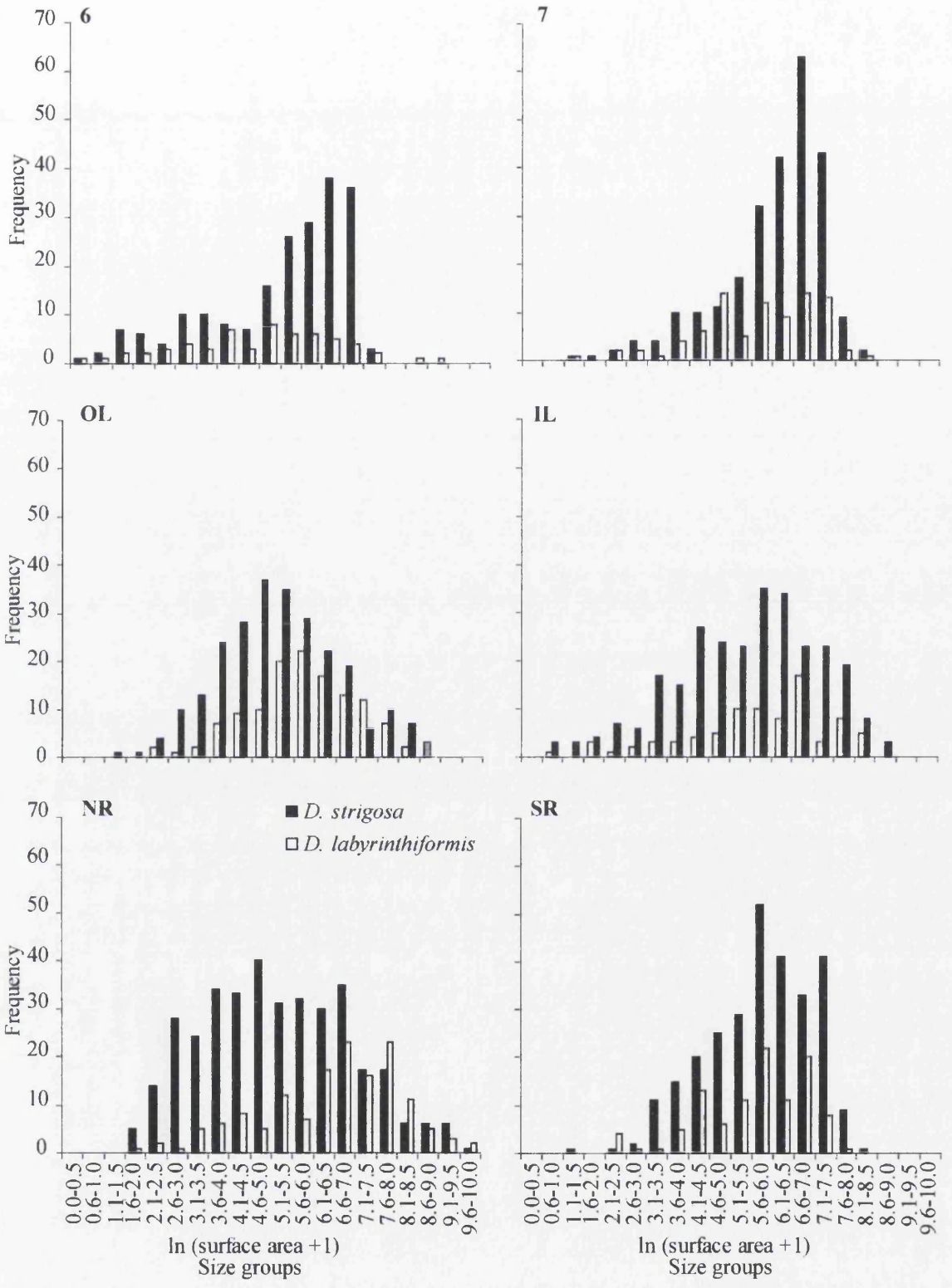


Fig. 22 *Diploria* spp. size demographics data showing size-frequency distributions of ln (+ 1) transformed surface area data of *Diploria labyrinthiformis* and *Diploria strigosa* colonies from locations 6 and 7 inside Castle Harbour, and from four locations outside the harbour.

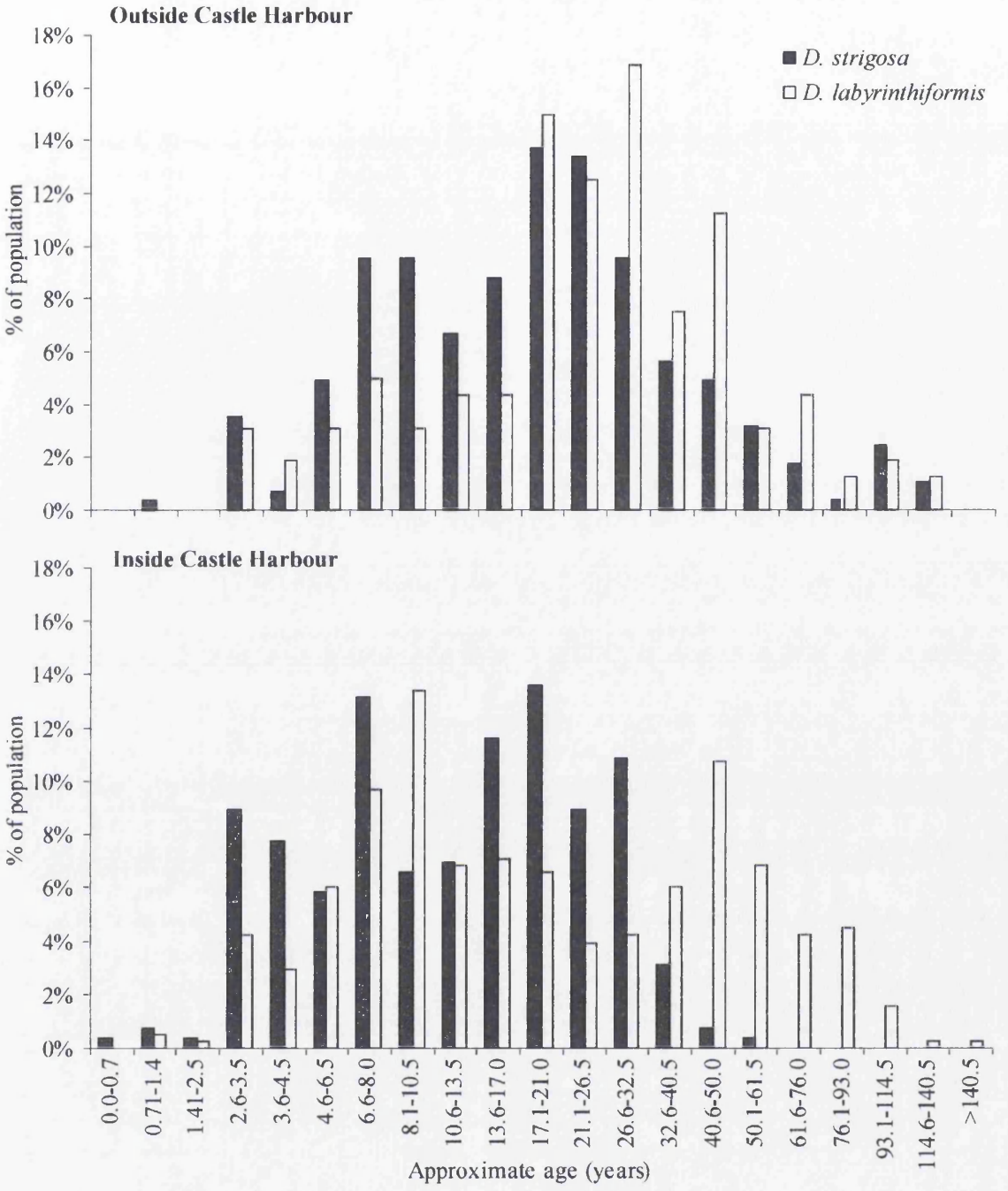


Fig. 23 *Diploria* spp. size demographics data showing age-frequency distributions of colonies with a height to length ratio of 0.4 – 0.6 only, based on ln (height + 1) transformed data. Age is interpreted from height at 4mm linear extension per year.

Looking at roughly hemispherical colonies only (those with a height to length ratio of 0.4 – 0.6), a clearly bi-modal age distribution of *D. labyrinthiformis* age could be seen inside Castle Harbour (Fig. 23), with significant negative kurtosis to the population (Table). This was not seen in *D. strigosa* age frequencies inside the harbour, and was not seen for either species outside the harbour (Fig. 23). There was no significant skewness to either of the *Diploria* spp. populations, inside or outside of the harbour (Table). Within Castle Harbour there was a clear absence of *D. strigosa* colonies older than ~60 years (Fig. 23), with only *D. labyrinthiformis* colonies found in the older age groups. Outside the harbour older age groups were comprised of both *D. labyrinthiformis* and *D. strigosa* (Fig. 23).

Chapter 4: Discussion

During this study a variety of coral reef surveys were conducted within the semi-enclosed basin of Castle Harbour, Bermuda, a degraded coral reef environment with a history of anthropogenic perturbations. Parallel surveys were also conducted at a number of locations representing Bermuda's other major reef zones. The surveys conducted in this study provide an insight into the current coral populations with regards to benthic cover, species composition, species abundance, health, larval settlement and recruitment, and size composition of the dominant hard corals, *Diploria* spp. These parameters are fundamental to coral reef community structure, and important to the recognition of coral reef decline or recovery. These data should provide information on the current state of Castle Harbour's coral reefs compared to other reefs in Bermuda.

4.1 Characterisation of coral reef substrata

Video surveys were conducted to provide information on coral cover and species composition at a number of locations within Castle Harbour, and at a variety of locations outside the harbour, representing the four major reefs zones of Bermuda. There are 34 hard coral (scleractinian) species known to Bermuda's reefs (Sterrer 1986). The video monitoring surveys from this study noted 14 of these species inside Castle Harbour and 17 outside. The three species not noted inside Castle Harbour are known to occur there nonetheless (pers. obs.). The species not noted inside Castle Harbour were *Dichocoenia stokesi, Meandrina meandrites,* and *Porites porites.* It is likely that these species were not recorded in the harbour by the video surveys because they are relatively rare species on all of Bermudas reefs, and with the additionally low cover in

Castle harbour the few individuals present are less likely to be observed. The hydrocoral *Millepora alcicornis*, the sea fan *Gorgonia ventalina*, and various morphological groups of sea rod species were seen at all studied locations both inside and outside Castle Harbour. This demonstrates that despite the major disturbances within the harbour, all coral species found outside the harbour can also be found inside. This information alone is not enough to assess the current state of Castle Harbour's reefs and so benthic cover, including coral cover, was also examined.

Analysis of the video survey data showed that coral cover is highest at study locations outside Castle Harbour, with greatest cover seen at the deeper reefs of the southern terrace (ST, Fig. 3). Presently hard coral cover inside Castle Harbour is depauperate when compared to survey locations outside the harbour, including other near-shore reefs, such as those of the inner and outer lagoon (Fig. 8). Castle Harbour was once noted for its clear waters (Verrill 1902), and numerous patch reefs with an abundance of large brain coral colonies (*Diploria* spp.) (Agassiz 1895). Based on these past observations by early naturalists, and owing to the similarity in reef types (patch reefs), depths, water temperature regimes and nutrient composition when compared to Bermuda's other near-shore reefs (Jones 2006), it would be reasonable to assume that coral cover inside Castle Harbour would be most similar to lagoonal reef locations. These locations have fairly even representation of *Diploria labyrinthiformis* and *Diploria strigosa*, as did Castle Harbour pre-dredging (Dodge and Vaisnys 1977). Other dominant framework species such as *Montastraea cavernosa* and *Montastraea franksi* have equal or greater representation than *Diploria* spp. on these reefs. However, coral cover in Castle Harbour is presently low (~5 %), and is dominated by hard coral species suggested to be tolerant to sediment stress (*Diploria* spp. and *Madracis* spp.) (Hubbard and Pocock 1972; Dryer and Logan 1978). This reduced coral cover and predominance

of sediment tolerant species makes the coral reef communities of Castle Harbour very different to those seen at any of the other locations in this study, as illustrated by the Multi Dimensional Scaling (MDS) maps (Fig. 10 and 11). These maps illustrate the conspicuous clustering of Castle Harbour's coral reef communities when compared to other study locations, highlighting the distinctiveness of the coral reef community within Castle Harbour.

Secchi disk readings, which indicate turbidity, were taken over a number of years by the Bermuda Inshore Waters Investigation (BIWI), and by Flood *et al.* (2005). Values obtained by BIWI gave values of ~6-7 m visibility inside Castle Harbour (Morris *et al.* 1977; Jones unpublished data), as did readings by Flood *et al.* (2005). Outside Castle Harbour Secchi disk readings have been consistently higher at ~10.0 m (Jones unpublished data), indicating lower turbidity levels. Sedimentation levels in Castle Harbour measured by Flood *et al.* (2005) showed rates of between 1-2 mg m^{-2} day^{-1}. Studies on sedimentation rates in the north lagoon were also between 1-2 mg m^{-2} day^{-1} (Jones unpublished data), indicating that sedimentation is no longer greater inside Castle Harbour when compared to external, near-shore reef locations. Another factor to take into consideration is water movement. Flow rates are relatively high near Castle Harbour's openings to the ocean, but the enclosed nature of the harbour means that flow rates decrease rapidly further inside the harbour (Morris *et al.* 1977; Knap *et al.* 1991; Flood *et al.* 2005). Therefore, although sedimentation rates are not different to those on patch reefs of the northern lagoon (Jones unpublished data), it is likely that infrequent re-suspension and clearance of settled sediments on reefs inside Castle Harbour results in the near-permanent presence of a sediment layer on the reef surface (pers. obs.). Sediments therefore still appear to have detrimental impacts on the coral reefs of Castle Harbour 60 years after the dredging activities ceased.

To understand the impact of the present sediment regime on the coral reefs of Castle Harbour, and whether coral cover and species composition in Castle Harbour has changed over the years as a result, data from this study were compared to data gathered within Castle Harbour by Dryer and Logan (1978) and by Flood *et al.* (2005). In contrast to the study by Dryer and Logan (1978), it would appear that some aspects of coral cover might have changed over the past 27 years. Thirty-five years after dredging operations ceased, their study of Castle Harbour showed coral communities to be dominated by the branching species *Madracis mirabilis* (33 % of total coral cover), *Oculina diffusa* (26 % of total coral cover) and *Madracis decactis* (12 % of total coral cover), with *Diploria labyrinthiformis* contributing only 3 % to total coral cover. In this study the three branching species combined (*M. mirabilis*, *M. decactis* and *O. diffusa*) presently contribute only 22 % to total coral cover inside Castle Harbour, and would thus appear to have reduced in abundance since the 1970's. However, as Flood *et al.* (2005) explained, the transects surveyed by Dryer and Logan (1978) were run from the reef top directly down the side onto surrounding sediments where *Oculina* spp. flourish on the area of sediment surrounding the perimeter of the reefs (Garrett *et al.* 1971; Dryer and Logan 1978). Transects used in this study ran from above the area of sediment at the reef base, onto the reef tops. Therefore transects assessed by Dryer and Logan (1978) would have included additional *Oculina* spp. colonies, increasing its apparent cover. This difference in monitoring technique may have contributed to the apparent change in dominance of this species on the reefs of Castle Harbour during Dryer and Logan's (1978) study; however it is unlikely to explain all of the difference seen between the studies.

Additional coral species that appear to have altered in relative dominance since Dryer and Logan's (1978) study are *Diploria labyrinthiformis* and *Diploria strigosa.* Through

examinations of dead coral composition within the harbour, there is evidence to suggest that prior to the dredging activities *Diploria* spp. were equally abundant within Castle Harbour (Dodge and Vaisnys 1977). In the present study, *D. labyrinthiformis* is the dominant hard coral species within the harbour, on average contributing 38 % to total coral cover, whilst *D. strigosa* is second most dominant, on average contributing 19 % to total coral cover. In the study by Dryer and Logan (1978) *D. labyrinthiformis* contributed only 3 % to total coral cover whilst *D. strigosa* contributed only 0.2 % to total coral cover. The pronounced change in dominance of *D. strigosa* between 1978 and the present video monitoring study may have been caused by the inclusion of those locations to the east of the airport peninsula (locations 6 and 7) in the present study. At these locations there is a switch in species dominance from *D. labyrinthiformis* to *D. strigosa*, the dominant of the two species across the rest of the Bermuda reef platform. This switch in species dominance on these reefs is attributed to these locations' proximity to the clear, inflowing oceanic waters of the south shore. This water flow creates favourable enough conditions to negate the supposedly superior sediment shedding abilities of *D. labyrinthiformis* (Hubbard and Pocock 1972), useful in the rest of Castle Harbour's turbid, low flow environment, allowing *D. strigosa* to reclaim its dominance on these reefs. This switch in species dominance makes these reefs very different to the majority of reefs in Castle Harbour. With regards to the apparent increase in percentage cover by both *Diploria* spp. over time, considering that over 30 years have passed between Dryer and Logan's (1978) study and this one, it is likely that growth of individual colonies has increased relative cover by these species. Size demographics of *Diploria* spp. corroborate this (Section 4.6).

Flood *et al.* (2005) conducted a study of Castle Harbour's reefs over the summer of 2003. Comparing coral cover values from this study directly to those of Flood *et al.*

(2005), and taking into account variations in methodology between the studies, it appears that coral cover has been relatively stable between 2003 and 2005, with ~4-5 % cover to the west of the airport peninsula, and ~6-8 % at the location closest to the south shore opening. The variations in methodology mentioned are that Flood *et al.* (2005) did not include the very tops of the reefs in their video surveys, and it is here that many of the larger *Diploria* spp. colonies are located. This resulted in slightly lower coral cover values obtained in their video monitoring study (~3 % lower). However, coral cover values obtained by Flood *et al.*'s (2005) size class surveys seem to corroborate with the video survey data from this study. The stability in coral cover between 2003 and 2005 is remarkable because the coral reefs of Bermuda experienced the worst hurricane to hit Bermuda in 50 years (hurricane Fabian, September 2003), with apparently little damage to the shallow coral reefs of Castle Harbour. This is because Bermuda's reefs are dominated by massive and incrusting species *Diploria* spp. and *Montastraea* spp. (Jones 2004, 2005), and lack the branching *Acropora* spp. corals, dominant on many other reefs systems. Branching corals are intrinsically more susceptible to storm damage because of their growth form (Stoddart 1974; Woodley *et al.* 1981), whilst massive and encrusting species are less prone to mechanical damage from such events. Therefore, the coral reefs of Castle Harbour were not severely damaged by the hurricane of 2003, so coral cover and species composition on the study reefs have remained stable between 2003 (Flood *et al.* 2005) and the present study.

Gorgonian abundance is another element of coral community structure that was examined in this study. Gorgonians were found to be most abundant on the terrace and rim reefs surveyed in this study (ST, SR, NR; Fig. 3), where they cover 10.6 % of the substrate in comparison to just 2.0 % on lagoonal patch reefs (OL, IL). Within the Caribbean, gorgonian abundance has been documented to be greater in areas of

increased water movement, low inclination, hard substrata (Kinzie 1973), and lower levels of sedimentation (Sanchez *et al.* 1997). This substratum type, along with low sedimentation levels, is characteristic of the terrace and rim reefs around Bermuda. Gorgonian populations in Castle Harbour are concentrated on the reef tops (pers. obs.) and are dominated by the sea fan *Gorgonia ventalina* (total cover 3.1 %). Other gorgonian species are less common within the harbour, with sea rods and sea plumes covering only 1.0 % and 0.5 % respectively. Gorgonian cover (mainly *G. ventalina*) increases to the south and east of Castle Harbour, where water flow is significantly higher (Flood *et al.* 2005), and where sediment deposition is therefore likely to be lower. This relatively high abundance of *G. ventalina* on these shallow, somewhat exposed reef tops has been seen at other Caribbean locations, where *G. ventalina* colonies have been seen to aggregate in shallower, more turbulent areas (Kinzie 1973). These factors have been shown to have positive impacts on gorgonian cover (Kinzie 1973; Antonius 1981; Kuta and Richardson 1996; Richardson 1998; Alker *et al.* 2001; Harvell *et al.* 2002).

Short, turf algae are one the least conspicuous features of a reef, however, they cover much of coral reef substrata (Borowitzka 1981). Inside Castle Harbour turf algae cover significantly more of the substrata than on reefs outside the harbour. Within Castle Harbour turf algal cover varies significantly and is greatest at locations to the west of the peninsula (locations 1 and 2; Fig. 3), reducing to the south of the harbour (location 5; Fig. 3). Turf algae have been shown to be capable of persisting in areas of elevated sediment, where abundance of corals and other algal groups is low (Sousa *et al.* 1981; D'Antonio 1986; Umar *et al.* 1998). Turf algae in areas of elevated sedimentation have the ability to accumulate fine sediments (Sousa *et al.* 1981; Seapy and Littler 1982; Nugues and Roberts 2003b), and by trapping such sediments, turf algae have been

shown to reduce the availability of suitable settlement substrata for juvenile corals, (Steneck 1997; Fabricius and De'ath 2001). High turf algal cover inside Castle Harbour, and more specifically at locations to the west of the peninsula, could be attributed to the increasing proportion of un-colonised substrata available at these locations (Section 3.1), caused by the mass coral mortalities during and after the dredging activities. Macro-algal cover inside Castle Harbour is not statistically different when compared to locations outside the harbour. One of the main influences on macro-algal cover on coral reefs appears to be the presence of grazing fish species, which feed on the available algae (Borowitzka 1981). The similarity in macro-algal cover inside and outside Castle Harbour indicates that grazing pressures are similar throughout. In addition, the similarity in macro-algal cover between reefs inside and outside the harbour indicates that the waters of Castle Harbour do not have significantly higher nutrient levels than waters outside the harbour. Data collected by Jones (2006), indicate that nutrient levels in Castle Harbour are not significantly different from waters of the north lagoon. High loads of particulate nutrients are known to stimulate macro-algal growth (Schaffelke 1999) which in turn can have negative effects on coral recruitment and growth (Hughes 1994; Gilmour 1999; Kuffner *et al.* 2006).

4.2 Assessing coral condition

Lesion formation through partial mortality of coral colony surfaces is a good indicator of coral reef health (Ginsberg *et al.* 2001). The health of individual coral colonies is investigated in order to understand the overall condition of the reef locations examined in this study. For coral diseases known to occur in Bermuda, there is evidence to suggest a direct relationship between disease prevalence and elevated seawater temperatures (Antonius 1981; Kuta and Richardson 1996; Richardson 1998; Alker *et al.*

2001; Harvell *et al.* 2002), and increases in sedimentation (Antonius 1988; Bruckner *et al.* 1997). In Bermuda seawater temperatures have the tendency to be higher in- and near-shore compared to off-shore (Jones 2005, 2006), while sedimentation has been a suspected problem for the corals in Castle Harbour ever since the dredging activities of the 1940's (Dodge and Vaisnys 1977; Dryer and Logan 1978; Flood *et al.* 2005). This could lead to the conclusion that coral disease has the potential to be highly detrimental to the already devastated coral populations within Castle Harbour.

In general, previous studies have shown prevalence of disease on Bermuda's reefs to be fairly low (<3 %; Jones 2005). Globally, black band disease alone tends to affect between 1 and 10 % of coral populations (Green and Bruckner 2000), with episodes of widespread infection affecting ~50 % of colonies (Richardson and Carlton 1993). Total disease levels recorded in this study showed ~3 % of coral colonies on reefs outside Castle Harbour had some evidence of disease. Total disease occurrence was greatest at the rim and terrace locations (total mean occurrence of 2.8 % of susceptible colonies), where coral cover is greatest (Section 3.1). On the lagoonal reefs total disease affected 1.5 % of colonies. Total coral disease inside Castle Harbour was very low/non-existent, with only 0.2 % of all colonies surveyed displaying any evidence of disease.

To explain this low level of disease in a reef environment prone to conditions often associated with elevated incidence of disease (Richardson 1998; Harvell *et al.* 2002), other factors must be considered. It is known from recent studies by Jones (2004) that *Diploria labyrinthiformis* colonies on Bermuda's reefs appear almost completely unaffected by black band disease, and are much less susceptible to white plague disease than *D. strigosa.* This reduced vulnerability of *D. labyrinthiformis* to these two diseases has not been reported elsewhere and the cause is not currently known (Jones 2004). The

lack of disease inside Castle Harbour is most likely attributed to the fact that there is very low coverage of the coral species most susceptible to disease in Bermuda (*Diploria strigosa* and *Montastraea franksi*). Higher levels of disease at the rim and terrace reef locations are most likely a result of the greater densities of *D. strigosa* and *M. franksi* at these locations (Section 3.1). Overall, disease does not appear to be a significantly shaping factor with regards to the coral reef communities of Castle Harbour.

Corals under stress from either natural or anthropogenic processes are prone to partial mortality, which has been shown to be a good indicator of coral reef health (Ginsberg *et al.* 2001; Nugues and Roberts 2003a). Partial coral colony mortality can be caused by a variety of factors including disease (Gladfelter 1982; Peters 1984), bio-erosion (Bruckner *et al.* 2000), physical disturbance (Bak and Luckhurst 1980) and sedimentation (Bak 1978; Rogers 1990; Nugues and Roberts 2003a; Wielgus *et al.* 2004; Garzon-Ferreira *et al.* 2005). In this study, partial mortality of hard coral colonies was greatest on the lagoonal patch reefs, followed by the reefs of Castle Harbour, with the rim/terrace reefs having the lowest incidence of partial mortality. High levels of partial colony mortality on lagoonal reefs have been seen in other studies conducted in the Caribbean (Diaz *et al.* 1995). This study shows that partial colony mortality is not greater within Castle Harbour when compared to similar reefs outside the harbour. This implies conditions that can induce partial coral colony mortality are not elevated within Castle Harbour, and that coral colonies within the harbour are not more susceptible to these conditions.

At the species level, some corals are more susceptible to partial mortality than others. *Montastraea annularis* is a coral species closely related to *M. franksi,* one of the dominant species at lagoonal locations, but not often seen in Castle Harbour. *M.*

annularis has been shown to be very susceptible to partial mortality, whilst *Diploria* spp., the two most dominant species inside Castle Harbour, appear much less so (Ginsberg *et al.* 2001; Garzon-Ferreira *et al.* 2005). The prevalence of susceptible coral species outside Castle Harbour could be assumed to be the cause for the greater incidence of partial colony mortality outside the harbour. However, when looking at occurrence of partial mortality on *Diploria* spp. only, it is still apparent that there is no evidence of elevated partial mortality inside Castle Harbour. The higher levels of partial mortality seen at the lagoonal locations and within Castle Harbour, when compared to the rim/terrace reefs, could better be explained by their depth. The relatively shallow reefs of the lagoon and Castle Harbour have been shown to be susceptible to UV bleaching during extremely low tides (Jones 2006). This results in partial colony mortality to the tops of coral colonies (Fig. 24), which then gather settling sediments, thus preventing tissue recovery. Partial mortality of adult coral colonies inside Castle Harbour does not appear to be a major factor when considering the depauperate nature of the reefs in Castle Harbour compared to those outside the harbour.

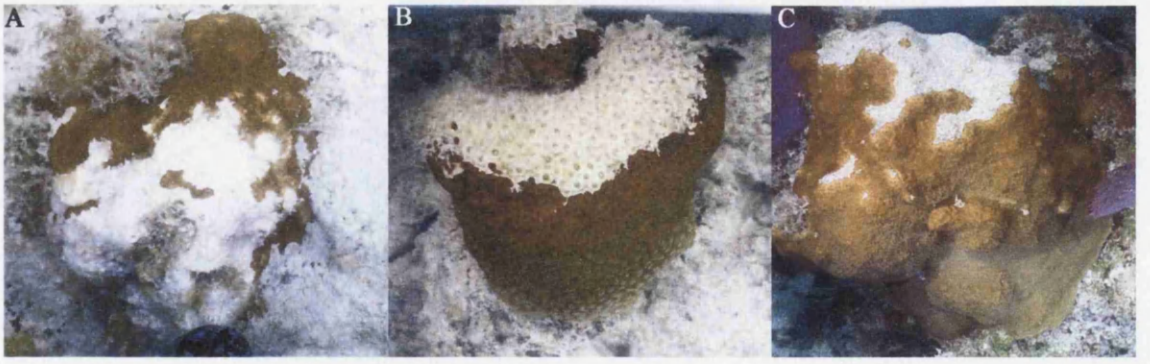


Fig. 24 Partial mortality to the tops of coral colonies within Castle Harbour, caused by UV bleaching during April 2006. A and C: *Montastraea franksi*, B: *Montastraea cavernosa*.

4.3 Quantification and qualification of hard coral settlement

Recruitment and survival of juvenile corals play key roles in shaping coral community structure, especially following periods of disturbance (Connell 1985; Hughes 1996; Glassom *et al.* 2006; Vermeij 2006). Rates of coral larval settlement are affected by availability of larvae and their ability to settle (Hunte and Wittenberg 1992). The likelihood of coral settlement can be greatly influenced by a number of environmental factors such as illumination (Maida *et al.* 1994; Harriott and Simpson 1997), substrate type and orientation (Glassom 2006; Vermeij 2006), algal type and abundance (Birrell *et al.* 2005; Kuffner *et al.* 2006), sedimentation (Gleason 1996) and presence of other benthic organisms (Fairfull and Harriott 1999; Carlton 2001; Vermeij 2006). Therefore, coral settlement was studied across the different reef zones of the Bermuda platform, as these different reef zones show variations in these parameters.

During the 24-week deployment period of this settlement study, a total of 745 recruits on 400 tiles installed across the Bermuda platform were found. Settlement varied with reef zone, with mean number of recruits greatest on the rim and lagoonal patch reefs of the northern platform (78-128 recruits per m^2). Inside Castle Harbour recruitment ranged from 2-32 recruits per m^2, which was comparable to recruitment levels seen on the deeper rim and terrace reefs of the south shore. Settlement rates from this study are comparable to those seen in other studies on the rim reefs of Bermuda (15-160 per m^2 per year, on the northern rim reef; (Smith 1985, 1992), and to those seen at other high latitude and/or western Atlantic reefs: Barbados, 79 per m^2 (Hunte and Wittenberg 1992); Australia, 132 per m^2 (Harriott and Banks 1995) Bahamas, 106 per m^2 (Avery and Liddell 1997), see Table 6 in Glassom *et al.* (2004).

The numbers of settled corals seen in this study indicate that settlement was compromised within Castle Harbour and on the south shore reefs. It is interesting to see that there was also significant inter-location variation of settlement rates within Castle Harbour. Low settlement rates within Castle Harbour in general, and more specifically at certain locations could be attributed to a number of factors. The lowest levels of settlement were seen at those locations immediately to the west of the peninsula (locations 1, 2 and 3b). These are the areas most likely to have reduced sediment re-suspension because of lower flow rates (Flood *et al.* 2005), possibly caused by hydrodynamic obstruction by the airport peninsula. This results in a near-permanent layer of sediment on the reef surface. Sediment deposition to the reef surface has been shown to reduce coral larval settlement, and to smother newly settled recruits (Babcock and Davies 1991; Babcock and Mundy 1996; Gilmour 1999). In addition, the trapping of sediments by turf algae can exacerbate this problem (Purcell 2000; Birrell *et al.* 2005). Turf algae are more prevalent inside Castle Harbour than out, with locations immediately to the west of the peninsula (locations 1 and 2) having greatest turf algal cover. Birrell *et al.* (2005) concluded that reefs dominated by turf algae might experience slower recovery rates through reduced settlement, especially when combined with high sedimentation. On tiles within Castle Harbour, there was substantially more sediment entrapped in turf and macro-algae than on tiles from outside (pers. obs.). Greatest levels of sediment were seen on upper, horizontal surfaces of tiles from within Castle Harbour (pers. obs.). In addition to entrapment of sediments by algae, a study by Kuffner *et al.* (2006) indicated some macro-algae species act as negative settlement cues for coral larvae, as well as causing increased mortality of those recruits that do settle, causing further reductions to coral larval settlement. The settlement patterns seen in this study highlight what has been shown for a number of years; that coral larvae do not settle randomly (Lewis 1974a; Morse *et al.* 1988; Resing and Best 1988; Harrison

and Wallace 1990; Babcock and Mundy 1996), indicating that sediment entrapment by algae is likely to be an inhibiting factor, contributing to the low settlement rates seen in and across Castle Harbour.

Not only did tiles from within Castle Harbour appear to have considerable amounts of sediment on them, but they also had substantial growth of sessile invertebrates (bryozoans, serpulids, ascidians, bivalves and sponges) on the undersides of horizontal tiles, and in the gap between tiles (pers. obs.). Space pre-emption by competing benthic organisms can reduce settlement (Vermeij 2006), whilst recruit overgrowth by benthic organisms can obscure evidence of settlement, making counts of coral skeletons less accurate. Past studies have shown recruitment to artificial substrata to be greatest when competition from algae and other encrusting invertebrates was reduced (Birkeland 1977; Birkeland *et al.* 1981; Rogers *et al.* 1984; Baird and Hughes 1997; Vermeij 2006). This suggests that sediment entrapment by algae may be reducing the amount of suitable settlement substrate, therefore negatively impacting settlement rates, whilst overgrowth by other benthic organisms may be increasing post-settlement mortality of recruits that do settle within Castle Harbour.

Light penetration is another consideration with regards to low settlement rates within Castle Harbour. It has been shown that low illumination can reduce coral larval settlement (Babcock and Mundy 1996). Within Castle Harbour, secchi disc readings have shown that turbidity in Castle Harbour is higher when compared to waters from outside the harbour (Morris *et al.* 1977; Barnes and Bodungen 1978; Jones unpublished observations). However, most of the reefs within the harbour are relatively shallow, which may compensate for any decreases in light penetration caused by the turbid waters. Further studies by the Marine Environmental Program (MEP) at the Bermuda

Institute of Ocean Sciences (BIOS) will confirm whether light penetration is indeed reduced inside Castle Harbour when compared to outside locations.

Preliminary identifications of coral recruit skeletons seen on the tiles indicate that brooding species were the most dominant of recruits. This has been shown to be the case in previous studies conducted on Bermuda's reefs (Smith 1992), and elsewhere (Table 6 in Glassom *et al.* 2004; Abelson *et al.* 2005; Vermeij 2006). It has been thought that brooding species tend to dominate the pool of recruits on Atlantic reefs (Harriott 1999) potentially because they release larger, well-developed (Hughes and Tanner 2000; Vermeij 2006), and rapid settling larvae (Lewis 1974a; Goreau *et al.* 1981; Neves and de Silveira 2003), which have better chances of survival because of their increased size (Meesters *et al.* 1996; Vermeij 2006). Broadcast spawning species such as *Diploria* spp. have been shown to have lower settlement rates in comparison to brooding species (Smith 1992). Smith (1992) hypothesised that these broadcast spawning, massive coral species sacrifice short-term recruitment success for longer-term juvenile survival. This would corroborate with the *Diploria* spp. dominated coral populations currently found in Castle Harbour.

Low settlement on the study reefs of the south shore was not expected as these reefs have high coral cover and lack obvious detrimental influences. Larval supply may be an issue since although coral cover is high, it is mostly composed of broadcast spawning coral species *Diploria* spp. and *Montastraea* spp.; there is low representation by the brooding coral species that make up the majority of settling corals at other locations. Brooding coral species have been shown to have larvae that settle rapidly (Lewis 1974a; Goreau *et al.* 1981; Neves and de Silveira 2003) and so adult presence is likely to affect larval supply in the immediate area (Harriott 1999).

Another factor that may be preventing larval settlement at the south shore locations is current patterns, especially at the southern rim reef location (SR). These reefs are subjected to strong water movement (pers. obs.), which may hinder coral larval attachment to the reef substrate. However, this is an unlikely explanation for the low settlement rates seen at the southern terrace location, as water movement at the reef surface is not notably strong (pers. obs.). Further factors with the potential to negatively affect coral larval settlement on the south shore reefs are temperature and light. The south shore reefs are the deepest of the study reefs, and at these depths water temperatures and irradiance levels are likely to be lower than on shallower reefs. Temperature (Wilson and Harrison 1997) and irradiance (Babcock and Mundy 1996) both negatively impact coral larval settlement at low levels. Low rates of coral larval settlement may not be the cause for the low numbers seen on the south shore reefs. Post settlement processes such as grazing and overgrowth by other encrusting organisms may obscure the skeletons of newly settled recruits. However, these are unlikely explanations for the low settlement rates since fish grazing does not appear to be more intense than at other sites (pers. obs.), and the tiles from the south shore sites had less growth by other encrusting organisms than tiles with greater numbers of settled spat from other locations (pers. obs.). These data could also be evidence of the stochastic nature of coral spawning and larval settlement, with an anomalously low settlement year having been recorded. Further studies into coral larval settlement at these locations need to be conducted to fully understand the reasons for the low numbers witnessed in this study.

Size measurements of *Porites* spp. recruits show that there appears to be a gradation in dominant recruit size from larger individuals near-shore, to smaller ones off-shore. The dominant size group of *Porites* spp. recruits within Castle Harbour was 2.2-2.4 cm

diameter, whilst at the lagoonal zone it was smaller at 1.9-2.1 cm, and at the terrace/rim zone it was smaller still at 1.6-1.8 cm. This implies either earlier spawning, or elevated growth rates in near-shore waters. Delayed spawning of corals in cooler, off-shore waters compared to the same species in warmer, near-shore waters has been noted (Harrison *et al.* 1984; Willis *et al.* 1985; de Putron 2003), whilst data on linear skeletal extension rates of adult *Diploria* spp. from Bermuda's reefs have shown increased growth rates of in-shore and near-shore colonies (A. Cohen, pers. comm.). Size-frequency distributions of *Favia*-like recruits indicate that there is no clear trend between recruit size and reef zone.

These settlement surveys were an experimental study conducted with the intention of finding out approximate settlement numbers to the various zones of Bermuda's reef platform. Meanwhile, a complimentary study to photographically catalogue the initial stages of corallite formation of the major hard coral species found on Bermuda's reefs is being conducted (de Putron, pers. comm.). So far development of *Porites astreoides, Favia fragum* and *Siderastrea* spp. have been documented, though *Siderastrea* spp. have been found difficult to distinguish because of wide variations in their skeletal development (Fig. 25). Studies on *Diploria* spp. and *Montastraea* spp. are ongoing. As such, identification to genus level is only possible at present for *P. astreoides* and *F. fragum.* Once this latter study is completed, full identification of the recruits to the tiles of this study should be achievable, allowing more detailed conclusions to be made about the factors affecting coral larval settlement on these study reefs. These data will allow identification of which corals are settling where, and in what quantities, complementing the data on settlement numbers obtained in this study.

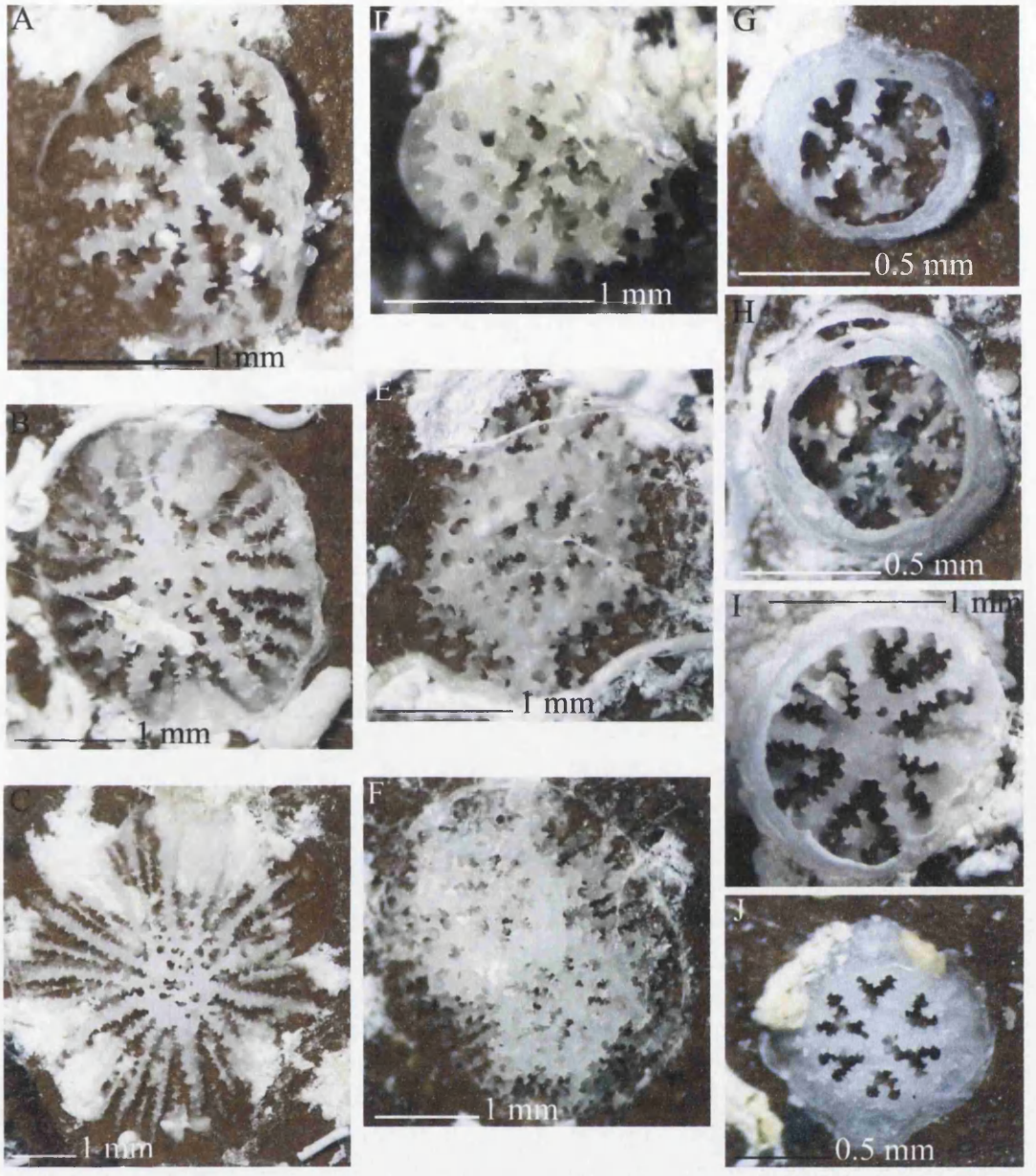


Fig. 25 Images showing variations in corallite development between A-C; *Favia*-like spp., D-F; *Porites* spp., G-J; *Siderastrea*-like spp.

4.4 Quantification and qualification of hard coral growth and survival within Castle Harbour – juveniles

Juvenile coral surveys, within repeatedly monitored permanent quadrats, conducted in this study provide information on the growth and survival of coral recruits during their first few years after settlement to the reef. This study supplements the data gathered from the settlement study by providing species specific information on coral

recruitment. Juvenile surveys were conducted at two locations (four sites) within Castle Harbour (locations 2 and 5, Fig. 3) over a four-year study period. The data from this study show that there were significantly greater numbers of 1.) existing juvenile corals, and 2.) new coral recruits at the location closest to the south shore opening in comparison with the location to the west of the peninsula (Section 3.5). This corroborates with the settlement data, which was also greater at the southern location (Section 4.3). Mean recruitment rates from these quadrat surveys were comparable to other studies (Sammarco 1980; Rogers *et al.* 1984; Fitzhardinge 1985; Smith 1997), however, they were lower than those recorded from previous studies in Bermuda, conducted on the northern rim reefs (15 m^{-2}) (See Table 3 in Smith, 1992, for comparisons), implying lower recruitment rates inside Castle Harbour.

Growth and survival of coral recruits is vital to coral reef recovery and continued existence. Evidence suggests it can be said that there was a significantly greater proportion of the juvenile coral population at the location nearest the south shore opening that was actively growing (rather than static, reducing in colony size, or dying) when compared to the location to the west of the airport peninsula (Fig. 3). Reductions in juvenile coral colony size between study years, and reductions in juvenile total colony death, were comparable between the two locations. In conjunction with the settlement data, this indicates that it is likely that coral larval settlement is compromised to the western side of the peninsula (Section 4.3), leading to the lower recruitment levels seen at this location in this study. As explained in Section 4.3, locations to the west of the peninsula have greater turf algal cover and reduced flow rates (Flood *et al.* 2005), and are thus more likely to have reduced sediment re-suspension rates, and greater sediment entrapment (Nugues and Roberts 2003b), resulting in the more frequent presence of a sediment layer on the reef surface, when compared to locations closer to

the south shore opening (pers. obs.). The presence of sediment on the reefs surface has been shown to reduce coral larval settlement, and to smother newly settled recruits (Babcock 1991; Babcock and Mundy 1996; Gilmour 1999; Birrell *et al.* 2005). Location 5 is nearer to inflowing oceanic waters, experiencing greater water flow rates (Flood *et al.* 2005), and most likely greater flushing and removal or surface sediments as a result. In addition, turbidity has been shown to be greater to the west of the peninsula (Morris *et al.* 1977; Flood *et al.* 2005). This also has been shown to reduce coral growth rates because reduced light levels result in reduced photosynthesis by the coral's symbiotic zooxanthellae (Rogers 1990). Slower flow, combined with sediment trapping by turf algae, and a turbid environment result in an unfavourable environment for settlement and growth of juvenile corals. This is likely to be the reason for the difference in the proportion of the juvenile coral population that grew between locations.

Species composition of coral recruits and their relative abundance often do not reflect that of adult populations (Smith 1997). It is often seen on Atlantic reefs that brooding corals, poritiids and agariciids, quantitatively dominate the pool of recruits but contribute only a small proportion to adult cover, whilst broadcast spawning species that often dominate the adult reef framework (e.g. *Diploria* and *Montastraea* spp.) show much lower levels of recruitment (Smith 1997). This relationship between reproductive mode and subsequent recruitment level has been seen in a number of studies (Bak and Engel 1979; Rogers *et al.* 1984; Hunte and Wittenberg 1992; Smith 1992, 1997; Vermeij 2006). Following this trend, the majority (>80 %) of juvenile corals within the permanent quadrats in Castle Harbour were brooding coral species; *Agaricia* spp., *Siderastrea* spp., *Favia fragum* and *Porites astreoides* (Duerden 1902; Duerden 1904; Vaughan 1908; Vaughan 1909; Vaughan 1910; Mavor 1915; Lewis 1974a: see Table 1 in Fadlallah 1983). This indicates that much of the larval supply to these reefs is likely

to come from brooding colonies in the immediate vicinity, since brooding corals release larvae that can settle rapidly (Lewis 1974b; Goreau *et al.* 1981; Neves and de Silveira 2003). There were relatively few *Diploria* spp., and no *Montastraea* spp. juveniles seen in this study (all broadcast spawners) (Matthai 1928; Cairns 1982; Szmant 1986). Smith (1992) found that although *Diploria* spp. were poor recruiters on the rim reefs of Bermuda, they suffered much lower rates of post settlement mortality, enabling these species to dominate the reefs. It would appear that this is also the case in this study, since despite low recruitment of *Diploria* spp., they are still the major component of hard coral cover inside Castle Harbour (see Section 3.1).

4.5 Quantification and qualification of hard coral growth and survival within Castle Harbour – adults

Estimates on adult (>5 cm diameter), massive coral growth, total colony mortality, and colony size reduction through partial mortality, provide another method of looking into individual coral survival, giving an impression of overall reef health at the adult life history stage. Permanent quadrat data on adult coral colonies from the location directly to the west of the airport peninsula, and the location closest to the south shore opening (locations 2 and 5), show that adult coral populations within the harbour seem fairly stable, and that the majority of adult colonies studied grew, rather than reduced in colony size, or suffered total colony mortality. The photoquadrats captured evidence of the effects of acute events such as hurricanes (hurricane Fabian, September 2003); where individual adult colonies suffered dislodging (Fig. 26), and UV bleaching (April, 2006); where partial mortality was seen (Fig. 24, Section 4.2, page 74). However, even with these major disturbances, there are few incidences of adult hard coral death in Castle Harbour. Overall the evidence suggests that the adult massive coral populations

within Castle Harbour are surviving and growing, which the size demographics data of *Diploria* spp. corroborates (Sections 3.1 and 3.7). A comparison to growth and survival of corals outside the harbour would provide some perspective on this; however these data are not currently available.

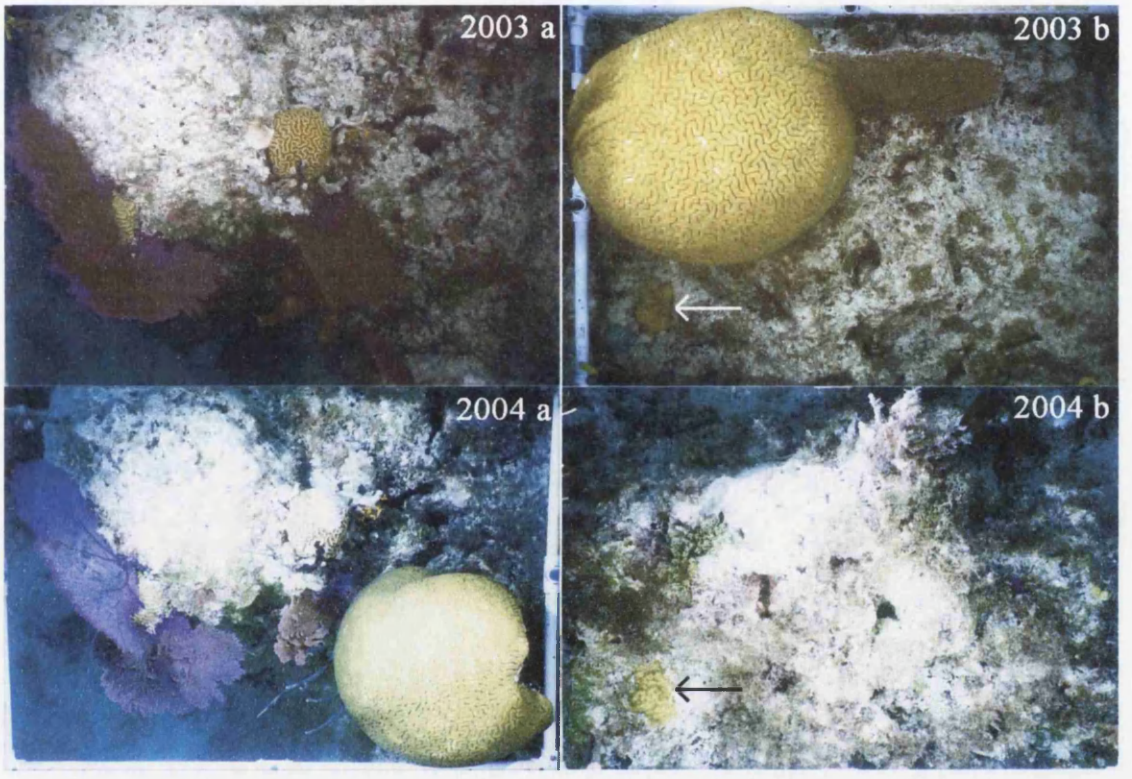


Fig. 26 Photographs indicating the dislodging of an adult *Diploria labyrinthiformis* colony from quadrat 'b' in 2003 (pre-hurricane), to the adjacent quadrat 'a' in 2004 (post-hurricane). Arrows indicate a *Porites astreoides* colony for quadrat reference.

4.6 *Diploria* spp. demographics determined by size

Understanding how and why coral cover changes is fundamental to coral reef management (Smith *et al.* 2005). Coral's life history processes are affected by their environment and this is represented in the size structure of the population (Meesters *et al.* 2001). For example, settlement and recruitment can be compromised by environmental factors (Gleason 1996; Fairfull and Harriott 1999; Carlton 2001; Vermeij

2006), resulting in low abundances of smaller size groups. Looking at coral size frequency distributions can provide valuable information on ecological processes at various life history stages, and the effects of these on the population as a whole (Bak and Meesters 1998).

Size distributions of broadcast spawning corals *Diploria* spp. highlight a number of interesting factors regarding the populations inside Castle Harbour. *D. strigosa* is the dominant of the two species outside Castle Harbour, and prior to dredging *Diploria* spp. were fairly evenly represented within the harbour (Dodge and Vaisnys 1977). Currently *D. labyrinthiformis* is proportionally more dominant throughout most of the harbour, though *D. strigosa* dominates on the reefs directly to the north of the opening to the south shore (the only point of water exchange between the harbour and open ocean), and east of the peninsula (locations 6 and 7, Fig. 3). The relative dominance of *D. labyrinthiformis* inside Castle Harbour can be looked at more closely through the size-frequency distributions at each location. Along a gradient of proximity to, and improved water exchange with the south shore (location 1 being furthest away, location 5 being closest, Fig. 3), the ratio of *D. strigosa* to *D. labyrinthiformis* becomes more even through the lower/medium size classes (starting with the smallest). However, *D. labyrinthiformis* always dominates the largest size classes throughout Castle Harbour. At locations to the north and east of the south shore opening (locations 6 and 7) *D. strigosa* dominates all but the smallest size classes (where the ratio is roughly equal). This is attributed to an increase in proximity to clear inflowing waters of the south shore, which causes better flushing and removal of sediments from the area, thus creating favourable enough conditions to negate *D. labyrinthiformis*' superior sediment shedding abilities (Section 4.2). This allows *D. strigosa* to reclaim its dominance on the reefs closest to clear water inflow, whilst the reefs further into the harbour remain

subjected to more turbid conditions, and lower flow rates (Flood *et al.* 2005), which allows sediments to build up on reef surfaces (pers. obs.), thus favouring *D. labyrinthiformis*' dominance.

Looking closely at the individual size frequency distributions from each location it can be seen that *Diploria* spp. population distributions outside Castle Harbour are most regularly skewed slightly to the left, with the left tail appearing long relative to the right tail (though often not significantly so). Meesters *et al.* (2001) demonstrated hard coral species that grow larger and live longer (such as *Diploria* spp.) are less dependant on frequent recruitment to sustain their populations, and so have populations that tend to have low frequencies of small colonies, resulting in size-frequency distributions that are skewed to the left. Kurtosis of *D. labyrinthiformis* populations is only significant inside Castle Harbour. The *Diploria labyrinthiformis* populations towards the middle of the harbour (location 3, Fig. 3) show significant peaked-ness (leptokurtosis), which combined with significant left skew, demonstrates a population dominated by large colonies (Fig. 21). The *D. labyrinthiformis* populations at the location directly to the west of the airport peninsula, and the location closest to the south shore opening (locations 2 and 5, Fig. 3), are clearly platykurtic, as evidenced by their bimodal size-frequency distributions (Fig. 21). These populations have lower than normal representation in the size classes about their means, indicating either lack of recruitment of these groups, or an event that selectively affected these size classes. Kurtosis values for *D. strigosa* populations inside Castle Harbour are significant at the middle location, the fringing reefs to the west of the harbour, and the location along the northern edge of the harbour, to the east of the airport peninsula (locations 3, 4 and 7, Fig. 3). The coral population at location 7 shows significant peaked-ness, and again, combined with its significant left skew demonstrates a population dominated by large colonies (Fig. 22).

The middle location and fringing reef location have significantly platykurtic *D. strigosa* populations which can again be seen in the bimodal size-frequency distributions, implying lower than normal representation in the size classes about their means (Fig. 21).

To better understand the significance of these patterns, approximate age data from roughly hemispherical colonies only within Castle Harbour was looked at. Age-frequency distributions of these data show there were no *D. strigosa* colonies older than 60 years recorded within Castle Harbour. With the dredge and landfill operations having happened 64 years ago, it can be concluded that *D. strigosa* colonies did not survive the dredging activities in Castle Harbour, and that recruitment must have been severely hindered for a number of years afterwards. Approximately 10 years post-dredging *D. strigosa* were recruiting to the reefs of Castle Harbour once again. Demographic patterns suggest that *D. labyrinthiformis*, however, did survive the dredging activities, with ~10 % of the current population having been alive prior to the time of dredging. Applying the results from these data to the remainder of the *Diploria* spp. population sampled in this study, the dominance of *D. labyrinthiformis* in the larger size groups is likely a combination of its initial ability to survive the dredging activities combined with its reportedly better sediment shedding abilities (Hubbard and Pocock 1972) in the subsequently turbid waters of Castle Harbour. Approximately equal recruitment of these congeners over more recent years, combined with location dependant growth and survival of juveniles along a gradient of improved water exchange with the south shore has led to increasingly equal representation of these two species in all but the largest size classes within Castle Harbour. This indicates a degree of recovery, with *Diploria* spp. populations representing more closely the ratio present prior to the dredging activities of the 1940's.

4.7 Modelling

The data collected thus far provide information over a four-year period in time. This is enough to loosely base an initial model projection of future populations on, however, unlikely assumptions must be made that the rates observed in this study will remain the same through time (Smith *et al.* 2005). Because of these assumptions, modelling enables *projections*, not *predictions*, of future populations to be made (Bierzychudek 1999; Ebert 1999). Using STELLA™ 7.0, and data gathered on growth and survival at each of the corals life history stages, a model was constructed to project future coral populations at two contrasting locations within Castle Harbour; the location to the west of the airport peninsula (location 2), and the location nearest to the south shore opening (location 5). An appropriate control location from outside Castle Harbour could not be found so a gradient of from (a) deep inside the harbour, in close the dumpsite and the area of past dredging activities, to (b) close to the south shore entrance, further away from the dumpsite and area of past dredging activities was used instead. The coral populations were divided into two sub-populations: juveniles (<50 mm) and adults (> 50 mm). Average numbers of each, per m^2 for each location, were used as the base numbers for the model. Applying the recruitment, growth and mortality rates from the respective locations could then alter these population numbers.

For the present adult coral populations of Castle Harbour space is unlikely to be impacting growth and survival, and therefore is not a parameter that is manifested in the population growth curves generated from these data.

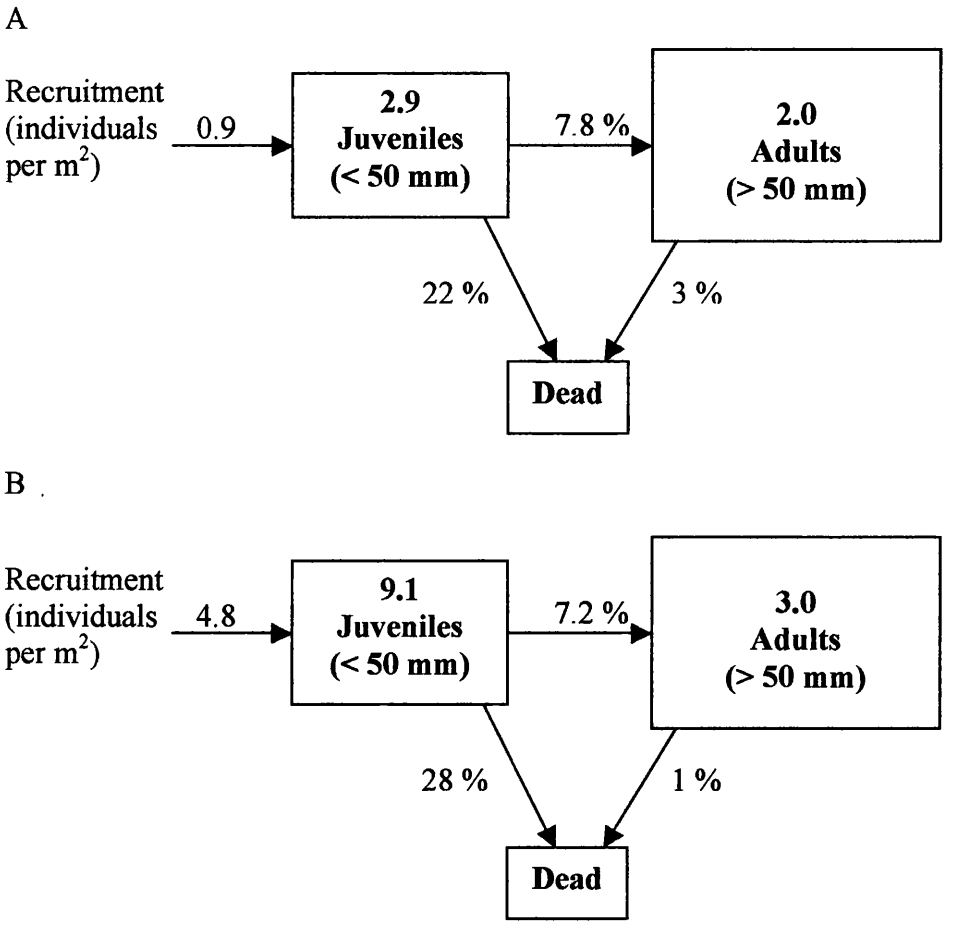


Fig. 27 Example of life-cycle diagrams for coral colonies, using data obtained from, **A**. location 2, to the west of the airport peninsula, **B**. location 5, closest to the south shore opening.

At present, the coral populations at the two study locations within Castle Harbour are quite different, with significantly greater coral cover seen at the location closest to the south shore opening (Section 3.1). However, parameters at the two locations are very similar in terms of adult and juvenile colony mortality, and recruitment rates of juveniles into the adult population (Fig. 27). Modelled projections of adult coral populations show that at the location to the west of the airport peninsula, populations are projected to increase slightly over the years, whilst coral populations at the location closest to the south shore opening are projected to increase more steeply (Fig. 28), assuming recruitment, growth and mortality rates remain the same. This steep linear

growth of the population is unlikely because limiting factors (at present, un-measured) such as competition for space will begin to play a role as the coral community recovers.

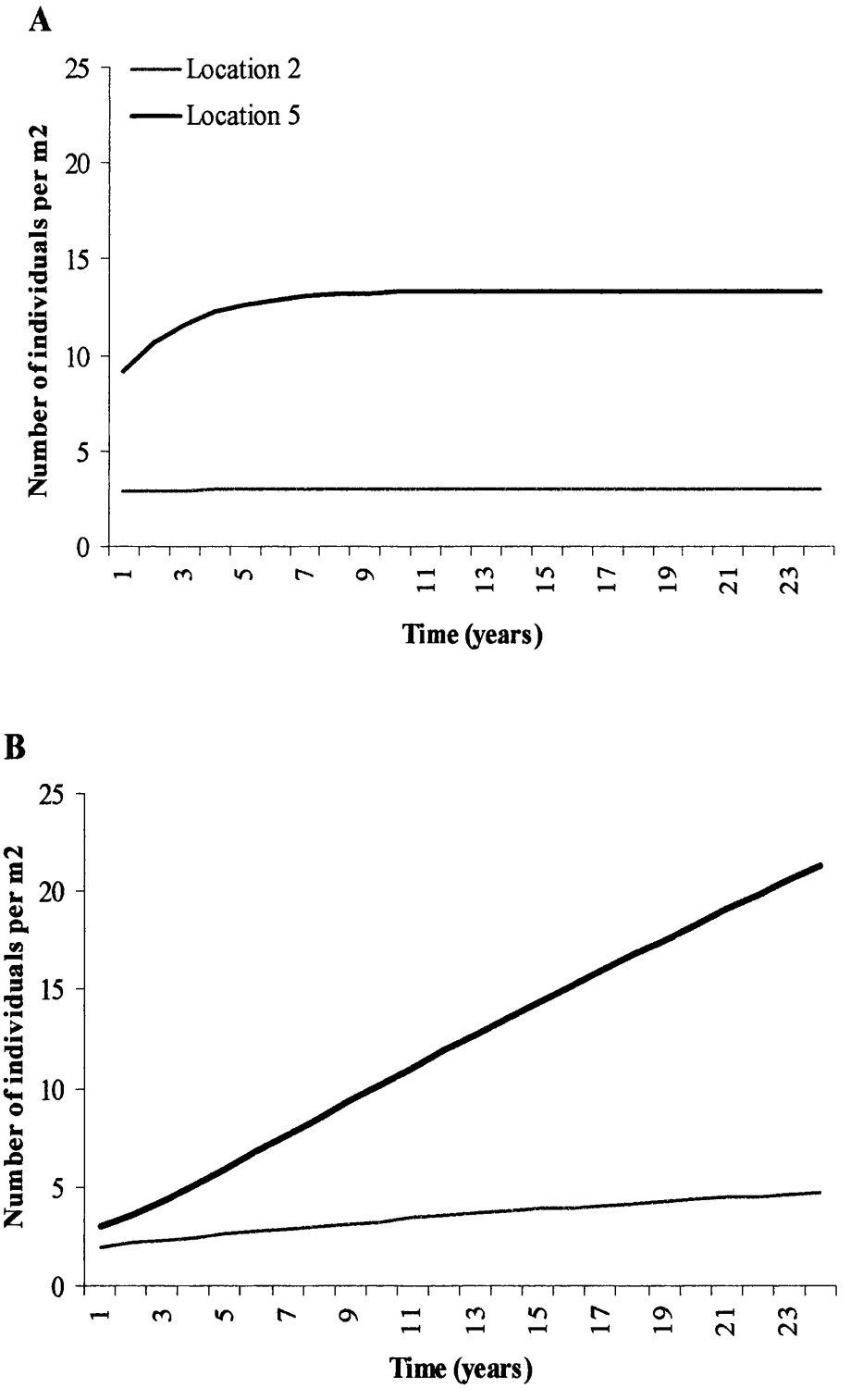


Fig. 28 Simulated projections of **A.** juvenile coral populations per m^2 and, **B.** adult coral populations per m^2, at location 2, to the west of the airport peninsula, and 5, closest to the south shore opening. The projected populations are assuming that recruitment, growth and mortality rates remain as recorded by these studies.

This difference in present and projected coral populations of Castle Harbour can be attributed to the number of juvenile corals recruiting to the reefs (Fig. 27). There are significantly greater numbers of juvenile corals recruiting to the reefs at the location closest to the south shore opening (Section 3.5). This reflects the higher rates of settlement seen at this location also (Section 3.4). All other parameters vary little between these locations (Fig. 27). The lower settlement and subsequent recruitment rates at the peninsula location are likely a result of the lower flow rates here (Flood *et al.* 2005), resulting in less sediment re-suspension. This causes a near-permanent layer of sediment to be present on the reef surface (pers. obs.), which inhibits coral settlement and recruitment (Hunte and Wittenberg 1992; Birrell *et al.* 2005) (Section 4.3).

As mentioned before, the data gathered are only from over a four-year time period. For more accurate projections, coral populations should me monitored over longer periods of time, which would provide greater detail on population change over time, and reduce the possibility of data being based on stochastic events.

Chapter 5: Conclusions and future work

The coral communities of Castle Harbour have been heavily impacted by human activities for over a century, with the dredge and landfill operations of the 1940's causing the greatest disturbance both physically and biologically. During these operations 12-15 x 10^6 m^3 of fill was dredged from the benthos of Castle Harbour and used to create 3 km^2 of land. In the process, 5.6 hectares of mangroves, 18.2 hectares of seagrass beds, and 24.4 hectares of coral reef within the harbour were either destroyed or buried (Sterrer and Wingate 1981; Smith 1999). The resulting changes to the land altered the hydrography of the basin, and left the harbour in a state of high turbidity, and reduced water flow in certain areas (Flood *et al.* 2005). Consequently, the coral communities of Castle Harbour suffered catastrophic mass mortalities. Past studies have shown major changes to the coral communities within, when compared to observations of Castle Harbour's reefs made prior to commencement of the dredging activities (Dodge and Vaisnys 1977; Dryer and Logan 1978).

As has been shown in previous studies (Dodge and Vaisnys 1977; Dryer and Logan 1978; Flood *et al.* 2005), coral cover inside Castle Harbour is highly depauperate when compared to similar reefs outside the harbour. It seems that the dredge and landfill activities of the 1940's are the probable cause (Dodge and Vaisnys 1977; Dryer and Logan 1978; Flood *et al.* 2005). Since the study by Dryer and Logan (1978) there has been no subsequent evidence of continued declines in coral cover within the harbour which leads to the question: are the coral reefs of Castle Harbour in a state of slow recovery, or are they now in a permanently depauperate state from which they are unlikely to recover? This study showed that total cover inside Castle Harbour is still much lower than on reefs outside the harbour, however, direct comparisons of data from

this study to Dodge and Vaisnys' (1977) and Dryer and Logan's (1978) studies suggest that, within Castle Harbour, total coral cover of the dominant reef-building coral species (*Diploria* spp.) appears to have increased slightly since the 1970's. Given that nearly 30 years has passed between these studies, the increase in percentage cover by *Diploria* spp. over time is likely caused, in part, by the growth of existing adult colonies (Sections 3.6 and 4.5), but also through recruitment of new colonies (Section 4.7).

Surprisingly, the coral communities of Castle Harbour appear to suffer only intermediate levels of partial mortality when compared to other reefs around the Bermuda reef platform, and there was little evidence of disease in these depauperate communities. This indicates a relatively healthy population and shows that it is not these parameters that are shaping the current coral communities.

Although coral recruitment has obviously added to coral cover over the past 30 years, this study has shown settlement and recruitment to be the weakest link in the life history stages of Castle Harbour's corals, especially at locations furthest away from inflowing oceanic waters. Both settlement and recruitment are lower inside Castle Harbour than on external reefs. Reasons for the low settlement and recruitment values seen inside Castle Harbour include poor connectivity with reefs over the rest of the Bermuda reef platform as a result of the harbour's semi-enclosed nature, resulting in poor larval supply. Also, both settlement and recruitment could be negatively affected by low flow and high turbidity rates as a result of the dredging activities (Morris *et al.* 1977; Flood *et al.* 2005). These factors combined result in poor larval supply, and reef surfaces unsuited to coral larval settlement and survival through sediment entrapment by algae and infrequent sediment re-suspension by the weak currents. Sediments have proven themselves to be detrimental to both coral larval settlement (Babcock 1991) and

survival of recruits (Hunte and Wittenberg 1992). As a result, recovery of coral reefs from sedimentation and turbidity is most likely in areas of good water flow, where sediments can be cleared from the area (Wilkinson 1999). Because of the alterations to the land mass surrounding Castle Harbour, and the low flow rates within the harbour, the dredge and land-fill operations have created a long term, maybe even permanent, change to the environment within Castle Harbour. Since the hydrology of the basin is unlikely to be changed in the near future, recovery of coral reefs inside Castle Harbour is dependant on coral species that can survive and reproduce in areas of prolonged sedimentation and elevated turbidity.

The modelling has illustrated how at the location directly to the west of the airport peninsula (deep within Castle Harbour) the low recruitment rates seen in this study could lead to an adult coral population that is barely maintained. With all other parameters approximately equal, but with elevated recruitment rates, the location closest to the south shore opening appears to have an adult coral population with the potential to increase over time. Even small increases in recruitment rate, with all other parameters remaining the same, could result in considerable population growth at both locations.

The coral reefs of Bermuda are typically dominated by *Diploria strigosa* and *Montastraea franksi*, whilst the coral reefs inside Castle Harbour are dominated by *Diploria labyrinthiformis*. Prior to the dredging activities, the coral reefs of Castle Harbour were dominated by both *Diploria* spp. (Agassiz 1895), in roughly equal proportions (Dodge and Vaisnys 1977). When looking at the demographics as determined by size/age of these species, it is clear that *D. strigosa* were far more susceptible to the dredging activities and were almost entirely eliminated from the harbour by the dredging activities. This is likely the cause for the observed alteration in

species dominance within Castle Harbour (Sections 3.7 and 4.7). The elevated levels of sedimentation within the harbour, caused by the dredging activities, also prevented *D. strigosa* settlement for a number of years post-dredging, whilst *D. labyrinthiformis* did not appear to be similarly affected. The superior survival of *D. labyrinthiformis* colonies is likely a result of *D. labyrinthiformis*' reportedly better sediment shedding abilities (Hubbard and Pocock 1972) in the subsequently turbid environment, leaving *D. labyrinthiformis* as the dominant species throughout most of Castle Harbour.

The coral reefs of Castle Harbour were catastrophically damaged by the dredging activities of the 1940's. From the data gathered in this study it could be assumed that the reefs further inside the harbour (away from the south shore opening) will remain in their depauperate state, with little hope of ever returning to their pre-dredging conditions. Those reefs nearer to the south shore opening have the highest coral cover of the reefs studied within the harbour, and have the greatest potential to continue on their apparent path to recovery.

Recovery of Castle Harbour's reefs has been, and will continue to be slow for a number of reasons. High latitude coral reefs, such as Bermuda's, exist at the extreme limits of hermatypic reef growth. At high latitudes, corals live close to their lower thermal tolerances and experience lower annual levels of photosynthetically active radiation (PAR) because of the low sun angle during the winter months (Wilkinson 1999). These factors mean that high latitude coral populations, such as Bermuda's, are slower growing than conspecifics of lower latitudes (Logan and Tomascik 1991). Consequently high latitude coral reefs are slower to recover from such mass mortality events as those seen in Castle Harbour (Cook *et al.* 1994).

Future research

There are many questions still to be resolved to enable a full understanding of the processes underlying the present state of Castle Harbour's coral reefs. Further hypotheses that should be tested include:

- Is larval supply to Castle Harbour compromised? Such a study would be conducted through analysis of colony genetics. These data would provide insight into the level of relatedness of colonies both inside and outside Castle Harbour, indicating the degree of connectivity between populations, and showing whether Castle Harbour's coral populations are self reliant with regards to larval supply, or whether they depend on supply from outside.

- How reproductively active are the major reef-builders in Castle Harbour, and is reproductive output location dependent? Answering this question would illustrate how reproductively successful Castle Harbour's reefs are up to the point of spawning. Elements of reproductive biology such as gamete size, number and synchronicity of spawning should be studied. To study the reproductive output of the major reef-building coral species within Castle Harbour would be hugely valuable to our understanding of the life history processes shaping these communities. This study would supplement the information gathered through the larval supply and connectivity study.

- Are there any correlations between reproductive output and environmental pollutants (potentially originating from the dumpsite)? This would be done in conjunction with the above study and would highlight potential impacts of

pollutants such as lead, cadmium, copper, polychlorinated biphenyls (PCB's) on reproductive ecology within Castle Harbour.

- What is the grazing pressure to the reefs of Castle Harbour, and how does this relate to algal cover and nutrient levels? Such a study would paint a more detailed picture of the 'top-down' versus 'bottom-up' pressures on Castle Harbour's reefs, and the impact this may be having on the coral communities at present.

All such data combined would provide a great basis for a study into the best methods to aid coral reef restoration. Coral reef restoration is defined as "...the return of an ecosystem to a close approximation of its condition prior to disturbance..." (Precht and Robbart 2006). Thus far, this study has established that coral settlement and recruitment are limiting factors within Castle Harbour, and that adult coral populations are relatively stable and healthy. As such, transplantation of adult colonies onto the reefs of Castle Harbour is a possible method of reef restoration, increasing coral cover and returning balance to the species composition within the harbour. Coral transplantation studies have shown several trends: coral transplants are more likely to survive when transplanted into low-energy, sheltered environments (Clark and Edwards 1995; Bowden-Kerby 1997; Zimmer 2006), selection of transplantation corals from an environment similar to the donor site seems most effective (Auberson 1982; Zimmer 2006), transplantation is most appropriate on reefs that are recruitment limited (Kojis and Quinn 2001; Zimmer 2006). This would appear to make Castle Harbour a suitable area to attempt such a project. Following coral reef restoration, long term monitoring would be required to establish the success or failure of the project (Precht and Robbart 2006). Benthic cover and composition, settlement rates and juvenile coral population

size and composition should be monitored to look for long-term changes in community composition and function.

With good background knowledge of the structure and function of Castle Harbour's reefs, and those un-impacted reefs surrounding the islands of Bermuda, a suitable restoration strategy can be formulated, increasing the likelihood of success. There is much to be learnt about what will and will not work with regards to coral reef restoration (Precht and Robbart 2006), and it is vital that any information gleaned is shared with the coral reef scientific community to aid further research.

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Appendices

Appendix 1: Coral cover outside Castle Harbour

Testing for homogeneity of variances among number of hard coral CPCe points at each *site* outside Castle Harbour to ensure replicate sites may be grouped into locations.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50

χ^2 = 9.1651, df = 9

c = 1.091667

χ^2c = 8.3956, P = 0.4948

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Coral cover

Defined by site

Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Site	297296.1800	9	33032.90889	93.5591	5.164 10^-24
Within	14122.8000	40	353.07000		

There are significant differences in coral cover between sites (P <0.05)

Post Hoc testing (multiple comparisons among means) using T', T-K, GT2 methods

Samples defined by: Site

Variable: Coral cover

Total sample size: 50

Comparing sample ILb against:

Sample:	ILa
Diff:	70.4000*
MSD(TK):	39.7892
MSD(GT2):	41.3918

Comparing sample STb against:

Sample:	STa
Diff:	53.0000*
MSD(TK):	39.7892
MSD(GT2):	41.3918

Comparing sample SRb against:

Sample:	SRa
Diff:	12.2000
MSD(TK):	39.7892
MSD(GT2):	41.3918

*** indicates P<=0.050 for at least one method**

Comparing sample OLb against:

Sample:	OLa
Diff:	20.0000
MSD(TK):	39.7892
MSD(GT2):	41.3918

Comparing sample NRa against:

Sample:	NRb
Diff:	7.4000
MSD(TK):	39.7892
MSD(GT2):	41.3918

Testing for homogeneity of variances among number of hard coral CPCe points at each *location* outside Castle Harbour.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50

χ^2 = 8.3859, df = 6

c = 1.072782

χ^2c = 7.8170, P = 0.2518

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Coral cover

Defined by location

Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Location	295787.1800	6	49297.86333	135.6087	2.778 10^-26
Within	15631.8000	43	363.53023		

There are significant differences in coral cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons among means) using T', T-K, GT2 methods

Samples defined by: Location

Variable: Coral cover

Total sample size: 50

Comparing sample ILb against:

Sample:	SR	ILa	NR	OL	STb	STa
Diff:	64.9000*	70.4000*	80.3000*	85.4000*	220.6000*	273.6000*
MSD(TK):	32.2943	37.2902	32.2943	32.2943	37.2902	37.2902
MSD(GT2):	33.4870	38.6675	33.4870	33.4870	38.6675	38.6675
MSD(T'):	37.2902	37.2902	37.2902	37.2902	37.2902	37.2902

Comparing sample SR against:

Sample:	ILa	NR	OL	STb	STa
Diff:	5.5000	15.4000	20.5000	155.7000*	208.7000*
MSD(TK):	32.2943	26.3682	26.3682	32.2943	32.2943
MSD(GT2):	33.4870	27.3420	27.3420	33.4870	33.4870
MSD(T'):	37.2902	26.3682	26.3682	37.2902	37.2902

Comparing sample ILa against:

Sample:	NR	OL	STb	STa
Diff:	9.9000	15.0000	150.2000*	203.2000*
MSD(TK):	32.2943	32.2943	37.2902	37.2902
MSD(GT2):	33.4870	33.4870	38.6675	38.6675
MSD(T'):	37.2902	37.2902	37.2902	37.2902

Comparing sample NR against:

Sample:	OL	STb	STa
Diff:	5.1000	140.3000*	193.3000*
MSD(TK):	26.3682	32.2943	32.2943
MSD(GT2):	27.3420	33.4870	33.4870
MSD(T'):	26.3682	37.2902	37.2902

Comparing sample OL against:

Sample:	STb	STa
Diff:	135.2000*	188.2000*
MSD(TK):	32.2943	32.2943
MSD(GT2):	33.4870	33.4870
MSD(T'):	37.2902	37.2902

Comparing sample STb against:

Sample:	STa
Diff:	53.0000*
MSD(TK):	37.2902
MSD(GT2):	38.6675
MSD(T'):	37.2902

*** indicates P<=0.050 for at least one method.**

Appendix 2: Coral cover inside Castle Harbour

Testing for homogeneity of variances among number of hard coral CPCe points at each *site* within Castle Harbour to ensure replicate sites may be grouped by location.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 7.8864, df = 13

c = 1.089286

$\chi^2 c$ = 7.2400, P = 0.8894

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Coral cover

Defined by site

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Site	5632.6429	13	433.28022	5.2351	5.298 10^-6
Within	4634.8000	56	82.76429		

There are significant differences in coral cover amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: Coral cover

Total sample size: 70

Comparing sample 1a against:
Sample: 1b
Diff: 3.6000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 2b against:
Sample: 2a
Diff: 7.0000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 3a against:
Sample: 3b
Diff: 6.6000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 4a against:
Sample: 4b
Diff: 13.0000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 5b against:
Sample: 5a
Diff: 0.6000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 6b against:
Sample: 6a
Diff: 0.2000
MSD(TK): 20.1659
MSD(GT2): 20.9429

Comparing sample 7b against:
Sample: 7a
Diff: 6.4000
MSD(TK): 20.1659
MSD(GT2): 20.9429

*** indicates P<=0.050 for at least one method**

Testing for homogeneity of variances among number of hard coral CPCe points at each *location* within Castle Harbour.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 6.1708, df = 6

c = 1.042328

$\chi^2 c$ = 5.9202, P = 0.4322

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Coral cover

Defined by location

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Location	4842.9429	6	807.15714	9.3743	2.423 10^-7
Within	5424.5000	63	86.10317		

There are significant differences in coral cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: Coral cover

Total sample size: 70

Comparing sample 6 against:

Sample:	1	4	2	3	7	5
Diff:	2.5000	9.0000	9.6000	11.0000	11.5000	28.0000*
MSD(TK):	12.6383	12.6383	12.6383	12.6383	12.6383	12.6383
MSD(GT2):	13.0718	13.0718	13.0718	13.0718	13.0718	13.0718
MSD(T'):	12.6383	12.6383	12.6383	12.6383	12.6383	12.6383

Comparing sample 1 against:

Sample:	4	2	3	7	5
Diff:	6.5000	7.1000	8.5000	9.0000	25.5000*
MSD(TK):	12.6383	12.6383	12.6383	12.6383	12.6383
MSD(GT2):	13.0718	13.0718	13.0718	13.0718	13.0718
MSD(T'):	12.6383	12.6383	12.6383	12.6383	12.6383

Comparing sample 4 against:

Sample:	2	3	7	5
Diff:	0.6000	2.0000	2.5000	19.0000*
MSD(TK):	12.6383	12.6383	12.6383	12.6383
MSD(GT2):	13.0718	13.0718	13.0718	13.0718
MSD(T'):	12.6383	12.6383	12.6383	12.6383

Comparing sample 2 against:

Sample:	3	7	5
Diff:	1.4000	1.9000	18.4000*
MSD(TK):	12.6383	12.6383	12.6383
MSD(GT2):	13.0718	13.0718	13.0718
MSD(T'):	12.6383	12.6383	12.6383

Comparing sample 3 against:

Sample:	7	5
Diff:	0.5000	17.0000*
MSD(TK):	12.6383	12.6383
MSD(GT2):	13.0718	13.0718
MSD(T'):	12.6383	12.6383

Comparing sample 7 against:

Sample:	5
Diff:	16.5000*
MSD(TK):	12.6383
MSD(GT2):	13.0718
MSD(T'):	12.6383

*** indicates P<=0.050 for at least one method.**

Appendix 3: Gorgonian cover

Testing for homogeneity of variances among number of gorgonian CPCe points at each *reef zone.*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 120
χ^2 = 51.6297, df = 3
c = 1.029175
χ^2c = 50.1661, P = 7.364 10^-11

The variances of the samples are heterogeneous (P <0.05)

$\log_{10}$ (Number of points on 'Gorgonians' +1)
χ^2 = 7.0464, df = 3
c = 1.029175
χ^2 c = 6.8466, P = 0.0770

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: $\log_{10}$ (Number of points on 'Gorgonians'+1)
Defined by reef zone
Sample size: 120

ANOVA Table

Level	SS	df	MS	Fs	P
Zone	6.2784	4	1.56961	10.3027	3.635 10^-7
Within	17.5202	115	0.15235		

There are significant differences in gorgonian cover amongst reef zones (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Zone

Variable: $\log_{10}$ (Number of points on 'Gorgonians'+1)

Total sample size: 120

Comparing sample Inner lagoon against:

Sample:	Outer lagoon	Castle Harbour	Terrace/Rim
Diff:	0.1408	0.3383	0.7530*
MSD(TK):	0.4531	0.3425	0.3700
MSD(GT2):	0.4649	0.3514	0.3796
MSD(T'):	0.4532	0.4532	0.4532

Comparing sample Outer lagoon against:

Sample:	Castle Harbour	Terrace/Rim
Diff:	0.1975	0.6122*
MSD(TK):	0.3425	0.3700
MSD(GT2):	0.3514	0.3796
MSD(T'):	0.4532	0.4532

Comparing sample Castle Harbour against:

Sample:	Terrace/Rim
Diff:	0.4147*
MSD(TK):	0.2211
MSD(GT2):	0.2268
MSD(T'):	0.2617

*** indicates P<=0.050 for at least one method.**

Appendix 4: Gorgonian cover outside Castle Harbour

Testing for homogeneity of variances among number of gorgonian CPCe points at each *site* outside Castle Harbour to ensure replicate sites may be grouped by location.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50
χ^2 = 24.1373, df = 9
c = 1.091667
χ^2c = 22.1105, P = 0.0085

The variances of the samples are heterogeneous (P <0.05)

SQRT (Number of points on 'Gorgonians' + 0.5)
χ^2 = 5.0801, df = 9
c = 1.091667
χ^2c = 4.6535, P = 0.8634

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)
Defined by variable site
Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Site	346.4581	9	38.49535	52.6114	2.300 10^-19
Within	29.2677	40	0.73169		

There are significant differences in gorgonian cover amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: SQRT (Number of points on 'Gorgonians'+ 0.5)

Total sample size: 50

Comparing sample ILa against:

Sample:	ILb
Diff:	2.0944*
MSD(TK):	1.8113
MSD(GT2):	1.8843

Comparing sample OLa against:

Sample:	OLb
Diff:	0.2592
MSD(TK):	1.8113
MSD(GT2):	1.8843

Comparing sample STb against:

Sample:	STa
Diff:	0.8167
MSD(TK):	1.8113
MSD(GT2):	1.8843

Comparing sample NRa against:

Sample:	NRb
Diff:	1.6287
MSD(TK):	1.8113
MSD(GT2):	1.8843

Comparing sample SRa against:

Sample:	SRb
Diff:	1.5381
MSD(TK):	1.8113
MSD(GT2):	1.8843

*** indicates P<=0.050 for at least one method**

Testing for homogeneity of variances among number of gorgonian CPCe points at each *location* outside Castle Harbour.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50

χ^2 = 34.1041, df = 5

c = 1.061448

χ^2c = 32.1298, P = 5.600 10^-6

The variances of the samples are heterogeneous (P <0.05)

SQRT (Number of points on 'Gorgonians' + 0.5)

χ^2 = 5.8075, df = 5

c = 1.061448

χ^2 c = 5.4713, P = 0.3611

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)

Defined by variable location

Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Location	332.0760	5	66.41520	66.9481	1.913 10^-19
Within	43.6498	44	0.99204		

There are significant differences in gorgonian cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)

Total sample size: 50

Comparing sample ILa against:

Sample:	OL	ILb	ST	NR	SR
Diff:	1.3998	2.0944*	2.5917*	4.6925*	7.9092*
MSD(TK):	1.6253	1.8767	1.6253	1.6253	1.6253
MSD(GT2):	1.6824	1.9427	1.6824	1.6824	1.6824
MSD(T'):	1.8767	1.8767	1.8767	1.8767	1.8767

Comparing sample OL against:

Sample:	ILb	ST	NR	SR
Diff:	0.6946	1.1919	3.2927*	6.5094*
MSD(TK):	1.6253	1.3270	1.3270	1.3270
MSD(GT2):	1.6824	1.3737	1.3737	1.3737
MSD(T'):	1.8767	1.3270	1.3270	1.3270

Comparing sample ILb against:

Sample:	ST	NR	SR
Diff:	0.4973	2.5981*	5.8148*
MSD(TK):	1.6253	1.6253	1.6253
MSD(GT2):	1.6824	1.6824	1.6824
MSD(T'):	1.8767	1.8767	1.8767

Comparing sample ST against:

Sample:	NR	SR
Diff:	2.1008*	5.3175*
MSD(TK):	1.3270	1.3270
MSD(GT2):	1.3737	1.3737
MSD(T'):	1.3270	1.3270

Comparing sample NR against:

Sample:	SR
Diff:	3.2167*
MSD(TK):	1.3270
MSD(GT2):	1.3737
MSD(T'):	1.3270

*** indicates P<=0.050 for at least one method.**

Appendix 5: Gorgonian cover inside Castle Harbour

Testing for homogeneity of variances among number of gorgonian CPCe points at each *site* inside Castle Harbour to ensure replicate sites may be grouped by location.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70
χ^2 = 34.8871, df = 13
c = 1.089286
χ^2c = 32.0275, P = 0.0024

The variances of the samples are heterogeneous (P <0.05)

SQRT (Number of points on 'Gorgonians' + 0.5)
χ^2 = 15.9400, df = 13
c = 1.089286
χ^2c = 14.6334, P = 0.3308

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)
Defined by site
Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Site	193.9444	13	14.91880	13.9829	3.633 10^-13
Within	59.7481	56	1.06693		

There are significant differences in gorgonian cover amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)

Total sample size: 70

Comparing sample 1b against:

Sample:	1a
Diff:	1.4236
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 2a against:

Sample:	2b
Diff:	0.0742
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 3a against:

Sample:	3b
Diff:	3.4452*
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 4a against:

Sample:	4b
Diff:	1.8849
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 5b against:

Sample:	5a
Diff:	1.6259
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 6a against:

Sample:	6b
Diff:	1.9976
MSD(TK):	2.2896
MSD(GT2):	2.3778

Comparing sample 7a against:

Sample:	7b
Diff:	1.0385
MSD(TK):	2.2896
MSD(GT2):	2.3778

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among number of gorgonian CPCe points at each *location* inside Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 27.4156, df = 7

c = 1.054788

χ^2c = 25.9916, P = 0.0005

The variances of the samples are heterogeneous (P <0.05)

SQRT (Number of points on 'Gorgonians'+ 0.5)

χ^2 = 5.3645, df = 7

c = 1.054788

χ^2c = 5.0859, P = 0.6495

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)

Defined by variable location

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Location	160.7010	7	22.95729	15.3063	1.899 10^-11
Within	92.9915	62	1.49986		

There are significant differences in gorgonian cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: SQRT(Number of points on 'Gorgonians'+ 0.5)

Total sample size: 70

Comparing sample 2 against:

Sample:	1	3a	4	6	5	7	3b
Diff:	0.7013	1.1770	2.5518*	2.6686*	2.7114*	4.4287*	4.6222*
MSD(TK):	1.7180	2.1041	1.7180	1.7180	1.7180	1.7180	2.1041
MSD(GT2):	1.7782	2.1778	1.7782	1.7782	1.7782	1.7782	2.1778
MSD(T'):	1.7180	2.4296	1.7180	1.7180	1.7180	1.7180	2.4296

Comparing sample 1 against:

Sample:	3a	4	6	5	7	3b
Diff:	0.4758	1.8505*	1.9674*	2.0102*	3.7275*	3.9209*
MSD(TK):	2.1041	1.7180	1.7180	1.7180	1.7180	2.1041
MSD(GT2):	2.1778	1.7782	1.7782	1.7782	1.7782	2.1778
MSD(T'):	2.4296	1.7180	1.7180	1.7180	1.7180	2.4296

Comparing sample 3a against:

Sample:	4	6	5	7	3b
Diff:	1.3748	1.4916	1.5344	3.2517*	3.4452*
MSD(TK):	2.1041	2.1041	2.1041	2.1041	2.4296
MSD(GT2):	2.1778	2.1778	2.1778	2.1778	2.5147
MSD(T'):	2.4296	2.4296	2.4296	2.4296	2.4296

Comparing sample 4 against:

Sample:	6	5	7	3b
Diff:	0.1168	0.1597	1.8769*	2.0704
MSD(TK):	1.7180	1.7180	1.7180	2.1041
MSD(GT2):	1.7782	1.7782	1.7782	2.1778
MSD(T'):	1.7180	1.7180	1.7180	2.4296

Comparing sample 6 against:

Sample:	5	7	3b
Diff:	0.0428	1.7601*	1.9536
MSD(TK):	1.7180	1.7180	2.1041
MSD(GT2):	1.7782	1.7782	2.1778
MSD(T'):	1.7180	1.7180	2.4296

Comparing sample 5 against:

Sample:	7	3b
Diff:	1.7173	1.9108
MSD(TK):	1.7180	2.1041
MSD(GT2):	1.7782	2.1778
MSD(T'):	1.7180	2.4296

Comparing sample 7 against:

Sample:	3b
Diff:	0.1935
MSD(TK):	2.1041
MSD(GT2):	2.1778
MSD(T'):	2.4296

*** indicates P<=0.050 for at least one method.**

Appendix 6: Turf algal cover

Testing for homogeneity of variances among number of turf algae CPCe points inside Castle Harbour compared to outside Castle Harbour (CH).

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 120
χ^2 = 4.7243, df = 1
c = 1.009942
χ^2c = 4.6778, P = 0.0306

The variances of the samples are heterogeneous (P <0.05)

SQRT (Turf algal cover)
χ^2 = 0.1583, df = 1
c = 1.009942
χ^2 c = 0.1567, P = 0.6922

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Turf algal cover)
Defined by variable: In OR Out
Sample size: 120

ANOVA Table

Level	SS	df	MS	Fs	P
IN/OUT	340.6148	1	340.61478	58.7377	5.571 10^-12
Within	684.2715	118	5.79891		

There are significant differences in turf algal cover in CH compared to out (P <0.05)

Appendix 7: Turf algal cover inside Castle Harbour

Testing for homogeneity of variances among number of turf algae CPCe points at each *site* inside Castle Harbour to ensure replicate sites may be grouped by location.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 25.7951, df = 13

c = 1.089286

$\chi^2 c$ = 23.6808, P = 0.0342

The variances of the samples are heterogeneous (P <0.05)

ln(Turf algal cover)

χ^2 = 21.7323, df = 13

c = 1.089286

$\chi^2 c$ = 19.9509, P = 0.0964

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: ln(Turf algal cover)

Defined by site

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Site	5.7052	13	0.43886	20.3196	1.309 10^-16
Within	1.2095	56	0.02160		

There are significant differences in turf algal cover amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: ln(Turf algal cover)

Total sample size: 70

Comparing sample 1a against:

Sample:	1b
Diff:	0.2350
MSD(GT2):	0.3383
MSD(TK):	0.3258

Comparing sample 2b against:

Sample:	2a
Diff:	0.0960
MSD(TK):	0.3258
MSD(GT2):	0.3383

Comparing sample 3b against:

Sample:	3a
Diff:	0.1305
MSD(TK):	0.3258
MSD(GT2):	0.3383

Comparing sample 4a against:

Sample:	4b
Diff:	0.5014*
MSD(TK):	0.3258
MSD(GT2):	0.3383

Comparing sample 5a against:

Sample:	5b
Diff:	0.0500
MSD(TK):	0.3258
MSD(GT2):	0.3383

Comparing sample 6a against:

Sample:	6b
Diff:	0.1139
MSD(GT2):	0.3383
MSD(TK):	0.3258

Comparing sample 7b against:

Sample:	7a
Diff:	0.4148*
MSD(TK):	0.3258
MSD(GT2):	0.3383

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among number of turf algae CPCe points at each *location* inside Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70
χ^2 = 23.3027, df = 8
c = 1.064132
χ^2c = 21.8983, P = 0.0051

The variances of the samples are heterogeneous (P <0.05)

$\log_{10}$(Turf algal cover)
χ^2 = 16.2713, df = 8
c = 1.064132
χ^2c = 15.2907, P = 0.0537

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: $\log_{10}$(Turf algal cover)
Defined by location
Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Location	1.0304	8	0.12880	28.6912	6.114 10^-18
Within	0.2738	61	0.00449		

There are significant differences in gorgonian cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: $\log_{10}$(Turf algal cover)

Total sample size: 70

Comparing sample 4a against:

Sample:	7b	7a	4b	5	6	3	1	2
Diff:	0.0300	0.2102*	0.2178*	0.2635*	0.3196*	0.3451*	0.3664*	0.4018*
MSD(TK):	0.1363	0.1363	0.1363	0.1180	0.1180	0.1180	0.1180	0.1180
MSD(GT2):	0.1412	0.1412	0.1412	0.1223	0.1223	0.1223	0.1223	0.1223

Comparing sample 7b against:

Sample:	7a	4b	5	6	3	1	2
Diff:	0.1802*	0.1878*	0.2335*	0.2896*	0.3151*	0.3364*	0.3718*
MSD(TK):	0.1363	0.1363	0.1180	0.1180	0.1180	0.1180	0.1180
MSD(GT2):	0.1412	0.1412	0.1223	0.1223	0.1223	0.1223	0.1223

Comparing sample 7a against:

Sample:	4b	5	6	3	1	2
Diff:	0.0076	0.0533	0.1094	0.1350*	0.1563*	0.1916*
MSD(TK):	0.1363	0.1180	0.1180	0.1180	0.1180	0.1180
MSD(GT2):	0.1412	0.1223	0.1223	0.1223	0.1223	0.1223

Comparing sample 4b against:

Sample:	5	6	3	1	2
Diff:	0.0457	0.1018	0.1274*	0.1486*	0.1840*
MSD(TK):	0.1180	0.1180	0.1180	0.1180	0.1180
MSD(GT2):	0.1223	0.1223	0.1223	0.1223	0.1223

Comparing sample 5 against:

Sample:	6	3	1	2
Diff:	0.0561	0.0817	0.1030*	0.1383*
MSD(TK):	0.0963	0.0963	0.0963	0.0963
MSD(GT2):	0.0998	0.0998	0.0998	0.0998

Comparing sample 6 against:

Sample:	3	1	2
Diff:	0.0256	0.0469	0.0822
MSD(TK):	0.0963	0.0963	0.0963
MSD(GT2):	0.0998	0.0998	0.0998

Comparing sample 3 against:

Sample:	1	2
Diff:	0.0213	0.0566
MSD(TK):	0.0963	0.0963
MSD(GT2):	0.0998	0.0998

Comparing sample 1 against:

Sample:	2
Diff:	0.0354
MSD(TK):	0.0963
MSD(GT2):	0.0998

*** indicates P<=0.050 for at least one method.**

Appendix 8: Turf algal cover outside Castle Harbour

Testing for homogeneity of variances among number of turf algae CPCe points at each *site* outside Castle Harbour to ensure replicate sites may be grouped by location.

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50

χ^2 = 13.5832, df = 9

c = 1.091667

$\chi^2 c$ = 12.4426, P = 0.1895

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Turf Algae Abundance

Defined by site

Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Site	176668.5	9	19629.83333	34.8356	3.534 10^-16
Within	22540.0	40	563.50000		

There are significant differences in turf algal cover amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: Turf algal cover

Total sample size: 50

Comparing sample STa against:

Sample:	STb
Diff:	11.0000
MSD(TK):	50.2669
MSD(GT2):	52.2914

Comparing sample NRa against:

Sample:	NRb
Diff:	18.2000
MSD(TK):	50.2669
MSD(GT2):	52.2914

Comparing sample ILa against:

Sample:	ILb
Diff:	110.2000*
MSD(GT2):	52.2914
MSD(TK):	50.2669

Comparing sample OLa against:

Sample:	OLb
Diff:	7.2000
MSD(TK):	50.2669
MSD(GT2):	52.2914

Comparing sample SRb against:

Sample:	SRa
Diff:	28.4000
MSD(TK):	50.2669
MSD(GT2):	52.2914

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among number of turf algae CPCe points at each *location* outside Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 50

χ^2 = 6.7927, df = 5

c = 1.061448

χ^2c = 6.3995, P = 0.2693

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Turf algal cover

Defined by location

Sample size: 50

ANOVA Table

Level	SS	df	MS	Fs	P
Location	173391.900	5	34678.380	59.1034	2.074 10^-18
Within	25816.600	44	586.74091		

There are significant differences in turf algal cover amongst locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: Turf algal cover

Total sample size: 50

Comparing sample ST against:

Sample:	NR	ILa	OL	SR	ILb
Diff:	69.2000*	90.9000*	110.3000*	137.5000*	201.1000*
MSD(TK):	32.2726	39.5256	32.2726	32.2726	39.5256
MSD(GT2):	33.4072	40.9153	33.4072	33.4072	40.9153
MSD(T'):	32.2726	45.6403	32.2726	32.2726	45.6403

Comparing sample NR against:

Sample:	ILa	OL	SR	ILb
Diff:	21.7000	41.1000*	68.3000*	131.9000*
MSD(TK):	39.5256	32.2726	32.2726	39.5256
MSD(GT2):	40.9153	33.4072	33.4072	40.9153
MSD(T'):	45.6403	32.2726	32.2726	45.6403

Comparing sample ILa against:

Sample:	OL	SR	ILb
Diff:	19.4000	46.6000*	110.2000*
MSD(TK):	39.5256	39.5256	45.6403
MSD(GT2):	40.9153	40.9153	47.2449
MSD(T'):	45.6403	45.6403	45.6403

Comparing sample OL against:

Sample:	SR	ILb
Diff:	27.2000	90.8000*
MSD(TK):	32.2726	39.5256
MSD(GT2):	33.4072	40.9153
MSD(T'):	32.2726	45.6403

Comparing sample SR against:

Sample:	ILb
Diff:	63.6000*
MSD(TK):	39.5256
MSD(GT2):	40.9153
MSD(T'):	45.6403

*** indicates P<=0.050 for at least one method.**

Appendix 9: Macro-algal cover

Testing for homogeneity of variances among number of macro algae CPCe points inside Castle Harbour compared to outside Castle Harbour (CH).

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 120
χ^2 = 11.7684, df = 1
c = 1.008809
χ^2c = 11.6656, P = 0.0006

Data could not be normalized through transformation.

Kruskal-Wallis statistics

Variable: Macro-algal cover
Samples: In OR Out
Total sample size = 120

Results
Kruskal-Wallis statistic, H = 0.1179, df = 1
Correction for ties, D = 0.99987152
Adjusted H = 0.1179, P[ChiSq>=H] = 0.7313

There are no significant differences in macro-algal cover inside CH compared to outside (P >0.05)

Appendix 10: SIMilarity PERcentage analysis of benthic groups inside Castle Harbour to illustrate the major differences between sites. Analysis conducted with PRIMER.

Groups 4b & 4a
Average dissimilarity = 19.02

	4b	4a			
Species	Av.Abund	Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	16.16	4.25	22.33	22.33
TURF ALGAE	15.38	11.94	3.31	17.41	39.74
Gorgonia ventalina	5.44	3.72	1.65	8.69	48.43
Madracis decactis	1.79	0.45	1.30	6.82	55.25
Diploria labyrinthiformis	4.01	2.69	1.27	6.69	61.94

Groups 4b & 3b
Average dissimilarity = 17.27

	Group 4b	Group 3b			
Species	Av.Abund	Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	7.61	3.74	21.66	21.66
Pseudoplexaura_Plexaurella	0.63	3.45	2.54	14.70	36.36
TURF ALGAE	15.38	17.22	1.66	9.60	45.96
Diploria strigosa	0.45	1.74	1.16	6.73	52.70
Plexaura	0.63	1.85	1.09	6.34	59.03

Groups 4a & 3b
Average dissimilarity = 30.19

	Group 4a	Group 3b			
Species	Av.Abund	Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	7.61	7.96	26.36	26.36
TURF ALGAE	11.94	17.22	4.91	16.25	42.61
Pseudoplexaura_Plexaurella	1.19	3.45	2.11	6.98	49.59
Plexaura	0.00	1.85	1.72	5.70	55.29
Gorgonia ventalina	3.72	5.25	1.42	4.71	60.00

Groups 4b & 3a
Average dissimilarity = 19.96

	Group 4b	Group 3a			
Species	Av.Abund	Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	6.61	5.02	25.13	25.13
TURF ALGAE	15.38	18.37	2.91	14.58	39.71
Gorgonia ventalina	5.44	3.04	2.33	11.69	51.40
SPONGES	1.68	2.97	1.26	6.31	57.71
Diploria labyrinthiformis	4.01	3.01	0.98	4.89	62.60

Groups 4a & 3a
Average dissimilarity = 24.99

	Group 4a	Group 3a			
Species	Av.Abund	Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	6.61	9.63	38.53	38.53
TURF ALGAE	11.94	18.37	6.47	25.89	64.42
Millepora alcicornis	0.00	1.19	1.19	4.78	69.20
Madracis decactis	0.45	1.42	0.98	3.90	73.10
Porites astreoides	1.79	0.90	0.90	3.62	76.72

Groups 3b & 3a
Average dissimilarity = 19.03

Species	Group 3b Av.Abund	Group 3a Av.Abund	Av.Diss	Contrib%	Cum.%
Pseudoplexaura_Plexaurella	3.45	1.10	2.21	11.59	11.59
Gorgonia ventalina	5.25	3.04	2.08	10.91	22.49
Plexaura	1.85	0.00	1.74	9.12	31.61
Stephanocoenia michelinii	0.00	1.55	1.46	7.66	39.27
Eunicea/Muricea	1.19	0.00	1.12	5.86	45.13

Groups 4b & 1b
Average dissimilarity = 28.30

Species	Group 4b Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	5.77	6.34	22.41	22.41
Gorgonia ventalina	5.44	1.41	4.26	15.04	37.45
TURF ALGAE	15.38	19.32	4.17	14.74	52.19
Diploria strigosa	0.45	2.05	1.69	5.99	58.18
Porites astreoides	1.85	0.63	1.28	4.54	62.72

Groups 4a & 1b
Average dissimilarity = 33.07

Species	Group 4a Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	5.77	11.42	34.54	34.54
TURF ALGAE	11.94	19.32	8.10	24.50	59.04
Gorgonia ventalina	3.72	1.41	2.54	7.67	66.71
Pseudoplexaura_Plexaurella	1.19	0.00	1.30	3.94	70.65
Porites astreoides	1.79	0.63	1.27	3.85	74.51

Groups 3b & 1b
Average dissimilarity = 26.44

Species	Group 3b Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	5.25	1.41	3.90	14.76	14.76
Pseudoplexaura_Plexaurella	3.45	0.00	3.51	13.27	28.03
TURF ALGAE	17.22	19.32	2.14	8.09	36.11
Plexaura	1.85	0.00	1.88	7.11	43.22
MACROALGAE	7.61	5.77	1.88	7.09	50.32

Groups 3a & 1b
Average dissimilarity = 16.26

Species	Group 3a Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	3.04	1.41	1.81	11.10	11.10
Millepora alcicornis	1.19	0.00	1.32	8.09	19.19
Pseudoplexaura_Plexaurella	1.10	0.00	1.22	7.51	26.69
SPONGES	2.97	1.90	1.19	7.33	34.03
Diploria strigosa	1.00	2.05	1.16	7.16	41.19

Groups 4b & 1a
Average dissimilarity = 23.29

Species	Group 4b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	4.71	7.17	30.78	30.78
Gorgonia ventalina	5.44	2.66	2.83	12.15	42.93
Diploria labyrinthiformis	4.01	1.56	2.50	10.71	53.65
TURF ALGAE	15.38	17.25	1.91	8.20	61.84
Porites astreoides	1.85	0.45	1.42	6.11	67.95

Groups 4a & 1a
Average dissimilarity = 32.15

Species	Group 4a Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	4.71	12.08	37.57	37.57
TURF ALGAE	11.94	17.25	5.60	17.42	54.98
Millepora alcicornis	0.00	1.69	1.78	5.53	60.51
Plexaura	0.00	1.42	1.50	4.65	65.16
Porites astreoides	1.79	0.45	1.42	4.41	69.57

Groups 3b & 1a
Average dissimilarity = 21.20

Species	Group 3b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.61	4.71	2.84	13.38	13.38
Pseudoplexaura_Plexaurella	3.45	0.64	2.76	13.00	26.39
Gorgonia ventalina	5.25	2.66	2.54	12.00	38.39
Diploria labyrinthiformis	3.92	1.56	2.31	10.90	49.29
Siderastrea radians	0.00	1.55	1.52	7.18	56.47

Groups 3a & 1a
Average dissimilarity = 14.08

Species	Group 3a Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	4.71	2.02	14.34	14.34
Diploria labyrinthiformis	3.01	1.56	1.54	10.97	25.31
Plexaura	0.00	1.42	1.51	10.73	36.04
TURF ALGAE	18.37	17.25	1.19	8.42	44.46
Pseudopterogorgia	0.78	1.79	1.08	7.69	52.15

Groups 1b & 1a
Average dissimilarity = 18.72

Species	Group 1b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
TURF ALGAE	19.32	17.25	2.41	12.87	12.87
Millepora alcicornis	0.00	1.69	1.97	10.50	23.37
Diploria labyrinthiformis	3.10	1.56	1.80	9.63	33.01
Plexaura	0.00	1.42	1.66	8.84	41.85
Gorgonia ventalina	1.41	2.66	1.45	7.73	49.58

Groups 4b & 2b
Average dissimilarity = 20.80

Species	Group 4b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	5.44	2.00	3.40	16.35	16.35
MACROALGAE	11.76	8.55	3.19	15.31	31.66
TURF ALGAE	15.38	18.59	3.18	15.29	46.95
Montastraea cavernosa	0.00	1.85	1.83	8.81	55.76
Porites astreoides	1.85	0.00	1.83	8.80	64.56

Groups 4a & 2b
Average dissimilarity = 27.65

Species	Group 4a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	8.55	7.82	28.27	28.27
TURF ALGAE	11.94	18.59	6.82	24.65	52.92
Montastraea cavernosa	0.00	1.85	1.90	6.87	59.78
Porites astreoides	1.79	0.00	1.84	6.65	66.43
Gorgonia ventalina	3.72	2.00	1.77	6.39	72.82

Groups 3b & 2b
Average dissimilarity = 22.76

Species	Group 3b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Pseudoplexaura_Plexaurella	3.45	0.00	3.29	14.47	14.47
Gorgonia ventalina	5.25	2.00	3.10	13.63	28.09
Plexaura	1.85	0.00	1.76	7.75	35.85
Porites astreoides	1.62	0.00	1.54	6.78	42.63
TURF ALGAE	17.22	18.59	1.31	5.75	48.38

Groups 3a & 2b
Average dissimilarity = 13.11

Species	Group 3a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	8.55	2.01	15.30	15.30
Montastraea cavernosa	0.00	1.85	1.92	14.62	29.92
Millepora alcicornis	1.19	0.00	1.23	9.37	39.28
Pseudoplexaura_Plexaurella	1.10	0.00	1.14	8.69	47.98
Gorgonia ventalina	3.04	2.00	1.07	8.20	56.17

Groups 1b & 2b
Average dissimilarity = 16.33

Species	Group 1b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	8.55	3.15	19.27	19.27
Montastraea cavernosa	0.00	1.85	2.09	12.82	32.10
Diploria strigosa	2.05	0.78	1.44	8.84	40.93
Madracis decactis	0.63	1.67	1.18	7.22	48.15
Zoanthus spp./Other Zoanthids	0.00	1.00	1.14	6.96	55.12

Groups 1a & 2b
Average dissimilarity = 18.77

Species	Group 1a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	8.55	4.16	22.17	22.17
Montastraea cavernosa	0.00	1.85	2.01	10.70	32.87
Millepora alcicornis	1.69	0.00	1.83	9.75	42.62
Plexaura	1.42	0.00	1.54	8.21	50.82
TURF ALGAE	17.25	18.59	1.45	7.72	58.54

Groups 4b & 2a
Average dissimilarity = 25.94

Species	Group 4b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	6.96	4.80	18.52	18.52
TURF ALGAE	15.38	19.44	4.06	15.66	34.18
Gorgonia ventalina	5.44	1.79	3.64	14.05	48.23
Porites astreoides	1.85	0.00	1.85	7.12	55.35
Madracis mirabilis	1.68	0.00	1.68	6.48	61.83

Groups 4a & 2a
Average dissimilarity = 33.80

Species	Group 4a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	6.96	9.54	28.21	28.21
TURF ALGAE	11.94	19.44	7.76	22.97	51.18
Gorgonia ventalina	3.72	1.79	2.00	5.92	57.10
Porites astreoides	1.79	0.00	1.86	5.49	62.60
Madracis mirabilis	1.55	0.00	1.61	4.76	67.36

Groups 3b & 2a
Average dissimilarity = 23.17

Species	Group 3b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	5.25	1.79	3.33	14.38	14.38
Pseudoplexaura_Plexaurella	3.45	0.00	3.32	14.34	28.72
TURF ALGAE	17.22	19.44	2.14	9.24	37.96
Porites astreoides	1.62	0.00	1.56	6.72	44.68
Madracis mirabilis	1.35	0.00	1.30	5.60	50.28

Groups 3a & 2a
Average dissimilarity = 16.72

Species	Group 3a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis mirabilis	1.74	0.00	1.82	10.87	10.87
Montastraea cavernosa	0.00	1.27	1.33	7.94	18.80
Gorgonia ventalina	3.04	1.79	1.31	7.81	26.62
Diploria labyrinthiformis	3.01	4.20	1.25	7.50	34.12
Millepora alcicornis	1.19	0.00	1.24	7.42	41.54

Groups 1b & 2a
Average dissimilarity = 14.51

Species	Group 1b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.27	1.45	10.00	10.00
MACROALGAE	5.77	6.96	1.36	9.40	19.40
Diploria labyrinthiformis	3.10	4.20	1.26	8.70	28.10
Montastraea franksi	0.00	1.10	1.26	8.67	36.76
Oculina spp.	0.45	1.42	1.11	7.64	44.40

Groups 1a & 2a
Average dissimilarity = 21.57

Species	Group 1a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria labyrinthiformis	1.56	4.20	2.90	13.46	13.46
MACROALGAE	4.71	6.96	2.46	11.41	24.88
TURF ALGAE	17.25	19.44	2.40	11.11	35.99
Millepora alcicornis	1.69	0.00	1.85	8.57	44.55
Montastraea cavernosa	0.00	1.27	1.39	6.45	51.00

Groups 2b & 2a
Average dissimilarity = 14.14

Species	Group 2b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	8.55	6.96	1.69	11.97	11.97
Diploria labyrinthiformis	2.65	4.20	1.65	11.70	23.67
Madracis mirabilis	1.35	0.00	1.44	10.16	33.83
Diploria strigosa	0.78	1.85	1.14	8.08	41.90
Madracis decactis	1.67	0.63	1.11	7.83	49.74

Groups 4b & 5b
Average dissimilarity = 19.34

Species	Group 4b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	9.45	2.10	10.86	10.86
Gorgonia ventalina	5.44	3.44	1.81	9.37	20.23
SPONGES	1.68	3.41	1.57	8.14	28.37
Madracis decactis	1.79	3.44	1.50	7.75	36.12
Diploria strigosa	0.45	1.85	1.27	6.56	42.68

Groups 4a & 5b
Average dissimilarity = 25.83

Species	Group 4a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	9.45	6.30	24.37	24.37
TURF ALGAE	11.94	16.35	4.14	16.01	40.38
Madracis decactis	0.45	3.44	2.81	10.87	51.25
Madracis mirabilis	1.55	3.07	1.43	5.52	56.77
Porites astreoides	1.79	0.78	0.95	3.69	60.45

Groups 3b & 5b
Average dissimilarity = 18.80

Species	Group 3b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Pseudoplexaura_Plexaurella	3.45	0.78	2.35	12.49	12.49
Madracis decactis	1.56	3.44	1.66	8.81	21.29
MACROALGAE	7.61	9.45	1.61	8.59	29.88
Gorgonia ventalina	5.25	3.44	1.59	8.45	38.33
Madracis mirabilis	1.35	3.07	1.51	8.06	46.39

Groups 3a & 5b
Average dissimilarity = 17.42

Species	Group 3a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	9.45	2.69	15.42	15.42
Madracis decactis	1.42	3.44	1.92	11.00	26.42
TURF ALGAE	18.37	16.35	1.90	10.93	37.35
Madracis mirabilis	1.74	3.07	1.26	7.25	44.60
Millepora alcicornis	1.19	0.00	1.12	6.44	51.04

Groups 1b & 5b
Average dissimilarity = 23.52

Species	Group 1b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	9.45	3.78	16.06	16.06
TURF ALGAE	19.32	16.35	3.04	12.92	28.98
Madracis decactis	0.63	3.44	2.88	12.25	41.24
Madracis mirabilis	0.89	3.07	2.23	9.49	50.73
Gorgonia ventalina	1.41	3.44	2.08	8.84	59.57

Groups 1a & 5b
Average dissimilarity = 23.22

Species	Group 1a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	9.45	4.68	20.14	20.14
Madracis mirabilis	0.90	3.07	2.15	9.24	29.38
Madracis decactis	1.35	3.44	2.07	8.90	38.28
Diploria labyrinthiformis	1.56	3.35	1.77	7.64	45.92
Millepora alcicornis	1.69	0.00	1.66	7.16	53.08

Groups 2b & 5b
Average dissimilarity = 19.84

Species	Group 2b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
TURF ALGAE	18.59	16.35	2.15	10.83	10.83
Madracis decactis	1.67	3.44	1.70	8.58	19.41
Madracis mirabilis	1.35	3.07	1.66	8.37	27.78
Gorgonia ventalina	2.00	3.44	1.38	6.98	34.75
SPONGES	2.15	3.41	1.22	6.14	40.89

Groups 2a & 5b
Average dissimilarity = 23.91

Species	Group 2a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
TURF ALGAE	19.44	16.35	2.99	12.53	12.53
Madracis mirabilis	0.00	3.07	2.98	12.47	25.00
Madracis decactis	0.63	3.44	2.73	11.40	36.40
MACROALGAE	6.96	9.45	2.42	10.11	46.52
Gorgonia ventalina	1.79	3.44	1.60	6.70	53.21

Groups 4b & 5a
Average dissimilarity = 13.05

Species	Group 4b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Zoanthus spp./Other Zoanthids	1.10	2.65	1.36	10.41	10.41
Montastraea cavernosa	0.00	1.55	1.36	10.41	20.82
SPONGES	1.68	3.11	1.25	9.56	30.38
Madracis decactis	1.79	3.20	1.23	9.45	39.83
Diploria strigosa	0.45	1.79	1.17	9.00	48.83

Groups 4a & 5a
Average dissimilarity = 25.63

Species	Group 4a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	10.46	5.15	20.07	20.07
TURF ALGAE	11.94	16.00	3.66	14.26	34.34
Madracis decactis	0.45	3.20	2.48	9.69	44.02
Zoanthus spp./Other Zoanthids	0.78	2.65	1.69	6.60	50.62
Montastraea cavernosa	0.00	1.55	1.40	5.46	56.08

Groups 3b & 5a
Average dissimilarity = 14.04

Species	Group 3b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.61	10.46	2.41	17.15	17.15
Pseudoplexaura_Plexaurella	3.45	1.62	1.55	11.05	28.20
Madracis decactis	1.56	3.20	1.39	9.92	38.12
Zoanthus spp./Other Zoanthids	1.35	2.65	1.10	7.87	45.99
TURF ALGAE	17.22	16.00	1.03	7.33	53.32

Groups 3a & 5a
Average dissimilarity = 20.75

Species	Group 3a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	10.46	3.50	16.85	16.85
TURF ALGAE	18.37	16.00	2.15	10.37	27.22
Gorgonia ventalina	3.04	5.17	1.93	9.32	36.54
Madracis decactis	1.42	3.20	1.62	7.82	44.37
Zoanthus spp./Other Zoanthids	1.00	2.65	1.50	7.22	51.59

Groups 1b & 5a
Average dissimilarity = 30.29

Species	Group 1b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	10.46	4.61	15.21	15.21
Gorgonia ventalina	1.41	5.17	3.69	12.18	27.38
TURF ALGAE	19.32	16.00	3.26	10.76	38.15
Zoanthus spp./Other Zoanthids	0.00	2.65	2.60	8.60	46.75
Madracis decactis	0.63	3.20	2.53	8.34	55.08

Groups 1a & 5a
Average dissimilarity = 27.17

Species	Group 1a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	10.46	5.44	20.02	20.02
Gorgonia ventalina	2.66	5.17	2.38	8.76	28.78
Diploria labyrinthiformis	1.56	3.93	2.25	8.29	37.07
Madracis decactis	1.35	3.20	1.76	6.46	43.53
Millepora alcicornis	1.69	0.00	1.60	5.87	49.40

Groups 2b & 5a
Average dissimilarity = 21.11

Species	Group 2b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	2.00	5.17	2.92	13.85	13.85
TURF ALGAE	18.59	16.00	2.39	11.32	25.18
MACROALGAE	8.55	10.46	1.76	8.36	33.54
Zoanthus spp./Other Zoanthids	1.00	2.65	1.52	7.21	40.75
Pseudoplexaura_Plexaurella	0.00	1.62	1.49	7.07	47.82

Groups 2a & 5a
Average dissimilarity = 23.41

Species	Group 2a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.96	10.46	3.26	13.92	13.92
TURF ALGAE	19.44	16.00	3.21	13.69	27.62
Gorgonia ventalina	1.79	5.17	3.15	13.44	41.06
Zoanthus spp./Other Zoanthids	0.00	2.65	2.47	10.56	51.61
Madracis decactis	0.63	3.20	2.39	10.23	61.84

Groups 5b & 5a
Average dissimilarity = 12.58

Species	Group 5b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	3.44	5.17	1.47	11.69	11.69
Zoanthus spp./Other Zoanthids	1.19	2.65	1.25	9.92	21.62
Montastraea franksi	0.00	1.19	1.01	8.03	29.65
MACROALGAE	9.45	10.46	0.86	6.81	36.46
Agaricia fragilis	1.00	0.00	0.85	6.79	43.25

Groups 4b & 6a
Average dissimilarity = 29.19

Species	Group 4b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	7.03	4.79	16.41	16.41
Diploria labyrinthiformis	4.01	1.10	2.95	10.11	26.52
Diploria strigosa	0.45	2.93	2.52	8.62	35.14
Madracis decactis	1.79	0.00	1.82	6.22	41.36
Madracis mirabilis	1.68	0.00	1.70	5.83	47.19

Groups 4a & 6a
Average dissimilarity = 37.77

Species	Group 4a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	7.03	9.59	25.39	25.39
TURF ALGAE	11.94	16.85	5.16	13.65	39.04
Plexaura	0.00	2.14	2.25	5.96	45.01
Diploria strigosa	1.00	2.93	2.03	5.37	50.38
SPONGES	2.54	0.63	2.00	5.30	55.68

Groups 3b & 6a
Average dissimilarity = 18.94

Species	Group 3b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria labyrinthiformis	3.92	1.10	2.75	14.52	14.52
SPONGES	2.77	0.63	2.08	10.99	25.51
Madracis decactis	1.56	0.00	1.52	8.02	33.52
Madracis mirabilis	1.35	0.00	1.31	6.93	40.46
Zoanthus spp./Other Zoanthids	1.35	0.00	1.31	6.92	47.38

Groups 3a & 6a
Average dissimilarity = 25.13

Species	Group 3a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
SPONGES	2.97	0.63	2.48	9.88	9.88
Plexaura	0.00	2.14	2.27	9.05	18.93
Diploria strigosa	1.00	2.93	2.05	8.15	27.08
Diploria labyrinthiformis	3.01	1.10	2.03	8.06	35.14
Madracis mirabilis	1.74	0.00	1.84	7.33	42.47

Groups 1b & 6a
Average dissimilarity = 26.33

Species	Group 1b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	1.41	4.45	3.53	13.39	13.39
TURF ALGAE	19.32	16.85	2.86	10.86	24.25
Pseudoplexaura_Plexaurella	0.00	2.28	2.65	10.06	34.31
Plexaura	0.00	2.14	2.49	9.46	43.77
Diploria labyrinthiformis	3.10	1.10	2.33	8.85	52.62

Groups 1a & 6a
Average dissimilarity = 21.41

Species	Group 1a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	7.03	2.58	12.04	12.04
Gorgonia ventalina	2.66	4.45	2.00	9.33	21.37
Pseudoplexaura_Plexaurella	0.64	2.28	1.83	8.55	29.92
Diploria strigosa	1.35	2.93	1.76	8.23	38.15
Siderastrea radians	1.55	0.00	1.73	8.08	46.22

Groups 2b & 6a
Average dissimilarity = 29.36

Species	Group 2b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Gorgonia ventalina	2.00	4.45	2.64	9.00	9.00
Pseudoplexaura_Plexaurella	0.00	2.28	2.46	8.39	17.40
Diploria strigosa	0.78	2.93	2.33	7.94	25.33
Plexaura	0.00	2.14	2.32	7.89	33.23
TURF ALGAE	18.59	16.85	1.87	6.37	39.60

Groups 2a & 6a
Average dissimilarity = 25.98

Species	Group 2a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria labyrinthiformis	4.20	1.10	3.39	13.06	13.06
Gorgonia ventalina	1.79	4.45	2.90	11.17	24.23
TURF ALGAE	19.44	16.85	2.82	10.86	35.09
Pseudoplexaura_Plexaurella	0.00	2.28	2.49	9.58	44.67
SPONGES	2.69	0.63	2.25	8.65	53.32

Groups 5b & 6a
Average dissimilarity = 27.03

Species	Group 5b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	3.39	12.52	12.52
Madracis mirabilis	3.07	0.00	3.02	11.18	23.70
SPONGES	3.41	0.63	2.73	10.11	33.81
MACROALGAE	9.45	7.03	2.38	8.80	42.61
Diploria labyrinthiformis	3.35	1.10	2.22	8.21	50.82

Groups 5a & 6a
Average dissimilarity = 26.87

Species	Group 5a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	10.46	7.03	3.23	12.02	12.02
Madracis decactis	3.20	0.00	3.02	11.24	23.27
Diploria labyrinthiformis	3.93	1.10	2.68	9.97	33.23
Zoanthus spp./Other Zoanthids	2.65	0.00	2.50	9.31	42.54
Madracis mirabilis	2.54	0.00	2.39	8.90	51.44

Groups 4b & 6b
Average dissimilarity = 29.34

Species	Group 4b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria labyrinthiformis	4.01	1.18	2.89	9.83	9.83
Diploria strigosa	0.45	3.03	2.64	8.99	18.83
MACROALGAE	11.76	9.31	2.51	8.55	27.37
TURF ALGAE	15.38	17.82	2.49	8.49	35.87
Gorgonia ventalina	5.44	3.26	2.23	7.60	43.46

Groups 4a & 6b
Average dissimilarity = 35.47

Species	Group 4a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	16.16	9.31	7.26	20.47	20.47
TURF ALGAE	11.94	17.82	6.22	17.53	38.01
Diploria strigosa	1.00	3.03	2.15	6.07	44.07
SPONGES	2.54	0.89	1.74	4.91	48.98
Madracis mirabilis	1.55	0.00	1.64	4.64	53.62

Groups 3b & 6b
Average dissimilarity = 28.50

Species	Group 3b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Pseudoplexaura_Plexaurella	3.45	0.00	3.39	11.90	11.90
Diploria labyrinthiformis	3.92	1.18	2.69	9.42	21.32
Gorgonia ventalina	5.25	3.26	1.96	6.89	28.21
SPONGES	2.77	0.89	1.84	6.46	34.67
MACROALGAE	7.61	9.31	1.67	5.85	40.52

Groups 3a & 6b
Average dissimilarity = 26.69

Species	Group 3a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	9.31	2.88	10.81	10.81
SPONGES	2.97	0.89	2.22	8.33	19.14
Diploria strigosa	1.00	3.03	2.17	8.14	27.28
Diploria labyrinthiformis	3.01	1.18	1.95	7.30	34.58
Madracis mirabilis	1.74	0.00	1.86	6.96	41.54

Groups 1b & 6b
Average dissimilarity = 23.84

Species	Group 1b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	9.31	4.15	17.41	17.41
Diploria labyrinthiformis	3.10	1.18	2.25	9.43	26.84
Gorgonia ventalina	1.41	3.26	2.16	9.05	35.89
TURF ALGAE	19.32	17.82	1.76	7.39	43.28
Pterogorgia	0.00	1.18	1.39	5.82	49.10

Groups 1a & 6b
Average dissimilarity = 26.14

Species	Group 1a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	9.31	5.16	19.72	19.72
Diploria strigosa	1.35	3.03	1.89	7.23	26.95
Madracis decactis	1.35	0.00	1.52	5.80	32.75
SPONGES	2.10	0.89	1.36	5.20	37.95
Oculina spp.	1.19	0.00	1.33	5.10	43.05

Groups 2b & 6b
Average dissimilarity = 24.23

Species	Group 2b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria strigosa	0.78	3.03	2.46	10.15	10.15
Madracis decactis	1.67	0.00	1.82	7.53	17.68
Diploria labyrinthiformis	2.65	1.18	1.60	6.61	24.29
Madracis mirabilis	1.35	0.00	1.47	6.06	30.36
SPONGES	2.15	0.89	1.37	5.64	36.00

Groups 2a & 6b
Average dissimilarity = 24.81

Species	Group 2a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria labyrinthiformis	4.20	1.18	3.33	13.41	13.41
MACROALGAE	6.96	9.31	2.59	10.42	23.84
SPONGES	2.69	0.89	1.98	7.98	31.81
TURF ALGAE	19.44	17.82	1.79	7.21	39.02
Gorgonia ventalina	1.79	3.26	1.61	6.50	45.52

Groups 5b & 6b
Average dissimilarity = 24.12

Species	Group 5b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	3.41	14.15	14.15
Madracis mirabilis	3.07	0.00	3.04	12.62	26.77
SPONGES	3.41	0.89	2.50	10.35	37.12
Diploria labyrinthiformis	3.35	1.18	2.15	8.91	46.03
TURF ALGAE	16.35	17.82	1.45	6.01	52.03

Groups 5a & 6b
Average dissimilarity = 29.56

Species	Group 5a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	3.05	10.30	10.30
Diploria labyrinthiformis	3.93	1.18	2.62	8.85	19.15
Zoanthus spp./Other Zoanthids	2.65	0.00	2.52	8.53	27.67
Madracis mirabilis	2.54	0.00	2.41	8.15	35.83
SPONGES	3.11	0.89	2.10	7.11	42.94

Groups 6a & 6b
Average dissimilarity = 17.97

Species	Group 6a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Pseudoplexaura_Plexaurella	2.28	0.00	2.55	14.18	14.18
MACROALGAE	7.03	9.31	2.54	14.15	28.33
Gorgonia ventalina	4.45	3.26	1.33	7.43	35.76
Pterogorgia	0.00	1.18	1.32	7.36	43.12
Plexaura	2.14	1.10	1.17	6.53	49.65

Groups 4b & 7a
Average dissimilarity = 20.62

Species	Group 4b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Diploria strigosa	0.45	3.92	3.25	15.75	15.75
Pseudoplexaura_Plexaurella	0.63	2.65	1.88	9.12	24.87
Madracis decactis	1.79	0.00	1.68	8.13	32.99
Madracis mirabilis	1.68	0.00	1.57	7.61	40.61
Eunicea/Muricea	0.45	1.73	1.20	5.82	46.43

Groups 4a & 7a
Average dissimilarity = 26.16

Species	Group 4a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
TURF ALGAE	11.94	15.38	3.32	12.69	12.69
MACROALGAE	16.16	12.81	3.24	12.39	25.09
Diploria strigosa	1.00	3.92	2.82	10.79	35.88
Eunicea/Muricea	0.00	1.73	1.67	6.40	42.28
Madracis mirabilis	1.55	0.00	1.50	5.73	48.01

Groups 3b & 7a
Average dissimilarity = 22.19

Species	Group 3b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.61	12.81	4.69	21.13	21.13
Diploria strigosa	1.74	3.92	1.97	8.88	30.01
TURF ALGAE	17.22	15.38	1.65	7.46	37.47
Madracis decactis	1.56	0.00	1.40	6.33	43.80
SPONGES	2.77	1.26	1.36	6.11	49.91

Groups 3a & 7a
Average dissimilarity = 30.82

Species	Group 3a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	12.81	6.04	19.60	19.60
TURF ALGAE	18.37	15.38	2.91	9.44	29.03
Diploria strigosa	1.00	3.92	2.85	9.24	38.27
Madracis mirabilis	1.74	0.00	1.69	5.49	43.76
Eunicea/Muricea	0.00	1.73	1.69	5.48	49.24

Groups 1b & 7a
Average dissimilarity = 30.25

Species	Group 1b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	12.81	7.46	24.65	24.65
TURF ALGAE	19.32	15.38	4.17	13.78	38.43
Gorgonia ventalina	1.41	4.49	3.26	10.78	49.21
Pseudoplexaura_Plexaurella	0.00	2.65	2.80	9.26	58.47
Diploria strigosa	2.05	3.92	1.98	6.56	65.03

Groups 1a & 7a
Average dissimilarity = 32.41

Species	Group 1a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	12.81	8.24	25.43	25.43
Diploria strigosa	1.35	3.92	2.62	8.09	33.52
Pseudoplexaura_Plexaurella	0.64	2.65	2.05	6.32	39.84
TURF ALGAE	17.25	15.38	1.91	5.88	45.72
Gorgonia ventalina	2.66	4.49	1.87	5.78	51.50

Groups 2b & 7a
Average dissimilarity = 31.92

Species	Group 2b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	8.55	12.81	4.22	13.23	13.23
TURF ALGAE	18.59	15.38	3.18	9.95	23.19
Diploria strigosa	0.78	3.92	3.12	9.78	32.96
Pseudoplexaura_Plexaurella	0.00	2.65	2.62	8.22	41.18
Gorgonia ventalina	2.00	4.49	2.47	7.74	48.92

Groups 2a & 7a
Average dissimilarity = 31.03

Species	Group 2a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.96	12.81	5.85	18.86	18.86
TURF ALGAE	19.44	15.38	4.06	13.08	31.94
Gorgonia ventalina	1.79	4.49	2.70	8.71	40.66
Pseudoplexaura_Plexaurella	0.00	2.65	2.65	8.53	49.19
Diploria strigosa	1.85	3.92	2.08	6.70	55.88

Groups 5b & 7a
Average dissimilarity = 24.94

Species	Group 5b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	3.13	12.55	12.55
MACROALGAE	9.45	12.81	3.05	12.23	24.78
Madracis mirabilis	3.07	0.00	2.79	11.20	35.98
SPONGES	3.41	1.26	1.95	7.83	43.81
Diploria strigosa	1.85	3.92	1.89	7.57	51.38

Groups 5a & 7a
Average dissimilarity = 21.91

Species	Group 5a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	2.80	12.79	12.79
Zoanthus spp./Other Zoanthids	2.65	0.00	2.32	10.59	23.38
Madracis mirabilis	2.54	0.00	2.22	10.12	33.50
MACROALGAE	10.46	12.81	2.06	9.39	42.89
Diploria strigosa	1.79	3.92	1.86	8.51	51.40

Groups 6a & 7a
Average dissimilarity = 17.71

Species	Group 6a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.03	12.81	5.86	33.07	33.07
Diploria labyrinthiformis	1.10	3.19	2.13	12.02	45.09
TURF ALGAE	16.85	15.38	1.49	8.44	53.53
Millepora alcicornis	1.61	0.45	1.18	6.68	60.21
Eunicea/Muricea	0.63	1.73	1.11	6.30	66.50

Groups 6b & 7a
Average dissimilarity = 21.51

Species	Group 6b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	9.31	12.81	3.58	16.64	16.64
Pseudoplexaura_Plexaurella	0.00	2.65	2.71	12.58	29.22
TURF ALGAE	17.82	15.38	2.49	11.57	40.79
Diploria labyrinthiformis	1.18	3.19	2.06	9.56	50.35
Eunicea/Muricea	0.00	1.73	1.77	8.23	58.58

Groups 4b & 7b
Average dissimilarity = 25.52

Species	Group 4b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	11.76	15.30	3.23	12.66	12.66
TURF ALGAE	15.38	12.35	2.76	10.82	23.49
Diploria strigosa	0.45	3.00	2.33	9.13	32.62
Eunicea/Muricea	0.45	2.68	2.04	8.01	40.63
Madracis decactis	1.79	0.00	1.64	6.42	47.05

Groups 4a & 7b
Average dissimilarity = 23.82

Species	Group 4a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
Eunicea/Muricea	0.00	2.68	2.53	10.63	10.63
Diploria strigosa	1.00	3.00	1.89	7.92	18.55
Gorgonia ventalina	3.72	5.64	1.81	7.59	26.14
Madracis mirabilis	1.55	0.00	1.47	6.15	32.29
Plexaura	0.00	1.55	1.46	6.14	38.43

Groups 3b & 7b
Average dissimilarity = 26.05

Species	Group 3b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.61	15.30	6.79	26.06	26.06
TURF ALGAE	17.22	12.35	4.29	16.48	42.54
Madracis decactis	1.56	0.00	1.37	5.28	47.82
Eunicea/Muricea	1.19	2.68	1.32	5.07	52.88
Diploria labyrinthiformis	3.92	2.45	1.29	4.97	57.85

Groups 3a & 7b
Average dissimilarity = 38.22

Species	Group 3a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.61	15.30	8.27	21.64	21.64
TURF ALGAE	18.37	12.35	5.73	14.98	36.62
Eunicea/Muricea	0.00	2.68	2.55	6.68	43.31
Gorgonia ventalina	3.04	5.64	2.47	6.47	49.78
Diploria strigosa	1.00	3.00	1.90	4.98	54.76

Groups 1b & 7b
Average dissimilarity = 40.73

Species	Group 1b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	5.77	15.30	9.84	24.17	24.17
TURF ALGAE	19.32	12.35	7.19	17.66	41.83
Gorgonia ventalina	1.41	5.64	4.36	10.71	52.54
Eunicea/Muricea	0.00	2.68	2.77	6.80	59.34
Pseudoplexaura_Plexaurella	0.00	2.24	2.31	5.67	65.01

Groups 1a & 7b
Average dissimilarity = 38.71

Species	Group 1a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	4.71	15.30	10.52	27.18	27.18
TURF ALGAE	17.25	12.35	4.87	12.58	39.76
Gorgonia ventalina	2.66	5.64	2.97	7.66	47.42
Eunicea/Muricea	0.00	2.68	2.67	6.89	54.32
Diploria strigosa	1.35	3.00	1.64	4.24	58.55

Groups 2b & 7b
Average dissimilarity = 37.39

Species	Group 2b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	8.55	15.30	6.54	17.49	17.49
TURF ALGAE	18.59	12.35	6.04	16.15	33.63
Gorgonia ventalina	2.00	5.64	3.52	9.42	43.05
Eunicea/Muricea	0.00	2.68	2.60	6.95	50.00
Pseudoplexaura_Plexaurella	0.00	2.24	2.17	5.79	55.79

Groups 2a & 7b
Average dissimilarity = 37.49

Species	Group 2a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	6.96	15.30	8.15	21.74	21.74
TURF ALGAE	19.44	12.35	6.92	18.47	40.21
Gorgonia ventalina	1.79	5.64	3.76	10.03	50.24
Eunicea/Muricea	0.00	2.68	2.62	6.99	57.23
Pseudoplexaura_Plexaurella	0.00	2.24	2.19	5.83	63.06

Groups 5b & 7b
Average dissimilarity = 33.92

Species	Group 5b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	9.45	15.30	5.20	15.34	15.34
TURF ALGAE	16.35	12.35	3.56	10.49	25.83
Madracis decactis	3.44	0.00	3.06	9.03	34.86
Madracis mirabilis	3.07	0.00	2.73	8.06	42.92
Eunicea/Muricea	0.00	2.68	2.39	7.04	49.95

Groups 5a & 7b
Average dissimilarity = 25.68

Species	Group 5a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	10.46	15.30	4.15	16.15	16.15
TURF ALGAE	16.00	12.35	3.12	12.16	28.32
Madracis decactis	3.20	0.00	2.74	10.69	39.00
Zoanthus spp./Other Zoanthids	2.65	0.00	2.27	8.85	47.85
Madracis mirabilis	2.54	0.00	2.17	8.46	56.31

Groups 6a & 7b
Average dissimilarity = 24.63

Species	Group 6a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	7.03	15.30	8.18	33.23	33.23
TURF ALGAE	16.85	12.35	4.46	18.09	51.32
Eunicea/Muricea	0.63	2.68	2.03	8.24	59.57
Diploria labyrinthiformis	1.10	2.45	1.34	5.44	65.01
Gorgonia ventalina	4.45	5.64	1.18	4.78	69.79

Groups 6b & 7b
Average dissimilarity = 27.43

Species	Group 6b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
MACROALGAE	9.31	15.30	5.98	21.79	21.79
TURF ALGAE	17.82	12.35	5.45	19.87	41.67
Eunicea/Muricea	0.00	2.68	2.68	9.76	51.43
Gorgonia ventalina	3.26	5.64	2.38	8.67	60.10
Pseudoplexaura_Plexaurella	0.00	2.24	2.23	8.13	68.23

Groups 7a & 7b
Average dissimilarity = 13.32

Species	Group 7b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
TURF ALGAE	15.38	12.35	2.77	20.80	20.80
MACROALGAE	12.81	15.30	2.28	17.11	37.91
Montastraea franksi	0.00	1.26	1.16	8.69	46.60
Gorgonia ventalina	4.49	5.64	1.05	7.86	54.46
Eunicea/Muricea	1.73	2.68	0.87	6.53	61.00

Appendix 11: SIMilarity PERcentage analysis of hard coral groups inside Castle Harbour to illustrate the major differences between sites. Analysis conducted with PRIMER.

Groups 4b & 4a
Average dissimilarity = 24.33

Species	Group 4b Av.Abund	Group 4a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.79	0.45	5.38	22.13	22.13
D. labyrinthiformis	4.01	2.69	5.28	21.72	43.85
Montastraea franksi	1.10	0.00	4.41	18.13	61.98
Agaricia fragilis	0.00	0.63	2.54	10.45	72.43
D. strigosa	0.45	1.00	2.21	9.09	81.52
Millepora alcicornis	0.45	0.00	1.8	7.40	88.92
Oculina species	1.00	0.63	1.48	6.09	95.01

Groups 4b & 3b
Average dissimilarity = 20.40

Species	Group 4b Av.Abund	Group 3b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.45	1.74	4.53	22.20	22.20
Siderastrea radians	1.10	0.00	3.86	18.93	41.12
Montastraea cavernosa	0.00	0.78	2.74	13.41	54.53
Stephanocoenia michelinii	0.78	0.00	2.73	13.36	67.90
Agaricia fragilis	0.00	0.45	1.58	7.74	75.64
Madracis mirabilis	1.68	1.35	1.17	5.73	81.37
Millepora alcicornis	0.45	0.78	1.15	5.61	86.98
Madracis decactis	1.79	1.56	0.83	4.06	91.04

Groups 4a & 3b
Average dissimilarity = 34.54

Species	Group 4a Av.Abund	Group 3b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	2.69	3.92	4.90	14.18	14.18
Montastraea franksi	0.00	1.19	4.76	13.78	27.96
Madracis decactis	0.45	1.56	4.43	12.81	40.77
Siderastrea radians	1.10	0.00	4.40	12.72	53.50
Stephanocoenia michelinii	0.90	0.00	3.59	10.38	63.87
Montastraea cavernosa	0.00	0.78	3.11	9.02	72.89
Millepora alcicornis	0.00	0.78	3.10	8.97	81.86
D. strigosa	1.00	1.74	2.95	8.54	90.40

Groups 4b & 3a
Average dissimilarity = 20.67

Species	Group 4b Av.Abund	Group 3a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.01	3.01	3.59	17.35	17.35
Porites astreoides	1.85	0.90	3.40	16.46	33.82
Stephanocoenia michelinii	0.78	1.55	2.78	13.43	47.25
Millepora alcicornis	0.45	1.19	2.63	12.73	59.98
D. strigosa	0.45	1.00	1.98	9.56	69.54
Montastraea franksi	1.10	0.64	1.66	8.04	77.57
Favia fragum	0.00	0.45	1.60	7.74	85.32
Madracis decactis	1.79	1.42	1.34	6.50	91.82

Groups 4a & 3a
Average dissimilarity = 27.39

Species	Group 4a Av.Abund	Group 3a Av.Abund	Av.Diss	Contrib%	Cum.%
Millepora alcicornis	0.00	1.19	4.84	17.66	17.66
Madracis decactis	0.45	1.42	3.95	14.42	32.09
Porites astreoides	1.79	0.90	3.66	13.37	45.45
Stephanocoenia michelinii	0.90	1.55	2.68	9.77	55.22
Montastraea franksi	0.00	0.64	2.60	9.48	64.70
Agaricia fragilis	0.63	0.00	2.59	9.45	74.15
Oculina species	0.63	1.10	1.89	6.90	81.06
Favia fragum	0.00	0.45	1.83	6.67	87.73
Siderastrea radians	1.10	0.78	1.32	4.81	92.54

Groups 3b & 3a
Average dissimilarity = 28.79

Species	Group 3b Av.Abund	Group 3a Av.Abund	Av.Diss	Contrib%	Cum.%
Stephanocoenia michelinii	0.00	1.55	5.54	19.25	19.25
D. labyrinthiformis	3.92	3.01	3.25	11.27	30.52
Montastraea cavernosa	0.78	0.00	2.78	9.66	40.18
Siderastrea radians	0.00	0.78	2.77	9.63	49.81
D. strigosa	1.74	1.00	2.63	9.14	58.94
Porites astreoides	1.62	0.90	2.57	8.94	67.88
Montastraea franksi	1.19	0.64	1.98	6.88	74.76
Agaricia fragilis	0.45	0.00	1.61	5.58	80.34
Favia fragum	0.00	0.45	1.60	5.55	85.89
Millepora alcicornis	0.78	1.19	1.46	5.08	90.96

Groups 4b & 1b
Average dissimilarity = 35.68

Species	Group 4b Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.45	2.05	6.58	18.44	18.44
Porites astreoides	1.85	0.63	4.99	13.98	32.42
Madracis decactis	1.79	0.63	4.77	13.36	45.78
Montastraea franksi	1.10	0.00	4.52	12.67	58.45
D. labyrinthiformis	4.01	3.10	3.73	10.44	68.89
Madracis mirabilis	1.68	0.89	3.22	9.04	77.93
Stephanocoenia michelinii	0.78	1.48	2.90	8.14	86.07
Oculina species	1.00	0.45	2.28	6.40	92.47

Groups 4a & 1b
Average dissimilarity = 24.29

Species	Group 4a Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
Porites astreoides	1.79	0.63	5.55	22.86	22.86
D. strigosa	1.00	2.05	5.03	20.70	43.56
Madracis mirabilis	1.55	0.89	3.15	12.96	56.52
Agaricia fragilis	0.63	0.00	3.04	12.50	69.02
Stephanocoenia michelinii	0.90	1.48	2.81	11.55	80.58
D. labyrinthiformis	2.69	3.10	1.97	8.11	88.69
Siderastrea radians	1.10	0.89	0.98	4.04	92.72

Groups 3b & 1b
Average dissimilarity = 38.97

Species	Group 3b Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
Stephanocoenia michelinii	0.00	1.48	6.08	15.60	15.60
Montastraea franksi	1.19	0.00	4.88	12.52	28.12
Porites astreoides	1.62	0.63	4.03	10.35	38.47
Madracis decactis	1.56	0.63	3.79	9.72	48.19
Siderastrea radians	0.00	0.89	3.67	9.41	57.60
D. labyrinthiformis	3.92	3.10	3.33	8.56	66.15
Montastraea cavernosa	0.78	0.00	3.19	8.19	74.35
Millepora alcicornis	0.78	0.00	3.18	8.15	82.50
Madracis mirabilis	1.35	0.89	1.85	4.75	87.26
Agaricia fragilis	0.45	0.00	1.84	4.73	91.99

Groups 3a & 1b
Average dissimilarity = 25.70

Species	Group 3a Av.Abund	Group 1b Av.Abund	Av.Diss	Contrib%	Cum.%
Millepora alcicornis	1.19	0.00	4.96	19.30	19.30
D. strigosa	1.00	2.05	4.39	17.09	36.39
Madracis mirabilis	1.74	0.89	3.52	13.71	50.10
Madracis decactis	1.42	0.63	3.29	12.78	62.88
Oculina species	1.10	0.45	2.72	10.58	73.46
Montastraea franksi	0.64	0.00	2.66	10.36	83.82
Favia fragum	0.45	0.00	1.87	7.29	91.11

Groups 4b & 1a
Average dissimilarity = 32.00

Species	Group 4b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.01	1.56	9.47	29.58	29.58
Porites astreoides	1.85	0.45	5.40	16.86	46.45
Millepora alcicornis	0.45	1.69	4.77	14.90	61.35
D. strigosa	0.45	1.35	3.47	10.86	72.21
Madracis mirabilis	1.68	0.90	3.02	9.43	81.64
Siderastrea radians	1.10	1.55	1.75	5.48	87.11
Madracis decactis	1.79	1.35	1.71	5.34	92.45

Groups 4a & 1a
Average dissimilarity = 37.80

Species	Group 4a Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
Millepora alcicornis	0.00	1.69	7.50	19.85	19.85
Porites astreoides	1.79	0.45	5.98	15.83	35.68
D. labyrinthiformis	2.69	1.56	5.05	13.36	49.04
Madracis decactis	0.45	1.35	4.01	10.61	59.64
Montastraea franksi	0.00	0.78	3.47	9.19	68.83
Madracis mirabilis	1.55	0.90	2.92	7.71	76.54
Agaricia fragilis	0.63	0.00	2.82	7.47	84.02
Oculina species	0.63	1.19	2.46	6.51	90.52

Groups 3b & 1a
Average dissimilarity = 37.97

Species	Group 3b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.92	1.56	9.08	23.92	23.92
Siderastrea radians	0.00	1.55	5.98	15.75	39.67
Porites astreoides	1.62	0.45	4.50	11.84	51.51
Millepora alcicornis	0.78	1.69	3.50	9.22	60.74
Stephanocoenia michelinii	0.00	0.90	3.46	9.11	69.84
Montastraea cavernosa	0.78	0.00	3.00	7.90	77.74
Agaricia fragilis	0.45	0.00	1.73	4.56	82.30
Madracis mirabilis	1.35	0.90	1.73	4.55	86.86
Montastraea franksi	1.19	0.78	1.58	4.17	91.02

Groups 3a & 1a
Average dissimilarity = 22.63

Species	Group 3a Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.01	1.56	5.69	25.16	25.16
Madracis mirabilis	1.74	0.90	3.29	14.56	39.72
Siderastrea radians	0.78	1.55	3.05	13.48	53.20
Stephanocoenia michelinii	1.55	0.90	2.57	11.36	64.56
Millepora alcicornis	1.19	1.69	1.96	8.67	73.23
Favia fragum	0.45	0.00	1.76	7.77	81.00
Porites astreoides	0.90	0.45	1.75	7.75	88.75
D. strigosa	1.00	1.35	1.37	6.03	94.78

Groups 1b & 1a
Average dissimilarity = 34.79

Species	Group 1b Av.Abund	Group 1a Av.Abund	Av.Diss	Contrib%	Cum.%
Millepora alcicornis	0.00	1.69	7.71	22.17	22.17
D. labyrinthiformis	3.10	1.56	7.08	20.34	42.51
Montastraea franksi	0.00	0.78	3.57	10.26	52.78
Oculina species	0.45	1.19	3.38	9.72	62.50
Madracis decactis	0.63	1.35	3.28	9.44	71.94
D. strigosa	2.05	1.35	3.21	9.23	81.17
Siderastrea radians	0.89	1.55	3.02	8.67	89.84
Stephanocoenia michelinii	1.48	0.90	2.68	7.70	97.54

Groups 4b & 2b
Average dissimilarity = 28.98

Species	Group 4b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.85	6.82	23.53	23.53
Porites astreoides	1.85	0.00	6.81	23.49	47.02
D. labyrinthiformis	4.01	2.65	5.00	17.25	64.27
Stephanocoenia michelinii	0.78	1.27	1.81	6.24	70.51
Favia fragum	0.00	0.45	1.66	5.72	76.24
Millepora alcicornis	0.45	0.00	1.66	5.72	81.95
Oculina species	1.00	0.63	1.37	4.72	86.67
Madracis mirabilis	1.68	1.35	1.23	4.23	90.90

Groups 4a & 2b
Average dissimilarity = 33.62

Species	Group 4a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.85	7.81	23.24	23.24
Porites astreoides	1.79	0.00	7.57	22.52	45.76
Madracis decactis	0.45	1.67	5.17	15.38	61.14
Montastraea franksi	0.00	1.00	4.23	12.58	73.72
Agaricia fragilis	0.63	0.00	2.68	7.97	81.69
Favia fragum	0.00	0.45	1.90	5.65	87.34
Stephanocoenia michelinii	0.90	1.27	1.56	4.65	91.99

Groups 3b & 2b
Average dissimilarity = 35.66

Species	Group 3b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Porites astreoides	1.62	0.00	5.95	16.67	16.67
Siderastrea radians	0.00	1.27	4.67	13.08	29.76
Stephanocoenia michelinii	0.00	1.27	4.66	13.07	42.83
D. labyrinthiformis	3.92	2.65	4.64	13.02	55.85
Montastraea cavernosa	0.78	1.85	3.94	11.04	66.89
D. strigosa	1.74	0.78	3.54	9.93	76.82
Millepora alcicornis	0.78	0.00	2.85	8.00	84.82
Agaricia fragilis	0.45	0.00	1.65	4.64	89.46
Favia fragum	0.00	0.45	1.65	4.64	94.10

Groups 3a & 2b
Average dissimilarity = 25.36

Species	Group 3a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.85	6.93	27.35	27.35
Millepora alcicornis	1.19	0.00	4.44	17.53	44.87
Porites astreoides	0.90	0.00	3.36	13.24	58.11
Siderastrea radians	0.78	1.27	1.84	7.27	65.38
Oculina species	1.10	0.63	1.74	6.87	72.25
Madracis mirabilis	1.74	1.35	1.46	5.76	78.01
Montastraea franksi	0.64	1.00	1.37	5.39	83.40
D. labyrinthiformis	3.01	2.65	1.32	5.22	88.62
Stephanocoenia michelinii	1.55	1.27	1.07	4.22	92.84

Groups 1b & 2b
Average dissimilarity = 34.37

Species	Group 1b Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.85	8.02	23.34	23.34
D. strigosa	2.05	0.78	5.53	16.08	39.42
Madracis decactis	0.63	1.67	4.52	13.14	52.56
Montastraea franksi	0.00	1.00	4.34	12.63	65.19
Porites astreoides	0.63	0.00	2.74	7.98	73.17
Madracis mirabilis	0.89	1.35	1.96	5.71	78.88
Favia fragum	0.00	0.45	1.95	5.68	84.56
D. labyrinthiformis	3.10	2.65	1.95	5.67	90.22

Groups 1a & 2b
Average dissimilarity = 33.73

Species	Group 1a Av.Abund	Group 2b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.85	7.51	22.27	22.27
Millepora alcicornis	1.69	0.00	6.84	20.29	42.56
D. labyrinthiformis	1.56	2.65	4.45	13.20	55.76
D. strigosa	1.35	0.78	2.33	6.90	62.66
Oculina species	1.19	0.63	2.25	6.67	69.33
Favia fragum	0.00	0.45	1.83	5.42	74.75
Madracis mirabilis	0.90	1.35	1.83	5.41	80.16
Porites astreoides	0.45	0.00	1.82	5.41	85.57
Stephanocoenia michelinii	0.90	1.27	1.50	4.44	90.01

Groups 4b & 2a
Average dissimilarity = 35.14

Species	Group 4b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Porites astreoides	1.85	0.00	6.96	19.80	19.80
Madracis mirabilis	1.68	0.00	6.33	18.01	37.82
D. strigosa	0.45	1.85	5.27	14.99	52.81
Montastraea cavernosa	0.00	1.27	4.78	13.60	66.41
Madracis decactis	1.79	0.63	4.37	12.42	78.83
Siderastrea radians	1.10	0.63	1.75	4.99	83.82
Favia fragum	0.00	0.45	1.69	4.82	88.64
Millepora alcicornis	0.45	0.00	1.69	4.82	93.46

Groups 4a & 2a
Average dissimilarity = 46.41

Species	Group 4a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Porites astreoides	1.79	0.00	7.77	16.73	16.73
Madracis mirabilis	1.55	0.00	6.73	14.49	31.23
D. labyrinthiformis	2.69	4.20	6.56	14.14	45.37
Montastraea cavernosa	0.00	1.27	5.50	11.84	57.21
Montastraea franksi	0.00	1.10	4.76	10.26	67.48
D. strigosa	1.00	1.85	3.67	7.90	75.38
Oculina species	0.63	1.42	3.39	7.30	82.68
Agaricia fragilis	0.63	0.00	2.75	5.92	88.60
Siderastrea radians	1.10	0.63	2.02	4.34	92.95

Groups 3b & 2a
Average dissimilarity = 31.84

Species	Group 3b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Porites astreoides	1.62	0.00	6.08	19.09	19.09
Madracis mirabilis	1.35	0.00	5.06	15.90	35.00
Madracis decactis	1.56	0.63	3.47	10.89	45.89
Stephanocoenia michelinii	0.00	0.78	2.92	9.16	55.05
Millepora alcicornis	0.78	0.00	2.92	9.16	64.21
Siderastrea radians	0.00	0.63	2.38	7.49	71.70
Oculina species	0.90	1.42	1.95	6.12	77.82
Montastraea cavernosa	0.78	1.27	1.84	5.78	83.60
Agaricia fragilis	0.45	0.00	1.69	5.31	88.91
Favia fragum	0.00	0.45	1.69	5.31	94.22

Groups 3a & 2a
Average dissimilarity = 36.87

Species	Group 3a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis mirabilis	1.74	0.00	6.66	18.06	18.06
Montastraea cavernosa	0.00	1.27	4.86	13.19	31.25
D. labyrinthiformis	3.01	4.20	4.60	12.47	43.72
Millepora alcicornis	1.19	0.00	4.54	12.33	56.04
Porites astreoides	0.90	0.00	3.43	9.31	65.35
D. strigosa	1.00	1.85	3.24	8.79	74.15
Madracis decactis	1.42	0.63	3.00	8.14	82.29
Stephanocoenia michelinii	1.55	0.78	2.98	8.08	90.37

Groups 1b & 2a
Average dissimilarity = 33.78

Species	Group 1b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.27	5.65	16.71	16.71
D. labyrinthiformis	3.10	4.20	4.91	14.53	31.25
Montastraea franksi	0.00	1.10	4.89	14.49	45.73
Oculina species	0.45	1.42	4.31	12.76	58.49
Madracis mirabilis	0.89	0.00	3.98	11.79	70.28
Stephanocoenia michelinii	1.48	0.78	3.15	9.32	79.60
Porites astreoides	0.63	0.00	2.82	8.34	87.94
Favia fragum	0.00	0.45	2.00	5.92	93.86

Groups 1a & 2a
Average dissimilarity = 42.45

Species	Group 1a Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.56	4.20	11.02	25.96	25.96
Millepora alcicornis	1.69	0.00	7.01	16.51	42.47
Montastraea cavernosa	0.00	1.27	5.28	12.43	54.91
Siderastrea radians	1.55	0.63	3.83	9.01	63.92
Madracis mirabilis	0.90	0.00	3.74	8.80	72.72
Madracis decactis	1.35	0.63	2.98	7.01	79.73
D. strigosa	1.35	1.85	2.07	4.88	84.61
Favia fragum	0.00	0.45	1.87	4.40	89.02
Porites astreoides	0.45	0.00	1.87	4.40	93.42

Groups 2b & 2a
Average dissimilarity = 30.10

Species	Group 2b Av.Abund	Group 2a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	2.65	4.20	6.15	20.42	20.42
Madracis mirabilis	1.35	0.00	5.34	17.73	38.16
D. strigosa	0.78	1.85	4.24	14.10	52.25
Madracis decactis	1.67	0.63	4.12	13.68	65.93
Oculina species	0.63	1.42	3.10	10.31	76.24
Siderastrea radians	1.27	0.63	2.51	8.35	84.59
Montastraea cavernosa	1.85	1.27	2.30	7.65	92.24

Groups 4b & 5b
Average dissimilarity = 36.40

Species	Group 4b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.79	3.44	5.10	14.02	14.02
D. strigosa	0.45	1.85	4.32	11.87	25.89
Madracis mirabilis	1.68	3.07	4.31	11.83	37.72
Montastraea franksi	1.10	0.00	3.41	9.36	47.08
Porites astreoides	1.85	0.78	3.31	9.10	56.18
Agaricia fragilis	0.00	1.00	3.10	8.52	64.70
Stephanocoenia michelinii	0.78	1.55	2.39	6.58	71.27
D. labyrinthiformis	4.01	3.35	2.03	5.58	76.86
Siderastrea radians	1.10	0.45	2.02	5.55	82.40
Montastraea cavernosa	0.00	0.63	1.96	5.37	87.78
Millepora alcicornis	0.45	0.00	1.39	3.82	91.60

Groups 4a & 5b
Average dissimilarity = 37.07

Species	Group 4a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	0.45	3.44	10.37	27.97	27.97
Madracis mirabilis	1.55	3.07	5.26	14.20	42.18
Porites astreoides	1.79	0.78	3.52	9.49	51.67
D. strigosa	1.00	1.85	2.93	7.90	59.57
D. labyrinthiformis	2.69	3.35	2.29	6.18	65.75
Stephanocoenia michelinii	0.90	1.55	2.26	6.10	71.85
Siderastrea radians	1.10	0.45	2.26	6.10	77.95
Montastraea cavernosa	0.00	0.63	2.19	5.91	83.86
Oculina species	0.63	1.10	1.60	4.33	88.19
Favia fragum	0.00	0.45	1.55	4.18	92.37

Groups 3b & 5b
Average dissimilarity = 33.60

Species	Group 3b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.56	3.44	5.82	17.33	17.33
Madracis mirabilis	1.35	3.07	5.33	15.86	33.19
Stephanocoenia michelinii	0.00	1.55	4.79	14.25	47.44
Montastraea franksi	1.19	0.00	3.68	10.95	58.38
Porites astreoides	1.62	0.78	2.59	7.72	66.10
Millepora alcicornis	0.78	0.00	2.39	7.13	73.23
D. labyrinthiformis	3.92	3.35	1.74	5.18	78.41
Agaricia fragilis	0.45	1.00	1.71	5.08	83.49
Favia fragum	0.00	0.45	1.38	4.11	87.61
Isophyllia sinuosa	0.00	0.45	1.38	4.11	91.72

Groups 3a & 5b
Average dissimilarity = 27.95

Species	Group 3a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.42	3.44	6.36	22.74	22.74
Madracis mirabilis	1.74	3.07	4.19	14.99	37.73
Millepora alcicornis	1.19	0.00	3.72	13.31	51.04
Agaricia fragilis	0.00	1.00	3.15	11.26	62.30
D. strigosa	1.00	1.85	2.65	9.48	71.78
Montastraea franksi	0.64	0.00	2.00	7.14	78.93
Montastraea cavernosa	0.00	0.63	1.98	7.10	86.03
Isophyllia sinuosa	0.00	0.45	1.40	5.03	91.05

Groups 1b & 5b
Average dissimilarity = 32.85

Species	Group 1b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	0.63	3.44	9.95	30.28	30.28
Madracis mirabilis	0.89	3.07	7.71	23.46	53.74
Agaricia fragilis	0.00	1.00	3.55	10.80	64.54
Oculina species	0.45	1.10	2.30	7.00	71.54
Montastraea cavernosa	0.00	0.63	2.24	6.81	78.35
Siderastrea radians	0.89	0.45	1.58	4.82	83.17
Favia fragum	0.00	0.45	1.58	4.82	88.00
Isophyllia sinuosa	0.00	0.45	1.58	4.82	92.82

Groups 1a & 5b
Average dissimilarity = 46.04

Species	Group 1a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis mirabilis	0.90	3.07	7.29	15.83	15.83
Madracis decactis	1.35	3.44	7.02	15.24	31.08
D. labyrinthiformis	1.56	3.35	6.02	13.08	44.16
Millepora alcicornis	1.69	0.00	5.65	12.27	56.43
Siderastrea radians	1.55	0.45	3.71	8.06	64.49
Agaricia fragilis	0.00	1.00	3.36	7.30	71.79
Montastraea franksi	0.78	0.00	2.62	5.68	77.47
Stephanocoenia michelinii	0.90	1.55	2.19	4.75	82.22
Montastraea cavernosa	0.00	0.63	2.12	4.61	86.82
D. strigosa	1.35	1.85	1.67	3.62	90.44

Groups 2b & 5b
Average dissimilarity = 36.35

Species	Group 2b Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.67	3.44	5.70	15.69	15.69
Madracis mirabilis	1.35	3.07	5.56	15.29	30.97
Montastraea cavernosa	1.85	0.63	3.92	10.79	41.77
D. strigosa	0.78	1.85	3.45	9.48	51.25
Agaricia fragilis	0.00	1.00	3.23	8.89	60.14
Montastraea franksi	1.00	0.00	3.23	8.87	69.01
Siderastrea radians	1.27	0.45	2.65	7.28	76.30
Porites astreoides	0.00	0.78	2.50	6.89	83.18
D. labyrinthiformis	2.65	3.35	2.25	6.20	89.38
Oculina species	0.63	1.10	1.50	4.12	93.50

Groups 2a & 5b
Average dissimilarity = 39.35

Species	Group 2a Av.Abund	Group 5b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis mirabilis	0.00	3.07	10.09	25.64	25.64
Madracis decactis	0.63	3.44	9.22	23.44	49.09
Montastraea franksi	1.10	0.00	3.61	9.18	58.27
Agaricia fragilis	0.00	1.00	3.29	8.37	66.64
D. labyrinthiformis	4.20	3.35	2.80	7.12	73.76
Porites astreoides	0.00	0.78	2.55	6.48	80.24
Stephanocoenia michelinii	0.78	1.55	2.54	6.46	86.70
Montastraea cavernosa	1.27	0.63	2.09	5.31	92.01

Groups 4b & 5a
Average dissimilarity = 22.97

Species	Group 4b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.55	4.80	20.89	20.89
Madracis decactis	1.79	3.20	4.36	18.96	39.84
D. strigosa	0.45	1.79	4.15	18.06	57.91
Madracis mirabilis	1.68	2.54	2.64	11.51	69.41
Porites astreoides	1.85	1.34	1.55	6.77	76.18
Siderastrea radians	1.10	0.63	1.44	6.26	82.44
Millepora alcicornis	0.45	0.00	1.39	6.04	88.48
Favia fragum	0.00	0.45	1.38	6.02	94.50

Groups 4a & 5a
Average dissimilarity = 38.17

Species	Group 4a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	0.45	3.20	9.52	24.95	24.95
Montastraea cavernosa	0.00	1.55	5.37	14.07	39.03
D. labyrinthiformis	2.69	3.93	4.31	11.28	50.31
Montastraea franksi	0.00	1.19	4.10	10.75	61.06
Madracis mirabilis	1.55	2.54	3.40	8.91	69.97
D. strigosa	1.00	1.79	2.74	7.17	77.14
Agaricia fragilis	0.63	0.00	2.19	5.75	82.89
Siderastrea radians	1.10	0.63	1.61	4.22	87.10
Porites astreoides	1.79	1.34	1.55	4.06	91.17

Groups 3b & 5a
Average dissimilarity = 21.28

Species	Group 3b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.56	3.20	5.08	23.85	23.85
Madracis mirabilis	1.35	2.54	3.66	17.23	41.08
Millepora alcicornis	0.78	0.00	2.39	11.24	52.32
Montastraea cavernosa	0.78	1.55	2.39	11.22	63.54
Siderastrea radians	0.00	0.63	1.96	9.19	72.73
Stephanocoenia michelinii	0.00	0.63	1.95	9.18	81.91
Agaricia fragilis	0.45	0.00	1.39	6.52	88.43
Favia fragum	0.00	0.45	1.38	6.49	94.92

Groups 3a & 5a
Average dissimilarity = 29.15

Species	Group 3a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.42	3.20	5.59	19.19	19.19
Montastraea cavernosa	0.00	1.55	4.87	16.70	35.89
Millepora alcicornis	1.19	0.00	3.71	12.74	48.63
D. labyrinthiformis	3.01	3.93	2.91	9.99	58.62
Stephanocoenia michelinii	1.55	0.63	2.88	9.88	68.50
Madracis mirabilis	1.74	2.54	2.50	8.59	77.09
D. strigosa	1.00	1.79	2.48	8.50	85.58
Montastraea franksi	0.64	1.19	1.72	5.91	91.50

Groups 1b & 5a
Average dissimilarity = 38.03

Species	Group 1b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	0.63	3.20	9.08	23.88	23.88
Madracis mirabilis	0.89	2.54	5.80	15.25	39.13
Montastraea cavernosa	0.00	1.55	5.49	14.43	53.56
Montastraea franksi	0.00	1.19	4.19	11.02	64.59
Stephanocoenia michelinii	1.48	0.63	3.00	7.90	72.48
D. labyrinthiformis	3.10	3.93	2.94	7.74	80.23
Porites astreoides	0.63	1.34	2.51	6.61	86.84
Oculina species	0.45	0.90	1.59	4.18	91.01

Groups 1a & 5a
Average dissimilarity = 42.76

Species	Group 1a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.56	3.93	7.97	18.63	18.63
Madracis decactis	1.35	3.20	6.20	14.51	33.13
Millepora alcicornis	1.69	0.00	5.64	13.19	46.32
Madracis mirabilis	0.90	2.54	5.48	12.82	59.14
Montastraea cavernosa	0.00	1.55	5.20	12.16	71.30
Siderastrea radians	1.55	0.63	3.08	7.20	78.50
Porites astreoides	0.45	1.34	3.00	7.01	85.51
Favia fragum	0.00	0.45	1.50	3.50	89.01
D. strigosa	1.35	1.79	1.48	3.47	92.48

Groups 2b & 5a
Average dissimilarity = 26.95

Species	Group 2b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.67	3.20	4.92	18.26	18.26
Porites astreoides	0.00	1.34	4.32	16.05	34.30
D. labyrinthiformis	2.65	3.93	4.13	15.31	49.61
Madracis mirabilis	1.35	2.54	3.82	14.18	63.79
D. strigosa	0.78	1.79	3.27	12.13	75.92
Siderastrea radians	1.27	0.63	2.04	7.57	83.49
Stephanocoenia michelinii	1.27	0.63	2.04	7.57	91.06

Groups 2a & 5a
Average dissimilarity = 25.61

Species	Group 2a Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	0.63	3.20	8.42	32.90	32.90
Madracis mirabilis	0.00	2.54	8.32	32.47	65.37
Porites astreoides	0.00	1.34	4.41	17.21	82.58
Oculina species	1.42	0.90	1.70	6.64	89.23
Montastraea cavernosa	1.27	1.55	0.93	3.65	92.87

Groups 5b & 5a
Average dissimilarity = 18.86

Species	Group 5b Av.Abund	Group 5a Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea franksi	0.00	1.19	3.27	17.34	17.34
Agaricia fragilis	1.00	0.00	2.76	14.66	31.99
Montastraea cavernosa	0.63	1.55	2.54	13.46	45.45
Stephanocoenia michelinii	1.55	0.63	2.53	13.40	58.85
D. labyrinthiformis	3.35	3.93	1.61	8.52	67.37
Porites astreoides	0.78	1.34	1.56	8.29	75.66
Madracis mirabilis	3.07	2.54	1.48	7.84	83.51
Isophyllia sinuosa	0.45	0.00	1.23	6.54	90.05

Groups 4b & 6a
Average dissimilarity = 64.33

Species	Group 4b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.01	1.10	12.64	19.65	19.65
D. strigosa	0.45	2.93	10.78	16.75	36.40
Madracis decactis	1.79	0.00	7.78	12.09	48.49
Madracis mirabilis	1.68	0.00	7.29	11.33	59.83
Porites astreoides	1.85	0.45	6.07	9.44	69.27
Millepora alcicornis	0.45	1.61	5.05	7.85	77.12
Siderastrea radians	1.10	0.00	4.77	7.42	84.54
Montastraea franksi	1.10	0.45	2.84	4.41	88.95
Montastraea cavernosa	0.00	0.63	2.74	4.27	93.21

Groups 4a & 6a
Average dissimilarity = 61.56

Species	Group 4a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	2.93	9.86	16.02	16.02
Millepora alcicornis	0.00	1.61	8.24	13.39	29.41
D. labyrinthiformis	2.69	1.10	8.14	13.22	42.63
Madracis mirabilis	1.55	0.00	7.93	12.88	55.51
Porites astreoides	1.79	0.45	6.87	11.16	66.66
Siderastrea radians	1.10	0.00	5.61	9.12	75.78
Agaricia fragilis	0.63	0.00	3.24	5.26	81.04
Montastraea cavernosa	0.00	0.63	3.23	5.24	86.29
Madracis decactis	0.45	0.00	2.29	3.73	90.01

Groups 3b & 6a
Average dissimilarity = 51.67

Species	Group 3b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.92	1.10	12.20	23.62	23.62
Madracis decactis	1.56	0.00	6.74	13.04	36.66
Madracis mirabilis	1.35	0.00	5.83	11.28	47.94
D. strigosa	1.74	2.93	5.17	10.00	57.94
Porites astreoides	1.62	0.45	5.06	9.80	67.74
Millepora alcicornis	0.78	1.61	3.63	7.02	74.76
Stephanocoenia michelinii	0.00	0.77	3.35	6.49	81.25
Montastraea franksi	1.19	0.45	3.22	6.23	87.48
Oculina species	0.90	0.45	1.95	3.78	91.26

Groups 3a & 6a
Average dissimilarity = 48.25

Species	Group 3a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	2.93	8.55	17.72	17.72
D. labyrinthiformis	3.01	1.10	8.45	17.52	35.24
Madracis mirabilis	1.74	0.00	7.69	15.93	51.17
Madracis decactis	1.42	0.00	6.27	13.00	64.18
Stephanocoenia michelinii	1.55	0.77	3.45	7.14	71.32
Siderastrea radians	0.78	0.00	3.44	7.13	78.45
Oculina species	1.10	0.45	2.88	5.97	84.41
Montastraea cavernosa	0.00	0.63	2.80	5.80	90.22

Groups 1b & 6a
Average dissimilarity = 49.25

Species	Group 1b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.10	1.10	10.57	21.46	21.46
Millepora alcicornis	0.00	1.61	8.50	17.27	38.73
Madracis mirabilis	0.89	0.00	4.72	9.57	48.31
Siderastrea radians	0.89	0.00	4.72	9.57	57.88
D. strigosa	2.05	2.93	4.65	9.44	67.32
Stephanocoenia michelinii	1.48	0.77	3.73	7.58	74.90
Madracis decactis	0.63	0.00	3.33	6.77	81.67
Montastraea cavernosa	0.00	0.63	3.33	6.77	88.43
Favia fragum	0.00	0.45	2.36	4.79	93.22

Groups 1a & 6a
Average dissimilarity = 39.88

Species	Group 1a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.35	2.93	7.71	19.32	19.32
Siderastrea radians	1.55	0.00	7.56	18.96	38.29
Madracis decactis	1.35	0.00	6.57	16.47	54.76
Madracis mirabilis	0.90	0.00	4.37	10.96	65.72
Oculina species	1.19	0.45	3.60	9.03	74.75
Montastraea cavernosa	0.00	0.63	3.08	7.72	82.47
D. labyrinthiformis	1.56	1.10	2.24	5.61	88.08
Favia fragum	0.00	0.45	2.18	5.46	93.54

Groups 2b & 6a
Average dissimilarity = 57.53

Species	Group 2b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.78	2.93	9.91	17.23	17.23
Madracis decactis	1.67	0.00	7.69	13.37	30.60
Millepora alcicornis	0.00	1.61	7.42	12.89	43.50
D. labyrinthiformis	2.65	1.10	7.15	12.44	55.93
Madracis mirabilis	1.35	0.00	6.19	10.77	66.70
Siderastrea radians	1.27	0.00	5.83	10.14	76.83
Montastraea cavernosa	1.85	0.63	5.59	9.73	86.56
Montastraea franksi	1.00	0.45	2.55	4.42	90.98

Groups 2a & 6a
Average dissimilarity = 46.23

Species	Group 2a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.20	1.10	14.69	31.77	31.77
Millepora alcicornis	0.00	1.61	7.62	16.49	48.26
D. strigosa	1.85	2.93	5.13	11.09	59.35
Oculina species	1.42	0.45	4.58	9.91	69.26
Montastraea franksi	1.10	0.45	3.08	6.67	75.93
Montastraea cavernosa	1.27	0.63	3.00	6.50	82.43
Madracis decactis	0.63	0.00	3.00	6.48	88.91
Siderastrea radians	0.63	0.00	3.00	6.48	95.39

Groups 5b & 6a
Average dissimilarity = 57.78

Species	Group 5b Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	12.77	22.11	22.11
Madracis mirabilis	3.07	0.00	11.40	19.73	41.84
D. labyrinthiformis	3.35	1.10	8.37	14.49	56.32
Millepora alcicornis	0.00	1.61	5.99	10.36	66.69
D. strigosa	1.85	2.93	4.03	6.98	73.67
Agaricia fragilis	1.00	0.00	3.72	6.44	80.10
Stephanocoenia michelinii	1.55	0.77	2.88	4.98	85.09
Oculina species	1.10	0.45	2.41	4.18	89.26
Isophyllia sinuosa	0.45	0.00	1.66	2.87	92.14

Groups 5a & 6a
Average dissimilarity = 55.98

Species	Group 5a Av.Abund	Group 6a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	11.86	21.19	21.19
D. labyrinthiformis	3.93	1.10	10.51	18.78	39.97
Madracis mirabilis	2.54	0.00	9.39	16.77	56.75
Millepora alcicornis	0.00	1.61	5.98	10.68	67.42
D. strigosa	1.79	2.93	4.22	7.55	74.97
Montastraea cavernosa	1.55	0.63	3.41	6.09	81.06
Porites astreoides	1.34	0.45	3.32	5.93	87.00
Montastraea franksi	1.19	0.45	2.74	4.89	91.89

Groups 4b & 6b
Average dissimilarity = 65.82

Species	Group 4b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.01	1.18	12.26	18.63	18.63
D. strigosa	0.45	3.03	11.21	17.03	35.66
Madracis decactis	1.79	0.00	7.78	11.82	47.48
Madracis mirabilis	1.68	0.00	7.29	11.08	58.56
Porites astreoides	1.85	0.63	5.27	8.01	66.57
Montastraea franksi	1.10	0.00	4.78	7.26	73.83
Oculina species	1.00	0.00	4.36	6.62	80.45
Montastraea cavernosa	0.00	0.89	3.88	5.90	86.34
Isophyllia sinuosa	0.00	0.77	3.36	5.11	91.45

Groups 4a & 6b

Average dissimilarity = 57.51

Species	Group 4a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.03	10.37	18.04	18.04
Madracis mirabilis	1.55	0.00	7.93	13.78	31.82
D. labyrinthiformis	2.69	1.18	7.69	13.37	45.20
Porites astreoides	1.79	0.63	5.92	10.30	55.50
Montastraea cavernosa	0.00	0.89	4.57	7.94	63.44
Isophyllia sinuosa	0.00	0.77	3.95	6.88	70.32
Millepora alcicornis	0.00	0.77	3.95	6.88	77.19
Siderastrea radians	1.10	0.45	3.33	5.79	82.99
Oculina species	0.63	0.00	3.24	5.63	88.62
Agaricia fragilis	0.63	0.00	3.24	5.63	94.25

Groups 3b & 6b
Average dissimilarity = 55.78

Species	Group 3b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.92	1.18	11.82	21.20	21.20
Madracis decactis	1.56	0.00	6.74	12.08	33.28
Madracis mirabilis	1.35	0.00	5.83	10.45	43.73
D. strigosa	1.74	3.03	5.60	10.04	53.77
Montastraea franksi	1.19	0.00	5.16	9.24	63.02
Stephanocoenia michelinii	0.00	1.10	4.74	8.50	71.52
Porites astreoides	1.62	0.63	4.26	7.64	79.16
Oculina species	0.90	0.00	3.89	6.97	86.13
Isophyllia sinuosa	0.00	0.77	3.35	6.01	92.14

Groups 3a & 6b
Average dissimilarity = 54.54

Species	Group 3a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.03	8.99	16.49	16.49
D. labyrinthiformis	3.01	1.18	8.07	14.79	31.28
Madracis mirabilis	1.74	0.00	7.69	14.10	45.38
Madracis decactis	1.42	0.00	6.27	11.51	56.88
Oculina species	1.10	0.00	4.86	8.91	65.79
Montastraea cavernosa	0.00	0.89	3.96	7.26	73.05
Isophyllia sinuosa	0.00	0.77	3.43	6.29	79.34
Montastraea franksi	0.64	0.00	2.82	5.16	84.51
Stephanocoenia michelinii	1.55	1.10	2.03	3.71	88.22
Favia fragum	0.45	0.00	1.98	3.63	91.85

Groups 1b & 6b
Average dissimilarity = 42.98

Species	Group 1b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	3.10	1.18	10.11	23.52	23.52
D. strigosa	2.05	3.03	5.17	12.04	35.56
Madracis mirabilis	0.89	0.00	4.72	10.97	46.53
Montastraea cavernosa	0.00	0.89	4.71	10.97	57.50
Isophyllia sinuosa	0.00	0.77	4.08	9.50	67.00
Millepora alcicornis	0.00	0.77	4.08	9.50	76.50
Madracis decactis	0.63	0.00	3.33	7.76	84.25
Oculina species	0.45	0.00	2.36	5.50	89.75
Siderastrea radians	0.89	0.45	2.36	5.49	95.24

Groups 1a & 6b
Average dissimilarity = 50.32

Species	Group 1a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.35	3.03	8.19	16.28	16.28
Madracis decactis	1.35	0.00	6.57	13.06	29.34
Oculina species	1.19	0.00	5.78	11.48	40.83
Siderastrea radians	1.55	0.45	5.39	10.71	51.53
Millepora alcicornis	1.69	0.77	4.43	8.81	60.34
Madracis mirabilis	0.90	0.00	4.37	8.69	69.03
Montastraea cavernosa	0.00	0.89	4.35	8.65	77.68
Montastraea franksi	0.78	0.00	3.80	7.55	85.23
Isophyllia sinuosa	0.00	0.77	3.77	7.49	92.72

Groups 2b & 6b
Average dissimilarity = 59.58

Species	Group 2b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.78	3.03	10.37	17.41	17.41
Madracis decactis	1.67	0.00	7.69	12.91	30.32
D. labyrinthiformis	2.65	1.18	6.75	11.33	41.66
Madracis mirabilis	1.35	0.00	6.19	10.40	52.05
Montastraea franksi	1.00	0.00	4.60	7.72	59.78
Montastraea cavernosa	1.85	0.89	4.39	7.37	67.15
Siderastrea radians	1.27	0.45	3.78	6.34	73.49
Isophyllia sinuosa	0.00	0.77	3.56	5.98	79.46
Millepora alcicornis	0.00	0.77	3.56	5.98	85.44
Oculina species	0.63	0.00	2.91	4.88	90.32

Groups 2a & 6b
Average dissimilarity = 51.35

Species	Group 2a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.20	1.18	14.27	27.80	27.80
Oculina species	1.42	0.00	6.69	13.03	40.83
D. strigosa	1.85	3.03	5.60	10.90	51.74
Montastraea franksi	1.10	0.00	5.19	10.12	61.85
Isophyllia sinuosa	0.00	0.77	3.66	7.13	68.98
Millepora alcicornis	0.00	0.77	3.66	7.13	76.11
Madracis decactis	0.63	0.00	3.00	5.84	81.94
Porites astreoides	0.00	0.63	2.99	5.82	87.76
Favia fragum	0.45	0.00	2.12	4.14	91.90

Groups 5b & 6b
Average dissimilarity = 53.36

Species	Group 5b Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	12.78	23.94	23.94
Madracis mirabilis	3.07	0.00	11.40	21.36	45.30
D. labyrinthiformis	3.35	1.18	8.05	15.08	60.38
D. strigosa	1.85	3.03	4.40	8.25	68.63
Oculina species	1.10	0.00	4.07	7.63	76.27
Agaricia fragilis	1.00	0.00	3.72	6.97	83.24
Millepora alcicornis	0.00	0.77	2.87	5.39	88.62
Stephanocoenia michelinii	1.55	1.10	1.69	3.16	91.79

Groups 5a & 6b

Average dissimilarity = 58.64

Species	Group 5a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	11.86	20.23	20.23
D. labyrinthiformis	3.93	1.18	10.19	17.38	37.61
Madracis mirabilis	2.54	0.00	9.39	16.02	53.63
D. strigosa	1.79	3.03	4.59	7.84	61.46
Montastraea franksi	1.19	0.00	4.39	7.49	68.96
Oculina species	0.90	0.00	3.33	5.67	74.63
Isophyllia sinuosa	0.00	0.77	2.87	4.89	79.52
Millepora alcicornis	0.00	0.77	2.87	4.89	84.41
Porites astreoides	1.34	0.63	2.64	4.50	88.91
Montastraea cavernosa	1.55	0.89	2.44	4.16	93.07

Groups 6a & 6b
Average dissimilarity = 24.66

Species	Group 6a Av.Abund	Group 6b Av.Abund	Av.Diss	Contrib%	Cum.%
Millepora alcicornis	1.61	0.77	4.75	19.26	19.26
Isophyllia sinuosa	0.00	0.77	4.38	17.77	37.03
Favia fragum	0.45	0.00	2.53	10.26	47.29
Montastraea franksi	0.45	0.00	2.53	10.26	57.55
Oculina species	0.45	0.00	2.53	10.26	67.81
Siderastrea radians	0.00	0.45	2.53	10.26	78.08
Stephanocoenia michelinii	0.77	1.10	1.82	7.36	85.44
Montastraea cavernosa	0.63	0.89	1.48	6.01	91.45

Groups 4b & 7a
Average dissimilarity = 47.72

Species	Group 4b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.45	3.92	13.59	28.48	28.48
Madracis decactis	1.79	0.00	7.01	14.70	43.18
Madracis mirabilis	1.68	0.00	6.57	13.77	56.95
Montastraea franksi	1.10	0.00	4.31	9.02	65.98
Oculina species	1.00	0.00	3.93	8.23	74.21
D. labyrinthiformis	4.01	3.19	3.19	6.68	80.89
Porites astreoides	1.85	1.18	2.60	5.44	86.33
Montastraea cavernosa	0.00	0.63	2.47	5.18	91.52

Groups 4a & 7a
Average dissimilarity = 42.09

Species	Group 4a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.92	13.22	31.42	31.42
Madracis mirabilis	1.55	0.00	7.02	16.69	48.11
Oculina species	0.63	0.00	2.87	6.82	54.92
Agaricia fragilis	0.63	0.00	2.87	6.82	61.74
Montastraea cavernosa	0.00	0.63	2.86	6.80	68.54
Porites astreoides	1.79	1.18	2.76	6.55	75.09
D. labyrinthiformis	2.69	3.19	2.28	5.42	80.51
Siderastrea radians	1.10	0.63	2.11	5.02	85.53
Madracis decactis	0.45	0.00	2.03	4.83	90.36

Groups 3b & 7a
Average dissimilarity = 43.84

Species	Group 3b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.74	3.92	8.53	19.45	19.45
Madracis decactis	1.56	0.00	6.08	13.86	33.31
Madracis mirabilis	1.35	0.00	5.26	11.99	45.31
Montastraea franksi	1.19	0.00	4.65	10.61	55.91
Oculina species	0.90	0.00	3.50	7.99	63.91
Stephanocoenia michelinii	0.00	0.89	3.49	7.96	71.87
D. labyrinthiformis	3.92	3.19	2.82	6.42	78.29
Siderastrea radians	0.00	0.63	2.47	5.63	83.92
Agaricia fragilis	0.45	0.00	1.76	4.01	87.93
Favia fragum	0.00	0.45	1.75	3.98	91.91

Groups 3a & 7a
Average dissimilarity = 41.66

Species	Group 3a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.92	11.64	27.93	27.93
Madracis mirabilis	1.74	0.00	6.92	16.60	44.54
Madracis decactis	1.42	0.00	5.65	13.55	58.09
Oculina species	1.10	0.00	4.37	10.49	68.58
Millepora alcicornis	1.19	0.45	2.94	7.06	75.64
Stephanocoenia michelinii	1.55	0.89	2.62	6.30	81.94
Montastraea franksi	0.64	0.00	2.53	6.08	88.02
Montastraea cavernosa	0.00	0.63	2.52	6.05	94.06

Groups 1b & 7a
Average dissimilarity = 31.96

Species	Group 1b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	2.05	3.92	8.71	27.26	27.26
Madracis mirabilis	0.89	0.00	4.16	13.03	40.29
Madracis decactis	0.63	0.00	2.94	9.21	49.50
Montastraea cavernosa	0.00	0.63	2.94	9.21	58.70
Stephanocoenia michelinii	1.48	0.89	2.74	8.57	67.28
Porites astreoides	0.63	1.18	2.56	8.01	75.29
Oculina species	0.45	0.00	2.08	6.52	81.81
Favia fragum	0.00	0.45	2.08	6.51	88.32
Millepora alcicornis	0.00	0.45	2.08	6.51	94.83

Groups 1a & 7a
Average dissimilarity = 53.79

Species	Group 1a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.35	3.92	11.16	20.75	20.75
D. labyrinthiformis	1.56	3.19	7.10	13.21	33.96
Madracis decactis	1.35	0.00	5.85	10.88	44.84
Millepora alcicornis	1.69	0.45	5.37	9.98	54.82
Oculina species	1.19	0.00	5.15	9.57	64.39
Siderastrea radians	1.55	0.63	4.00	7.43	71.82
Madracis mirabilis	0.90	0.00	3.89	7.24	79.06
Montastraea franksi	0.78	0.00	3.38	6.29	85.35
Porites astreoides	0.45	1.18	3.18	5.92	91.26

Groups 2b & 7a
Average dissimilarity = 50.27

Species	Group 2b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.78	3.92	12.97	25.79	25.79
Madracis decactis	1.67	0.00	6.89	13.71	39.51
Madracis mirabilis	1.35	0.00	5.55	11.04	50.55
Montastraea cavernosa	1.85	0.63	5.01	9.97	60.52
Porites astreoides	0.00	1.18	4.87	9.70	70.22
Montastraea franksi	1.00	0.00	4.12	8.20	78.42
Siderastrea radians	1.27	0.63	2.62	5.21	83.63
Oculina species	0.63	0.00	2.61	5.19	88.82
D. labyrinthiformis	2.65	3.19	2.23	4.44	93.26

Groups 2a & 7a
Average dissimilarity = 36.42

Species	Group 2a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.85	3.92	8.77	24.07	24.07
Oculina species	1.42	0.00	5.98	16.42	40.49
Porites astreoides	0.00	1.18	5.00	13.72	54.21
Montastraea franksi	1.10	0.00	4.64	12.75	66.95
D. labyrinthiformis	4.20	3.19	4.27	11.72	78.67
Montastraea cavernosa	1.27	0.63	2.69	7.37	86.04
Madracis decactis	0.63	0.00	2.68	7.35	93.40

Groups 5b & 7a
Average dissimilarity = 44.09

Species	Group 5b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	11.68	26.50	26.50
Madracis mirabilis	3.07	0.00	10.42	23.64	50.14
D. strigosa	1.85	3.92	7.05	15.99	66.13
Oculina species	1.10	0.00	3.72	8.45	74.58
Agaricia fragilis	1.00	0.00	3.40	7.72	82.30
Stephanocoenia michelinii	1.55	0.89	2.23	5.05	87.34
Isophyllia sinuosa	0.45	0.00	1.52	3.45	90.79

Groups 5a & 7a
Average dissimilarity = 42.31

Species	Group 5a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	10.85	25.65	25.65
Madracis mirabilis	2.54	0.00	8.59	20.31	45.95
D. strigosa	1.79	3.92	7.22	17.07	63.02
Montastraea franksi	1.19	0.00	4.02	9.50	72.52
Montastraea cavernosa	1.55	0.63	3.12	7.37	79.90
Oculina species	0.90	0.00	3.04	7.19	87.09
D. labyrinthiformis	3.93	3.19	2.51	5.93	93.02

Groups 6a & 7a
Average dissimilarity = 32.88

Species	Group 6a Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.10	3.19	10.39	31.61	31.61
Millepora alcicornis	1.61	0.45	5.78	17.58	49.18
D. strigosa	2.93	3.92	4.91	14.93	64.11
Porites astreoides	0.45	1.18	3.64	11.09	75.20
Siderastrea radians	0.00	0.63	3.13	9.53	84.72
Montastraea franksi	0.45	0.00	2.21	6.74	91.46

Groups 6b & 7a
Average dissimilarity = 27.98

Species	Group 6b Av.Abund	Group 7a Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.18	3.19	9.96	35.59	35.59
D. strigosa	3.03	3.92	4.41	15.77	51.36
Isophyllia sinuosa	0.77	0.00	3.84	13.71	65.07
Porites astreoides	0.63	1.18	2.73	9.75	74.82
Favia fragum	0.00	0.45	2.22	7.92	82.73
Millepora alcicornis	0.77	0.45	1.62	5.79	88.53
Montastraea cavernosa	0.89	0.63	1.30	4.64	93.16

Groups 4b & 7b
Average dissimilarity = 46.87

Species	Group 4b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.45	3.00	9.74	20.78	20.78
Madracis decactis	1.79	0.00	6.85	14.61	35.39
Madracis mirabilis	1.68	0.00	6.42	13.69	49.08
D. labyrinthiformis	4.01	2.45	5.95	12.70	61.78
Montastraea cavernosa	0.00	1.41	5.40	11.52	73.30
Oculina species	1.00	0.00	3.83	8.18	81.48
Siderastrea radians	1.10	0.45	2.49	5.32	86.80
Favia fragum	0.00	0.45	1.71	3.64	90.44

Groups 4a & 7b
Average dissimilarity = 47.58

Species	Group 4a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.00	8.79	18.48	18.48
Madracis mirabilis	1.55	0.00	6.83	14.36	32.84
Montastraea cavernosa	0.00	1.41	6.22	13.08	45.92
Montastraea franksi	0.00	1.26	5.57	11.70	57.62
Millepora alcicornis	0.00	0.89	3.94	8.27	65.89
Siderastrea radians	1.10	0.45	2.87	6.03	71.93
Oculina species	0.63	0.00	2.79	5.87	77.79
Agaricia fragilis	0.63	0.00	2.79	5.87	83.66
Stephanocoenia michelinii	0.90	0.45	1.98	4.16	87.82
Madracis decactis	0.45	0.00	1.98	4.16	91.98

Groups 3b & 7b
Average dissimilarity = 34.87

Species	Group 3b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	1.56	0.00	5.93	17.01	17.01
D. labyrinthiformis	3.92	2.45	5.58	16.01	33.03
Madracis mirabilis	1.35	0.00	5.13	14.72	47.75
D. strigosa	1.74	3.00	4.80	13.77	61.52
Oculina species	0.90	0.00	3.42	9.81	71.33
Montastraea cavernosa	0.78	1.41	2.42	6.94	78.27
Agaricia fragilis	0.45	0.00	1.71	4.92	83.19
Favia fragum	0.00	0.45	1.70	4.89	88.07
Siderastrea radians	0.00	0.45	1.70	4.89	92.96

Groups 3a & 7b
Average dissimilarity = 43.89

Species	Group 3a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.00	3.00	7.76	17.69	17.69
Madracis mirabilis	1.74	0.00	6.75	15.38	33.07
Madracis decactis	1.42	0.00	5.51	12.55	45.62
Montastraea cavernosa	0.00	1.41	5.50	12.52	58.15
Stephanocoenia michelinii	1.55	0.45	4.30	9.79	67.94
Oculina species	1.10	0.00	4.27	9.72	77.66
Porites astreoides	0.90	1.61	2.79	6.35	84.01
Montastraea franksi	0.64	1.26	2.44	5.57	89.58
D. labyrinthiformis	3.01	2.45	2.16	4.92	94.50

Groups 1b & 7b
Average dissimilarity = 45.49

Species	Group 1b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea cavernosa	0.00	1.41	6.39	14.06	14.06
Montastraea franksi	0.00	1.26	5.72	12.57	26.63
Stephanocoenia michelinii	1.48	0.45	4.69	10.30	36.93
Porites astreoides	0.63	1.61	4.43	9.74	46.67
D. strigosa	2.05	3.00	4.29	9.43	56.10
Madracis mirabilis	0.89	0.00	4.05	8.90	64.99
Millepora alcicornis	0.00	0.89	4.04	8.89	73.88
D. labyrinthiformis	3.10	2.45	2.95	6.48	80.36
Madracis decactis	0.63	0.00	2.86	6.29	86.65
Oculina species	0.45	0.00	2.03	4.45	91.10

Groups 1a & 7b
Average dissimilarity = 49.98

Species	Group 1a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	1.35	3.00	6.97	13.94	13.94
Montastraea cavernosa	0.00	1.41	5.97	11.95	25.89
Madracis decactis	1.35	0.00	5.70	11.40	37.29
Oculina species	1.19	0.00	5.01	10.03	47.32
Porites astreoides	0.45	1.61	4.91	9.83	57.15
Siderastrea radians	1.55	0.45	4.67	9.35	66.50
Madracis mirabilis	0.90	0.00	3.79	7.59	74.08
D. labyrinthiformis	1.56	2.45	3.77	7.55	81.63
Millepora alcicornis	1.69	0.89	3.34	6.68	8.31
Montastraea franksi	0.78	1.26	2.05	4.10	92.41

Groups 2b & 7b
Average dissimilarity = 43.91

Species	Group 2b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. strigosa	0.78	3.00	8.93	20.34	20.34
Madracis decactis	1.67	0.00	6.72	15.31	35.65
Porites astreoides	0.00	1.61	6.48	14.75	50.40
Madracis mirabilis	1.35	0.00	5.41	12.33	62.73
Millepora alcicornis	0.00	0.89	3.59	8.18	70.91
Siderastrea radians	1.27	0.45	3.30	7.52	78.43
Stephanocoenia michelinii	1.27	0.45	3.29	7.50	85.93
Oculina species	0.63	0.00	2.54	5.79	91.72

Groups 2a & 7b
Average dissimilarity = 34.12

Species	Group 2a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	4.20	2.45	7.22	21.16	21.16
Porites astreoides	0.00	1.61	6.63	19.44	40.60
Oculina species	1.42	0.00	5.83	17.08	57.68
D. strigosa	1.85	3.00	4.74	13.89	71.57
Millepora alcicornis	0.00	0.89	3.68	10.78	82.35
Madracis decactis	0.63	0.00	2.61	7.65	90.00

Groups 5b & 7b
Average dissimilarity = 53.17

Species	Group 5b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.44	0.00	11.44	21.52	21.52
Madracis mirabilis	3.07	0.00	10.21	19.20	40.72
Montastraea franksi	0.00	1.26	4.20	7.91	48.63
D. strigosa	1.85	3.00	3.83	7.21	55.84
Stephanocoenia michelinii	1.55	0.45	3.67	6.89	62.73
Oculina species	1.10	0.00	3.65	6.86	69.59
Agaricia fragilis	1.00	0.00	3.33	6.27	75.86
D. labyrinthiformis	3.35	2.45	3.00	5.64	81.50
Millepora alcicornis	0.00	0.89	2.97	5.59	87.09
Porites astreoides	0.78	1.61	2.78	5.22	92.31

Groups 5a & 7b
Average dissimilarity = 36.77

Species	Group 5a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Madracis decactis	3.20	0.00	10.63	28.90	28.90
Madracis mirabilis	2.54	0.00	8.41	22.88	51.78
D. labyrinthiformis	3.93	2.45	4.93	13.40	65.18
D. strigosa	1.79	3.00	4.01	10.89	76.07
Oculina species	0.90	0.00	2.98	8.10	84.17
Millepora alcicornis	0.00	0.89	2.97	8.07	92.24

Groups 6a & 7b
Average dissimilarity = 29.43

Species	Group 6a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.10	2.45	6.50	22.10	22.10
Porites astreoides	0.45	1.61	5.60	19.02	41.12
Montastraea franksi	0.45	1.26	3.93	13.35	54.47
Montastraea cavernosa	0.63	1.41	3.76	12.76	67.23
Millepora alcicornis	1.61	0.89	3.46	11.75	78.97
Oculina species	0.45	0.00	2.15	7.30	86.27
Siderastrea radians	0.00	0.45	2.15	7.30	93.57

Groups 6b & 7b
Average dissimilarity = 29.09

Species	Group 6b Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
D. labyrinthiformis	1.18	2.45	6.08	20.92	20.92
Montastraea franksi	0.00	1.26	6.08	20.89	41.81
Porites astreoides	0.63	1.61	4.71	16.19	58.00
Isophyllia sinuosa	0.77	0.00	3.72	12.79	70.79
Stephanocoenia michelinii	1.10	0.45	3.11	10.71	81.50
Montastraea cavernosa	0.89	1.41	2.50	8.59	90.09

Groups 7a & 7b
Average dissimilarity = 22.39

Species	Group 7a Av.Abund	Group 7b Av.Abund	Av.Diss	Contrib%	Cum.%
Montastraea franksi	0.00	1.26	5.42	24.21	24.21
D. strigosa	3.92	3.00	3.96	17.69	41.91
Montastraea cavernosa	0.63	1.41	3.35	14.96	56.87
D. labyrinthiformis	3.19	2.45	3.19	14.25	71.12
Millepora alcicornis	0.45	0.89	1.92	8.56	79.68
Stephanocoenia michelinii	0.89	0.45	1.92	8.56	88.24
Porites astreoides	1.18	1.61	1.84	8.22	96.45

Appendix 12: Partial colony mortality (PM)

Testing for homogeneity of variances among the proportion of colonies with PM at each *reef zone*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 120
χ^2 = 62.0975, df = 2
c = 1.015510
χ^2c = 61.1490, P = 5.274 10^-14

The variances of the samples are heterogeneous (P <0.05) and could not be normalized. The best transformation was:

Log_{10} (proportion of colonies with PM)
χ^2 = 21.7096, df = 2
c = 1.015510
χ^2c = 21.3781, P = 2.279 10^-5

Nested ANOVA statistics

Variable: log_{10}(proportion of colonies with PM)
Defined by zone
Sample size: 120

ANOVA Table

Level	SS	df	MS	Fs	P
Zone	6.8755	2	3.43777	88.0962	4.576 10^-24
Within	4.5657	117	0.03902		

There are significant differences in the proportion of colonies with PM between reef zones (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Zone

Variable: $\log_{10}$(proportion of colonies with PM)

Total sample size: 120

Comparing sample Rim/Terrace against:

Sample:	CH	Lagoon
Diff:	0.5144*	0.6414*
MSD(TK):	0.1023	0.1354
MSD(GT2):	0.1044	0.1381
MSD(T'):	0.1213	0.1486

Comparing sample CH against:

Sample:	Lagoon
Diff:	0.1270*
MSD(TK):	0.1189
MSD(GT2):	0.1213
MSD(T'):	0.1486

*** indicates P<=0.050 for at least one method.**

Appendix 13: Partial colony mortality (PM) of *Diploria* spp.

Testing for homogeneity of variances among the proportion of *Diploria labyrinthiformis* and *D. strigosa* populations with PM

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 239

χ^2 = 7.3338, df = 1

c = 1.004220

χ^2 c = 7.3029, P = 0.0069

The variances of the samples are heterogeneous (P <0.05)

SQRT (proportion of colonies with PM)

χ^2 = 1.1904, df = 1

c = 1.004220

χ^2c = 1.1854, P = 0.2763

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(proportion of colonies with PM)

Defined by species

Sample size: 239

ANOVA Table

Level	SS	df	MS	Fs	P
Species	0.2731	1	0.27309	5.2466	0.0229
Within	12.3360	37	0.05205		

There are significant differences in the proportion of colonies with PM between *Diploria* spp. (P <0.05)

Appendix 14: Partial colony mortality (PM) of *Diploria labyrinthiformis*

Testing for homogeneity of variances among the proportions of *D. labyrinthiformis* populations with PM, by *reef zone*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 120
χ^2 = 56.3121, df = 2
c = 1.015510
χ^2 c = 55.4520, P = 9.094 10^-13

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

SQRT (proportion of colonies with PM)
χ^2 = 18.9718, df = 2
c = 1.015510
χ^2c = 18.6820, P = 8.775 10^-5

Nested ANOVA statistics

Variable: SQRT(proportion of colonies with PM)
Defined by zone
Sample size: 120

ANOVA Table

Level	SS	df	MS	Fs	P
Zone	2.5381	2	1.26905	34.7532	1.423 10^-12
Within	4.2724	117	0.03652		

There are significant differences in the proportion of *D. labyrinthiformis* colonies with PM between reef zones (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Zone

Variable: SQRT(proportion of colonies with PM)

Total sample size: 120

Comparing sample Rim/Terrace against:

Sample:	CH	Lagoon
Diff:	0.3148*	0.3860*
MSD(TK):	0.0990	0.1309
MSD(GT2):	0.1009	0.1335
MSD(T'):	0.1173	0.1437

Comparing sample CH against:

Sample:	Lagoon
Diff:	0.0713
MSD(TK):	0.1150
MSD(GT2):	0.1173
MSD(T'):	0.1437

*** indicates P<=0.050 for at least one method.**

Appendix 15: Partial colony mortality (PM) *Diploria strigosa*

Testing for homogeneity of variances among the proportion of *D. strigosa* colonies with PM, by *reef zone*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 119

χ^2 = 35.4678, df = 2
c = 1.015533
χ^2 c = 34.9253, P = 2.607 10^-8

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

SQRT (proportion of colonies with PM + 0.5)
χ^2 = 33.3930, df = 2
c = 1.015533
χ^2c = 32.8822, P = 7.240 10^-8

Nested ANOVA statistics

Variable: SQRT(proportion of colonies with PM + 0.5)
Defined by zone
Sample size: 119

ANOVA Table

Level	SS	df	MS	Fs	P
Zone	0.2326	2	0.11629	17.1460	2.994 10^-7
Within	0.7868	116	0.00678		

There are significant differences in the proportion of *D. strigosa* colonies with PM between reef zones (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Zone

Variable: SQRT(proportion of colonies with PM + 0.5)

Total sample size: 119

Comparing sample Rim/Terrace against:

Sample:	CH	Lagoon
Diff:	0.0316	0.1348*
MSD(TK):	0.0428	0.0564
MSD(GT2):	0.0436	0.0576
MSD(T'):	0.0506	0.0619

Comparing sample CH against:

Sample:	Lagoon
Diff:	0.1032*
MSD(TK):	0.0497
MSD(GT2):	0.0506
MSD(T'):	0.0619

*** indicates P<=0.050 for at least one method.**

Appendix 16: Partial colony mortality (PM) of *Diploria labyrinthiformis* inside Castle Harbour

Testing for homogeneity of variances among the proportion of *D. labyrinthiformis* colonies with PM at each *site* within Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 24.8340, df = 13

c = 1.089286

χ^2 c = 22.7985, P = 0.0442

The variances of the samples are heterogeneous (P <0.05)

SQRT (Proportion of colonies with PM + 0.5)

χ^2 = 21.8950, df = 13

c = 1.089286

χ^2c = 20.1003, P = 0.0927

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(Proportion of colonies with PM + 0.5)

Defined by site

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Site	0.4072	13	0.03132	4.1067	9.900 10^-5
Within	0.4271	56	0.00763		

There are significant differences in the proportion of *D. labyrinthiformis* colonies with PM between sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: SQRT(Proportion of colonies with PM + 0.5)

Total sample size: 70

Comparing sample 1a against:

Sample:	1b
Diff:	0.0211
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 2a against:

Sample:	2b
Diff:	0.0284
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 3b against:

Sample:	3a
Diff:	0.0411
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 4b against:

Sample:	4a
Diff:	0.0481
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 5a against:

Sample:	5b
Diff:	0.0581
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 6a against:

Sample:	6b
Diff:	0.0237
MSD(TK):	0.1936
MSD(GT2):	0.2010

Comparing sample 7b against:

Sample:	7a
Diff:	0.0732
MSD(TK):	0.1936
MSD(GT2):	0.2010

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among the proportion of *Diploria labyrinthiformis* colonies with PM at each *location* within Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 70

χ^2 = 10.4220, df = 6

c = 1.042328

χ^2c = 9.9987, P = 0.1247

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: Proportion of colonies with PM

Defined by location

Sample size: 70

ANOVA Table

Level	SS	df	MS	Fs	P
Location	1.1404	6	0.19007	7.3945	5.163 10^-6
Within	1.6194	63	0.02570		

There are significant differences in the proportion of *D. labyrinthiformis* colonies with PM between locations (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: Proportion of colonies with PM

Total sample size: 70

Comparing sample 6 against:

Sample:	7	2	4	5	1	3
Diff:	0.1047	0.2287*	0.2710*	0.2911*	0.3620*	0.3807*
MSD(TK):	0.2184	0.2184	0.2184	0.2184	0.2184	0.2184
MSD(GT2):	0.2259	0.2259	0.2259	0.2259	0.2259	0.2259
MSD(T'):	0.2184	0.2184	0.2184	0.2184	0.2184	0.2184

Comparing sample 7 against:

Sample:	2	4	5	1	3
Diff:	0.1240	0.1663	0.1864	0.2573*	0.2760*
MSD(TK):	0.2184	0.2184	0.2184	0.2184	0.2184
MSD(GT2):	0.2259	0.2259	0.2259	0.2259	0.2259
MSD(T'):	0.2184	0.2184	0.2184	0.2184	0.2184

Comparing sample 2 against:

Sample:	4	5	1	3
Diff:	0.0423	0.0624	0.1333	0.1520
MSD(TK):	0.2184	0.2184	0.2184	0.2184
MSD(GT2):	0.2259	0.2259	0.2259	0.2259
MSD(T'):	0.2184	0.2184	0.2184	0.2184

Comparing sample 4 against:

Sample:	5	1	3
Diff:	0.0201	0.0910	0.1097
MSD(TK):	0.2184	0.2184	0.2184
MSD(GT2):	0.2259	0.2259	0.2259
MSD(T'):	0.2184	0.2184	0.2184

Comparing sample 5 against:

Sample:	1	3
Diff:	0.0709	0.0896
MSD(TK):	0.2184	0.2184
MSD(GT2):	0.2259	0.2259
MSD(T'):	0.2184	0.2184

Comparing sample 1 against:

Sample:	3
Diff:	0.0187
MSD(TK):	0.2184
MSD(GT2):	0.2259
MSD(T'):	0.2184

*** indicates P<=0.050 for at least one method.**

Appendix 17: Partial colony mortality (PM) of *Diploria strigosa* inside Castle Harbour

Testing for homogeneity of variances among the proportion of *D. strigosa* colonies with PM at each *site* within Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 69
χ^2 = 31.3554, df = 13
c = 1.091414
χ^2 c = 28.7292, P = 0.0071

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The transformation was:

SQRT (Proportion of colonies with PM)
χ^2 = 26.3676, df = 13
c = 1.091414
χ^2 c = 24.1591, P = 0.0297

Nested ANOVA statistics

Variable: SQRT(Proportion of colonies with PM)
Defined by site
Sample size: 69

ANOVA Table

Level	SS	df	MS	Fs	P
Site	1.0164	13	0.07819	1.3708	0.2034
Within	3.1370	55	0.05704		

There are no significant differences in the proportion of *D. strigosa* colonies with PM between locations (P >0.05)

Kruskal-Wallis statistics

Variable: Proportion of colonies with PM

Samples defined by site

Total sample size = 69

Results

Kruskal-Wallis statistic, H	=	18.1506, df = 13
Correction for ties, D	=	0.98116551
Adjusted H	=	18.4990, P[ChiSq>=H] = 0.1395

There are no significant differences in the proportion of *D. strigosa* colonies with PM between locations (P[ChiSq>=H] >0.05)

Appendix 18: Partial colony mortality (PM) of *Montastraea franksi*

Testing for homogeneity of variances among the proportion of *M. franksi* colonies with PM, by *reef zone*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 73

χ^2 = 16.4134, df = 2
c = 1.019714
χ^2 c = 16.0960, P = 0.0003

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. Data were closest to normal with no transformation

Nested ANOVA statistics

Variable: Proportion of colonies with PM
Defined by zone
Sample size: 73

ANOVA Table

Level	SS	df	MS	Fs	P
Zone	6.5352	2	3.26762	54.7129	4.926 10^-15
Within	4.1806	70	0.05972		

There are significant differences in the proportion of *M. franksi* colonies with PM between reef zones (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Zone

Variable: Proportion of colonies with PM

Total sample size: 73

Comparing sample Rim/Terrace against:

Sample:	Lagoon	CH
Diff:	0.5642*	0.6409*
MSD(TK):	0.1689	0.1622
MSD(GT2):	0.1724	0.1656
MSD(T'):	0.1854	0.1729

Comparing sample Lagoon against:

Sample:	CH
Diff:	0.0767
MSD(TK):	0.1789
MSD(GT2):	0.1826
MSD(T'):	0.1854

*** indicates P<=0.050 for at least one method.**

Appendix 19: Settlement

Testing for homogeneity of variances among the number of recruits per tile, by *reef area*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 400

χ^2 = 409.6781, df = 2
c = 1.003928
χ^2c = 408.0752, P = 0

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

Log_{10} (Recruits per tile +1)
χ^2 = 57.7577, df = 2
c = 1.003928
χ^2 c = 57.5317, P = 3.215 10^-13

Nested ANOVA statistics

Variable: log10(Recruits per tile +1)
Defined by CH/North/South
Sample size: 400

ANOVA Table

Level	SS	df	MS	Fs	P
CH/North/South	20.0100	3	6.67002	92.2238	2.811 10^-45
Within	28.6404	396	0.07232		

There are significant differences in the number of recruits per tile between reef areas (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: CH/North/South

Variable: $\log_{10}$(Recruits per tile +1)

Total sample size: 400

Comparing sample South against:

Sample:	CH	North
Diff:	0.0550	0.5253*
MSD(TK):	0.0836	0.0912
MSD(GT2):	0.0852	0.0930
MSD(T'):	0.1001	0.1001

Comparing sample CH against:

Sample:	North
Diff:	0.4702*
MSD(TK):	0.0729
MSD(GT2):	0.0744
MSD(T'):	0.0817

*** indicates P<=0.050 for at least one method**

Appendix 20: Settlement inside Castle Harbour

Testing for homogeneity of variances among the number of recruits per tile within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 200

χ^2 = 138.4846, df = 9
c = 1.019298
χ^2 c = 135.8627, P = 0

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

Log_{10} (Recruits per tile +1)
χ^2 = 61.6263, df = 9
c = 1.019298
χ^2c = 60.4596, P = 1.093 10^-9

Nested ANOVA statistics

Variable: log_{10} (Recruits per tile +1)
Defined by site
Sample size: 200

ANOVA Table

Level	SS	df	MS	Fs	P
Site	3.3009	9	0.36676	10.0416	1.416 10^-12
Within	6.9396	190	0.03652		

There are significant differences in the number of recruits per tile within Castle Harbour, by site (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: $\log_{10}$ (Recruits per tile +1)

Total sample size: 200

Comparing sample 1a against:

Sample:	1b
Diff:	0.0301
MSD(TK):	0.1935
MSD(GT2):	0.1995

Comparing sample 2a against:

Sample:	2b
Diff:	0.1065
MSD(TK):	0.1935
MSD(GT2):	0.1995

Comparing sample 3a against:

Sample:	3b
Diff:	0.3065*
MSD(TK):	0.1935
MSD(GT2):	0.1995

Comparing sample 4b against:

Sample:	4a
Diff:	0.0088
MSD(TK):	0.1935
MSD(GT2):	0.1995

Comparing sample 5a against:

Sample:	5b
Diff:	0.0187
MSD(TK):	0.1935
MSD(GT2):	0.1995

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among the number of recruits per tile within Castle Harbour, by *location*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 200

χ^2 = 132.7274, df = 5
c = 1.013512
χ^2 c = 130.9579, P = 0

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

SQRT (Recruits per tile)
χ^2 = 46.4560, df = 5
c = 1.013512
χ^2 c = 45.8367, P = 9.805 10^-9

Nested ANOVA statistics

Variable: SQRT (Recruits per tile)
Defined by location
Sample size: 200

ANOVA Table

Level	SS	df	MS	Fs	P
Location	28.6198	5	5.72395	17.7347	1.846 10^-14
Within	62.6145	194	0.32276		

There are significant differences in the number of recruits per tile within Castle Harbour, by location (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Location

Variable: SQRT (Recruits per tile)

Total sample size: 200

Comparing sample 1 against:

Sample:	2	3a	5	4	3b
Diff:	0.0104	0.2957	0.4134*	0.6567*	1.2214*
MSD(TK):	0.3656	0.4478	0.3656	0.3656	0.4478
MSD(GT2):	0.3764	0.4609	0.3764	0.3764	0.4609
MSD(T'):	0.3657	0.5171	0.3657	0.3657	0.5171

Comparing sample 2 against:

Sample:	3a	5	4	3b
Diff:	0.2853	0.4030*	0.6463*	1.2110*
MSD(TK):	0.4478	0.3656	0.3656	0.4478
MSD(GT2):	0.4609	0.3764	0.3764	0.4609
MSD(T'):	0.5171	0.3657	0.3657	0.5171

Comparing sample 3a against:

Sample:	5	4	3b
Diff:	0.1177	0.3610	0.9257*
MSD(TK):	0.4478	0.4478	0.5171
MSD(GT2):	0.4609	0.4609	0.5322
MSD(T'):	0.5171	0.5171	0.5171

Comparing sample 4 against:

Sample:	3	3b
Diff:	0.2433	0.8080*
MSD(TK):	0.3656	0.4478
MSD(GT2):	0.3764	0.4609
MSD(T'):	0.3657	0.5171

Comparing sample 4 against:

Sample:	3b
Diff:	0.5647*
MSD(TK):	0.4478
MSD(GT2):	0.4609
MSD(T'):	0.5171

* indicates P<=0.050 for at least one method.

Appendix 21: Permanent quadrats - juveniles

Testing for homogeneity of variances among the number of juvenile corals per m^2 within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 374

χ^2 = 170.6769, df = 3
c = 1.004544
$\chi^2 c$ = 169.9049, P = 0

The variances of the samples are heterogeneous (P <0.05).

Log_{10} (juveniles per m^2 +1)
χ^2 = 0.9475, df = 3
c = 1.004544
$\chi^2 c$ = 0.9432, P = 0.8150

Data successfully transformed (P >0.05).

Nested ANOVA statistics

Variable: Log_{10} (juveniles per m^2 +1)
Defined by site
Sample size: 374

ANOVA Table

Level	SS	df	MS	Fs	P
Site	16.0821	3	5.36068	49.5433	6.125 10^-27
Within	40.0347	370	0.10820		

There are significant differences in the number juvenile corals per m^2 within Castle Harbour, by site (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: Log_{10} (juveniles per m^2 +1)

Total sample size: 374

Comparing sample 2a against:		Comparing sample 5b against:	
Sample:	2b	Sample:	5a
Diff:	0.0870	Diff:	0.1138
MSD(TK):	0.1235	MSD(TK):	0.1258
MSD(GT2):	0.1266	MSD(GT2):	0.1289
MSD(T'):	0.1239	MSD(T'):	0.1334

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among the number of juvenile corals per m^2 within Castle Harbour, by *location* and *year.*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 374

χ^2 = 170.6769, df = 3

c = 1.004544

$\chi^2 c$ = 169.9049, P = 0

The variances of the samples are heterogeneous (P <0.05).

Log_{10} (juveniles per m^2 +1)

χ^2 = 0.9475, df = 3

c = 1.004544

$\chi^2 c$ = 0.9432, P = 0.8150

Data successfully transformed (P >0.05).

Nested ANOVA statistics

Variable: Log_{10} (juveniles per m^2 +1)

Level: 1 Defined by location

Level: 2 Defined by year

Sample size: 374

ANOVA Table

Level	SS	df	MS	Fs	P
Location	16.0821	3	5.36068	31.9768	5.269 10^-6
				(31.8828)	
Year	2.0117	12	0.16764	1.5784	0.0957
		(11.9	0.16814)		
Within	38.0230	358	0.10621		

There are significant differences in the number juvenile corals per m^2 within Castle Harbour, by location ($P < 0.05$), but not by year ($P > 0.05$)

Appendix 22: Permanent quadrats - juveniles

Testing for homogeneity of variances among the number of new coral recruits per m^2 within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 284

χ^2 = 212.2436, df = 3
c = 1.005963
χ^2c = 210.9855, P = 0

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

Log_{10} (recruits per m^2 +1)
χ^2 = 22.8079, df = 3
c = 1.005963
χ^2 c = 22.6727, P = 4.725 10^-5

Nested ANOVA statistics

Variable: Log_{10} (recruits per m^2 +1)
Defined by site
Sample size: 284

ANOVA Table

Level	SS	df	MS	Fs	P
site	12.7761	3	4.25870	40.6095	8.081 10^-22
Within	29.3635	280	0.10487		

There are significant differences in the number coral recruits per m^2 within Castle Harbour, by site (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: site

Variable: Log_{10} (recruits per m^2 +1)

Total sample size: 284

Comparing sample 2a against:		Comparing sample 5b against:	
Sample:	2b	Sample:	5a
Diff:	0.0455	Diff:	0.1195
MSD(TK)	0.1405	MSD(TK):	0.1407
MSD(GT2):	0.1440	MSD(GT2):	0.1442
MSD(T'):	0.1405	MSD(T'):	0.1447

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among the number of new coral recruits per m^2 within Castle Harbour, by *location*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 284

χ^2 = 212.2436, df = 3

c = 1.005963

χ^2c = 210.9855, P = 0

The variances of the samples are heterogeneous (P <0.05) and could not be normalized through transformation. The best transformation was:

Log_{10} (recruits per m^2 +1)

χ^2 = 22.8079, df = 3

c = 1.005963

χ^2c = 22.6727, P = 4.725 10^-5

Nested ANOVA statistics

Variable: $\log_{10}$(recruits m2+1)

Level: 1 Defined by location

Level: 2 Defined by year

Sample size: 284

ANOVA Table

Level	SS	df	MS	Fs	P
location	12.7761	3	4.25870	36.0888	5.362 10^-5
				(36.0851)	
year	0.9440	8	0.11801	1.1294	0.3435
		(8.0	0.11802)		
Within	28.4194	272	0.10448		

There are significant differences in the number coral recruits per m^2 within Castle Harbour, by location ($P < 0.05$), but not by year ($P > 0.05$)

Kruskal-Wallis statistics

Variable: recruits m2

Samples defined by location

Total sample size = 284

Results

Kruskal-Wallis statistic, H = 78.9716, df = 3

Correction for ties, D = 0.92466976

Adjusted H = 85.4052, P[ChiSq>=H] = 0

There are significant differences in the number coral recruits per m^2 within Castle Harbour, by location (P[ChiSq>=H] < 0.05).

Variable: recruits m2

Samples defined by year

Results

Kruskal-Wallis statistic, H = 2.1327, df = 2

Correction for ties, D = 0.92466976

Adjusted H = 2.3064, P[ChiSq>=H] = 0.3156

There are no significant differences in the number coral recruits per m^2 within Castle Harbour, by year (P[ChiSq>=H] > 0.05).

Appendix 23: Permanent quadrats - juveniles

Testing for homogeneity of variances among the proportion of the juvenile coral population per m^2 that grew within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 238

χ^2 = 7.7730, df = 3
c = 1.007239
$\chi^2 c$ = 7.7171, P = 0.0522

The variances of the samples are homogeneous (P >0.05).

Nested ANOVA statistics

Variable: Proportion that grew
Defined by site
Sample size: 238

ANOVA Table

Level	SS	df	MS	Fs	P
Site	1.1444	3	0.38148	3.0069	0.0311
Within	29.6876	234	0.12687		

There are significant differences in proportion of the juvenile coral population per m^2 that grew within Castle Harbour, by site (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: proportion of population that grew

Total sample size: 238

Comparing sample 2b against:		Comparing sample 5a against:	
Sample:	2a	Sample:	5b
Diff:	0.0144	Diff:	0.0886
MSD(TK):	0.1740	MSD(TK):	0.1664
MSD(GT2):	0.1783	MSD(GT2):	0.1706
MSD(T'):	0.1808	MSD(T'):	0.1774

*** indicates P<=0.050 for at least one method.**

Testing for homogeneity of variances among the proportion of the juvenile coral population that grew per m^2 within Castle Harbour, by *location*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 273

χ^2 = 2.7473, df = 1

c = 1.003695

$\chi^2 c$ = 2.7372, P = 0.0980

The variances of the samples are homogeneous (P >0.05).

Nested ANOVA statistics

Variable: Proportion that grew

Level: 1 Defined by location

Level: 2 Defined by year

Sample size: 273

ANOVA Table

Level	SS	df	MS	Fs	P
Location	1.4012	1	1.40115	8.6445	0.0148
				(8.5977)	
Year	1.6209	10	0.16209	1.4300	0.1670
		(9.8	0.16297)		
Within	29.5841	261	0.11335		

There are significant differences in proportion of the juvenile coral populations that grew per m^2 within Castle Harbour, by location ($P < 0.05$), but not by year ($P > 0.05$)

Appendix 24: Permanent quadrats - juveniles

Testing for homogeneity of variances among the proportion of the juvenile coral population per m^2 that reduced in colony size within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 273

χ^2 = 20.2553, df = 3
c = 1.006270
χ^2c = 20.1290, P = 0.0002

The variances of the samples are heterogeneous (P <0.05).

SQRT (proportion that reduced in size)
χ^2 = 5.6622, df = 3
c = 1.006270
χ^2c = 5.6269, P = 0.1312

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(proportion that reduced in size)
Defined by site
Sample size: 273

ANOVA Table

Level	SS	df	MS	Fs	P
Site	0.9568	3	0.31893	3.1472	0.0256
Within	27.2599	269	0.10134		

There are significant differences in the proportion of juvenile colonies that reduced in size amongst sites (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Site

Variable: SQRT (proportion that reduced in size)

Total sample size: 273

Comparing sample 4 against:

Sample: 3

Diff: 0.0413

MSD(TK): 0.1386

MSD(GT2): 0.1421

MSD(T'): 0.1391

Comparing sample 2 against:

Sample: 1

Diff: 0.1372

MSD(TK): 0.1446

MSD(GT2): 0.1482

MSD(T'): 0.154

*** indicates P<=0.050 for at least one method.**

There are no significant differences in proportion of juvenile colonies that reduced in size between replicate sites

Testing for homogeneity of variances among the proportion of the juvenile coral population per m^2 that reduced in colony size within Castle Harbour, by *location* and *year*

Nested ANOVA statistics

Variable: SQRT (proportion that reduced in size)

Level: 1 Defined by location

Level: 2 Defined by year

Sample size: 273

ANOVA Table

Level	SS	df	MS	Fs	P
Location	0.2870	1	0.28695	0.5984	0.4571
				(0.5897)	
Year	4.7952	10	0.47952	5.4098	2.782 10^-7
		(9.9	0.48661)		
Within	23.1346	261	0.08864		

There are no significant differences by location in the proportion of the coral population that reduced in colony size (P >0.05), but there are significant differences by year (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Year
Variable: SQRT (proportion that reduced in size)
Total sample size: 273

Comparing sample '03-'04 against:

Sample:	'04-'05	'05-'06
Diff:	0.1201*	0.2958*
MSD(TK):	0.1056	0.1053
MSD(GT2):	0.1076	0.1073
MSD(T'):	0.1078	0.1078

Comparing sample '04-'05 against:

Sample:	'05-'06
Diff:	0.1757*
MSD(TK):	0.1032
MSD(GT2):	0.1052
MSD(T'):	0.1037

*** indicates P<=0.050 for at least one method.**

Appendix 25: Permanent quadrats - juveniles

Testing for homogeneity of variances among the proportion of the juvenile coral population per m^2 that died within Castle Harbour, by *site*

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 275

χ^2 = 9.7090, df = 3
c = 1.006205
$\chi^2 c$ = 9.6491, P = 0.0218

The variances of the samples are heterogeneous (P <0.05).

SQRT (proportion of population that died)

χ^2 = 6.6134, df = 3
c = 1.006205
$\chi^2 c$ = 6.5726, P = 0.0868

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: SQRT(proportion of population that died)
Level: 1 Defined by location
Level: 2 Defined by site
Level: 3 Defined by year
Sample size: 275

ANOVA Table

Level	SS	df	MS	Fs	P
Location	1.1648	1	1.16476	1.4020	0.3580
			(1.3866)		
Site	1.6616	2	0.83080	2.6755	0.1289
		(2.0	0.84000	2.6607	0.1306
Year	2.4841	8	0.31052	2.5705	0.0102
		(7.9	0.31225)		
Within	31.7704	263	0.12080		

There are no significant differences in proportion of the juvenile coral population per m^2 that died within Castle Harbour, by location or site ($P > 0.05$), but there are significant differences between years ($P < 0.05$).

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Year
Variable: SQRT(proportion of population that died)
Total sample size: 275

Comparing sample '05-'06 against:

Sample:	'04-'05	'03-'04
Diff:	0.0524	0.1336*
MSD(TK):	0.1252	0.1277
MSD(GT2):	0.1276	0.1302
MSD(T'):	0.1264	0.1314

Comparing sample '04-'05 against:

Sample:	'03-'04
Diff:	0.0812
MSD(TK):	0.1287
MSD(GT2):	0.1312
MSD(T'):	0.1314

*** indicates P<=0.050 for at least one method.**

Appendix 26: Permanent quadrats - adults

Testing for homogeneity of variances among the proportion of adult colonies that grew per m^2 within Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 12

χ^2 = 3.3265, df = 3
c = 1.208333
$\chi^2 c$ = 2.7529, P = 0.4313

The variances of the samples are homogeneous (P >0.05)

Nested ANOVA statistics

Variable: proportion that grew
Level: 1 Defined by location
Level: 2 Defined by site
Sample size: 12

ANOVA Table

Level	SS	df	MS	Fs	P
Location	0.0339	1	0.03392	3.5189	0.2015
				(3.5189)	
Site	0.0193	2	0.00964	0.4526	0.6513
		(2.0	0.00964)		
Within	0.1704	8	0.02130		

There are no significant differences in the proportion of the adult population that grew between sites or locations (P >0.05)

Appendix 27: Permanent quadrats - adults

Testing for homogeneity of variances among the amount of adult colony growth per m^2 within Castle Harbour

Bartlett's test for homogeneity of variances (Sokal and Rohlf 1995) performed by the statistical package BIOMstat33.

Total sample size = 295

χ^2 = 477.0704, df = 3
c = 1.006333
$\chi^2 c$ = 474.0680, P = 0

The variances of the samples are heterogeneous (P <0.05)

Ln (amount of growth)
χ^2 = 7.7182, df = 3
c = 1.006333
$\chi^2 c$ = 7.6696, P = 0.0534

Data successfully transformed (P >0.05)

Nested ANOVA statistics

Variable: ln (amount of growth)
Level: 1 Defined by site
Level: 2 Defined by year
Sample size: 295

ANOVA Table

Level	SS	df	MS	Fs	P
Site	0.9902	3	0.33007	0.1824	0.9054
				(0.1781)	
Year	14.4736	8	1.80921	2.9196	0.0038
		(7.8	1.85304)		
Within	175.3662	283	0.61967		

There are no significant differences in the amount of growth seen between sites (P >0.05), but there are significant differences between years (P <0.05)

Post Hoc testing (multiple comparisons of means) using T',T-K,GT2 methods

Samples defined by: Year
Variable: ln (amount of growth)
Total sample size: 295

Comparing sample 2006 against:

Sample:	2005	2004
Diff:	0.0544	0.4511*
MSD(TK):	0.2786	0.2531
MSD(GT2):	0.2840	0.2581
MSD(T'):	0.2893	0.2686

Comparing sample 2005 against:

Sample:	2004
Diff:	0.3967*
MSD(TK):	0.2643
MSD(GT2):	0.2694
MSD(T'):	0.2893

*** indicates P<=0.050 for at least one method**