

CORAL COMMUNITY STRUCTURE AND PATTERNS OF SEDIMENTATION
IN CASTLE HARBOUR BERMUDA

by

VANESE SONIA FLOOD

(Under the Direction of Raymond P. Freeman-Lynde)

ABSTRACT

Sixty years after a dredge and landfill project, sedimentation rates in Castle Harbour, Bermuda remained high compared to control reefs elsewhere on the Bermuda platform and similar to those near an active shipping channel. Coral community structure, sedimentation rates, flow and light were measured after a 30-year gap in data. Coral cover and abiotic factors varied within and among study reefs highlighting the need to measure environmental variables at micro scales on declining coral reefs. Given the length of time since the dredge/fill disturbance some aspect of reef recovery was expected, yet coral cover on reefs in proximity to the dredge scar had decreased from 12% cover in 1978 to 2% coral cover in 2003.

INDEX WORDS: Sedimentation, Flow, Light, Corals, Castle Harbour Bermuda

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DEDICATION

This work is dedicated to my parents, Arthur and Isobel Flood who have encouraged and inspired me.

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TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	v
LIST OF TABLES.....	vii
LIST OF FIGURES	viii
CHAPTER	
1 INTRODUCTION AND LITERATURE REVEIW.....	1
2 CORAL COMMUNITY STRUCTURE AND PATTERNS OF SEDIMENTATION IN CASTLE HARBOUR BERMUDA.....	4
3 CONCLUSIONS.....	29
REFERENCES.....	38
APPENDICES.....	45
A SEDIMENTATION RATES	46

LIST OF TABLES

	Page
Table 2.1: CASTLE HARBOUR DATA SYNOPSIS, 2003	31
Table 2.2: CORALS MEASURED IN CASTLE HARBOUR.....	32
Table 2.3: PARTIAL MORTALITY OF <i>DIPLORIA LABYRINTHIFORMIS</i>	33
Table 2.4: PERCENT CORAL COVER, <i>H'</i> AND <i>J'</i> DATA FROM DRYER (1977).....	34

LIST OF FIGURES

	Page
Figure 2.1: STUDY AREA – BERMUDA, CASTLE HARBOUR, NORTH SHORE.....	35
Figure 2.2: <i>DIPLORIA LABYRINTHIFORMIS</i> COLONIES WITH SEDIMENT DAMAGE	36
Figure 2.3: PERCENT CORAL COVER, SEDIMENTATION RATE, FLOW RATE, ALGAE COVER.....	37

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

It is well documented that globally, coral reef health has been in decline. This decline can be attributed to several factors, some anthropogenic in nature (Brown et al., 1990). In particular, dredging events for coastal development produce heavy sedimentation and associated turbidity known to reduce diversity, percent cover, and fecundity of corals (Brown et al., 1990; Rogers, 1990). Sediments in extreme amounts lead to smothering, tissue necrosis and eventual death of the coral colony (Dodge and Vaisnys, 1977, Bak, 1978; Lasker, 1980).

Sediment loading, the rapid deposition of coarse silt and sand size sediments onto coral colony surfaces, induces the organism to expend energy in the form of cleaning behavior (Bak, 1978; Marszalak, 1981, Abdel-Salam and Porter, 1988). Cleaning behaviors vary from tentacular action, ciliary transport, polyp extension and least effectively through mucus production (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976; Lasker, 1980). Sediment tolerance may vary considerably among coral species, with some corals being far more resistant than others. This variation is dependent on sediment grain size, coral colony size, and coral colony morphology (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976). Additionally, since coral planulae larvae settlement is substrate specific, sediment cover on reef surfaces may inhibit larval recruitment (Tomascik and Sander, 1987), and thus preclude rapid succession and recovery of reef communities after disturbance events (Pastorok and Bilyard, 1985). Therefore, input of sediments into coral reef environments can change community structure by influencing the amount of cover and type of scleractinian or stony coral species represented.

Corals live in a symbiotic relationship with photosynthetic zooxanthellae responsible for the production of nutrients in amounts often sufficient to meet host metabolic requirements (Muller-Parker and D'Elia, 1997). Turbidity, the decrease in water clarity resulting primarily from the suspension of fine sediments (Marszalek, 1981), reduces light intensity and alters light quality. Under reduced light regimes net photosynthetic output by endosymbiotic zooxanthellae decreases (Pastorok and Bilyard, 1985), nighttime respiration rates increase (Abdel-Salam and Porter, 1988) and calcification rates are reduced (Bak, 1978). The combined effects of turbidity and sediment smothering act to increase coral colony energy output and reduce endosymbiont photosynthate production, coral growth rates and fecundity and can ultimately result in mortality.

In most marine environments subjected to sediment loading and turbidity, the duration of exposure is acute and the effects of sediments are usually ephemeral, lasting only during dredging, or for brief periods afterward (Bak, 1978; Dollar and Grigg, 1981; Marszalek, 1981; Brown, et al, 1990; Rogers, 1990). Brevity of exposure is usually due to location in respect to open ocean and strong currents, which remove sediments and thus abate the long-term effects of exposure to sedimentation (Rogers, 1990).

This study was conducted to evaluate coral community structure, sedimentation rates, flow rates and light levels on reefs in Castle Harbour, Bermuda, the site of an extensive 3 year dredge and landfill project begun in 1941 (Pitt et al, 2004). Early naturalists' accounts of this basin cited the outstanding clarity of the waters (Verrill, 1902) and noted an abundance of large colonies of *Diploria spp.* (brain corals) (Agassiz, 1895). Aerial photographs taken in 1940 prior to the dredging event show lush *Thalassia testudinum* (seagrass) beds encircling reefs and 11 acres of mangroves stretched across the northeastern shoreline of the basin.

Castle Harbour now provides a unique opportunity to study the effects of chronic sedimentation on the structure of reef coral communities (Dryer and Logan, 1978). The dredge and fill project provided 20 million cubic yards of fill for the creation of 583 acres of land necessary to build a war-time airport facility at its northeastern end (Block, 1969). The resulting turbidity can be seen in photographs taken during the operation. Reefs remaining in Castle Harbour were subjected to severe stress through sediment loading, increased turbidity and reduced water flow (Dryer and Logan, 1978). Approximately 36 years after dredging the remaining reef coral community was high in numbers of species (S), but lower in diversity (H' , a measure of the variety and relative abundance of species) (Magurran, 1988) and percent coral cover when compared to other reefs in Bermuda (Dryer and Logan, 1978). During this study, 60 years after the disturbance, visibility for diving remained limited to a few meters on Impact and Control reefs due to chronically high turbidity. Turbidity has remained high in CH, possibly due to trapped fine sediments and reduced water flow brought about by the dredging and subsequent landfill resulting in chronic sedimentation.

Continued re-suspension and transport of dredged material can cause reef degradation years after dredging activities have ceased (Bak, 1978; Rogers, 1990). Given the detailed data on percent coral cover, species richness, diversity and evenness gathered in the 1970s, Castle Harbour offers a unique opportunity to study the long-term effects of sediment on reef coral community structure and potential recovery from disturbance.

CHAPTER 2
CORAL COMMUNITY STRUCTURE AND PATTERNS OF SEDIMENTATION
IN CASTLE HARBOUR BERMUDA

¹ Flood, V. S. Submitted to Marine Pollution Bulletin.

ABSTRACT

Sixty years after a dredge and landfill project, sedimentation rates on coral reefs in Castle Harbour, Bermuda remained high compared to control reefs elsewhere on the Bermuda platform and similar to those near an active shipping channel. Coral community structure, sedimentation rates, flow and light were measured after a 30-year gap in data. Coral cover and abiotic factors varied within and among Control (distal to the dredge scar) and Impact reefs (proximal to the dredge scar), suggesting that it may be necessary to measure coral cover and environmental variables at micro scales to determine causality for the decline of coral reefs. Given the length of time since the dredge/fill disturbance some aspect of reef recovery was expected, yet coral cover on Impact reefs had decreased from 12% cover in 1978 to 2% coral cover in 2003. Light values were significantly higher at the Impact reefs and have remained unchanged since 1984 suggesting that landform changes in the basin have trapped sediments creating a chronically disturbed environment. Contrary to expectations sedimentation rates were not significantly different among Control and Impact reefs. Despite this similarity in sedimentation rates, coral cover was significantly lower on Impact reefs than on Control reefs where cover has remained relatively unchanged over a 30-year gap in monitoring. Flow was significantly higher on Control reefs suggesting that water motion may be controlling the community structure of reefs in the Castle Harbour basin and abating the effects of chronic sedimentation on reefs distal to the impacted area.

INTRODUCTION

The global decline in coral reef health can be attributed to several factors, some anthropogenic in nature (Brown et al., 1990). In particular, dredging events for coastal development have been on the rise as human populations increasingly gravitate toward coastal areas (Hanna, 1997). Heavy sedimentation and associated turbidity resulting from coastal development are known to reduce diversity, percent cover, and fecundity of corals (Brown et al., 1990; Rogers, 1990). Sediments in extreme amounts lead to smothering, tissue necrosis and eventual death of the coral colony (Dodge and Vaisnys, 1977, Bak, 1978; Lasker, 1980).

Siltation or sediment loading, the rapid deposition of coarse silt and sand size sediments onto colony surfaces, induces cleaning behavior and thus energy usage, as indicated by increased mucus production and distended, swollen polyps (Bak, 1978; Marszalak, 1981, Abdel-Salam and Porter, 1988). Sediment tolerance may vary considerably among coral species, with some corals being far more resistant than others. Sediment rejection by corals is dependent on sediment grain size, coral colony size, and coral colony morphology (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976). In hemispherical species, for example, larger colonies may be more susceptible to smothering than smaller ones because cleaning behavior (the random movement of sediment particles across the colony surface by tentacles) is uncoordinated from polyp to polyp, resulting in particles remaining on larger colonies longer (Dodge and Vaisnys, 1977). Sediment removal mechanisms vary from tentacular action, ciliary transport, polyp extension and least effectively through mucus production (Hubbard and Pocock, 1972; Bak and Elgershuizen, 1976; Lasker, 1980). Additionally, since coral planulae larvae settlement is substrate specific, sediment cover may inhibit larval recruitment (Tomascik and Sander, 1987), and thus preclude rapid succession and recovery of reef communities after disturbance events (Pastorok and Bilyard,

1985). Therefore, input of sediments into coral reef environments can change community structure by influencing the amount of cover and type of scleractinian or stony coral species represented.

The endosymbiotic relationship between coral hosts and their photosynthetic zooxanthellae is responsible for the production of nutrients in amounts often sufficient enough to meet host metabolic requirements (Muller-Parker and D'Elia, 1997). Turbidity, the decrease in water clarity resulting primarily from the suspension of fine sediments (Marszalek, 1981), reduces light intensity and alters light quality. Under reduced light regimes net photosynthetic output by endosymbiotic zooxanthellae decreases (Pastorok and Bilyard, 1985), nighttime respiration rates increase (Abdel-Salam and Porter, 1988) and calcification rates are reduced (Bak, 1978). The combined effects of turbidity and sediment smothering act to increase coral colony energy output and reduce endosymbiont photosynthate production, coral growth rates and fecundity and can ultimately result in mortality.

In most marine environments subjected to sediment loading and turbidity, the duration of exposure has been acute and the effects of sediments are usually ephemeral, lasting only during dredging, or for brief periods afterward (Bak, 1978; Dollar and Grigg, 1981; Marszalek, 1981; Brown, et al, 1990; Rogers, 1990). Brevity of exposure is usually due to location in respect to open ocean and strong currents, which remove sediments and thus abate the long-term effects of exposure to sedimentation (Rogers, 1990).

This study was conducted to evaluate coral community structure, sedimentation rates, flow rates and light levels on reefs in Castle Harbour (CH), Bermuda (Fig. 2.1a, Fig. 2.1b), the site of an extensive 3 year dredge and landfill project begun in 1941 (Flood, 2004; Pitt et al, 2004). Early naturalists' accounts of this basin cited the outstanding clarity of the waters

(Verrill, 1902) and noted an abundance of large colonies of *Diploria spp.* (brain corals) (Agassiz, 1895). Castle Harbour now provides a unique opportunity to study the effects of chronic sedimentation on the structure of reef coral communities (Dryer and Logan, 1978).

The Castle Harbour dredge and fill project provided 20 million cubic yards of fill for the creation of 583 acres of land necessary to build a war-time airport facility at its northeastern end (Block, 1969). Aerial photographs taken in 1940 prior to the dredging event show lush *Thalassia testudinum* (seagrass) beds encircling reefs and approximately 12.5 acres of mangroves (Sterrer and Wingate, 1981) stretched across the northeastern shoreline of the basin. The resulting geographic changes can be seen in the hatch-marked overlay (Fig. 1b). Coral reefs remaining in the harbour were subjected to severe stress through increased turbidity, sediment loading, and reduced water flow. Approximately 36 years after dredging the remaining reef coral community was high in numbers of species (S), but lower in diversity (H' , a measure of the variety and relative abundance of species) (Magurran, 1988) and percent coral cover when compared to other reefs in Bermuda (Dryer and Logan, 1978).

Previous studies in CH provided data for comparison and guidelines in the selection of Impact and Control reefs (Dryer, 1977; Dryer and Logan, 1978). Impact reefs were selected from those in the north west of the basin along the dredge scar and Control reefs were selected from those in the south west of the basin, distal to the impacted area and close to open water flow on the south shore of Bermuda. During this study, 60 years after the disturbance, visibility for diving remained limited to a few meters on Impact and Control reefs due to chronically high turbidity. Turbidity has remained high in CH, possibly due to trapped fine sediments and reduced water flow brought about by the dredging and subsequent landfill resulting in chronic sedimentation. Continued re-suspension and transport of dredged material can cause reef

degradation years after dredging activities have ceased (Bak, 1978; Rogers, 1990). Given the detailed data on percent coral cover, species richness, diversity and evenness gathered in the 1970s, CH offers a unique opportunity to study the long-term effects of sediment on reef coral community structure and potential recovery from disturbance.

Questions addressed by this study included: 1. How has the reef coral community changed in CH over the past thirty years in terms of percent cover, species richness and diversity, and how does this vary from impacted to control reefs? 2. What is the rate of sedimentation, the grain size range and distribution of sediments across the study reefs, and how does this compare to other Bermuda platform reefs? 3. Do coral colonies show signs of sediment-related damage, and does this correlate with sedimentation rates? 4. What are the flow rates across the CH study reefs? 5. What are the light levels across the CH study reefs?

Hypotheses tested: 1. Areas of chronic sedimentation have reduced percent coral cover, diversity and richness. 2. Sediment tolerant species are dominant. 3. A gradient exists in CH from Impact to Control sites where coral cover, diversity, species richness, flow rates, light levels and sediment grain size increase and sedimentation and sediment related damage decrease distal to the Impact reefs. 4. Areas subject to acute sedimentation from prop-wash have higher sedimentation rates than areas with chronic sedimentation. 5. The NS control site has less sedimentation than the acutely and chronically affected reefs.

MATERIALS AND METHODS

Study Site

The Bermuda Islands, located 1000 km ESE of Cape Hatteras, North Carolina, at 32°22.01'N and 64°40.59'W are the northernmost Atlantic limit of vigorous hermatypic or reef-

building corals (Dryer and Logan, 1978) (Fig. 2.1a). Castle Harbour, a semi-enclosed marine basin 4.75km in diameter, lies at the eastern end of Bermuda (Fig. 2.1b).

Average depth in most of CH is less than 10m, but ranges to 16m in some dredged areas. In the west of the basin, a maximum water flow velocity of 17cm s^{-1} was recorded during ebb and flow tide (Morris et al, 1977). These waters are the clearest in CH possibly as a result of this flow (Dryer and Logan 1978).

Reef community structure, sedimentation rates, flow and light data were collected in CH (Fig. 2.1b), while comparison sedimentation rate data were collected in the north shore lagoon (Fig. 2.1c). The two CH impact reefs (CHIE: $32^{\circ}21.576'N$, $64^{\circ}41.320'W$ and CHIW: $32^{\circ}21.429'N$, $64^{\circ}41.304'W$) lie in the northwestern quadrant of CH along the dredge scar remaining from the 1940s event (Fig. 1b). The two CH control reefs (CHCE: $32^{\circ}20.455'N$, $64^{\circ}40.787'W$ and CHCW: $32^{\circ}20.404'N$, $64^{\circ}40.946'W$) lie distal to the dredged area in the southeastern portion of the basin (Fig. 1b). To facilitate comparison with earlier studies, the four CH study reefs were selected using characteristics and locations approximating those of Dryer and Logan (1977). CH study reefs were approximately 1.5m deep at their apex and extended vertically down to approximately 5m in depth, matching the criteria for pinnacle reefs as described by Dryer and Logan (1977).

Sedimentation in CH was compared with control and experimental reef sites in the north shore lagoon (NS) (Fig. 2.1c), Bermuda. Portions of NS house an active shipping channel and are therefore an ideal measure of acute sedimentation on reefs, while other areas are relatively undisturbed and thus provided base-line sedimentation rates. A sediment plume in the NS shipping channel is visible from Government House and experienced observers can ascertain the type of ship from the resulting plume (Lord Vereker, Governor of Bermuda, personal

correspondence). An average of 4.6 vessels use this 32' channel weekly with drafts ranging from 15' (container ships) to 24' (cruise ships) (David Simmons, pers. corr.). Sedimentation rates were measured at several locales at different distances from the disturbance site in CH and at ship disturbed and undisturbed sites on NS to compare sediment loading from chronic and acute disturbance. The NS lagoon is dotted with patch reefs, has an overall area of 350 km² and averages 13m in depth. Reef tops on North Shore were 3m deep while reef sides extended down to 8m. The North Shore reefs (NSI: 32°18.726'N, 64°47.423'W; NSC: 32°18.509'N, 64°46.759'W) were chosen for proximity to (NSI) and distance from (NSC) an active shipping channel as comparison (NSI) and control (NSC), for sedimentation rates in CH (Fig. 2.1c). The north shore reefs share many characteristics in common with the reefs of Castle Harbour, such as near shore location and were thus the closest analogues. On the north shore reefs only sedimentation rates were measured, community structure will be the focus of a later study.

Statistical Analysis

All data were analyzed using the GLM (General Linear Model) procedure in SAS V8.02, except where otherwise noted.

Coral Community Structure

To test the hypotheses of reduced coral diversity and decreased reef cover at CH impact sites, digital video-based surveys of the control (CHCE, CHCW) and impact (CHIE, CHIW) reefs were conducted in September and October 2003 following the methodology of Aronson et al. (1994). On each of the four CH reefs, five 25-m transect tapes were haphazardly placed within representative zones at shallow (~1.5m), medium (~3.3m), and deep (~5m) depths for a

total of 15 transects per reef. For consistency of survey area, the video camera was fitted with a fixed rod to maintain a set distance from the reef surface recording an area 0.4m wide by 25m long.

Fifty-two frames from each of the sixty 25-m video transects were grabbed with frame capture software using a Macintosh computer and Adobe Photoshop 6.0 to create an image library of 3,120 photo quadrats. Images were processed using a preset Photoshop action (Murdoch and Aronson, 2001). Ten random dots were placed on each image using a Java script written specifically for this project. Under each random dot scleractinian corals were identified to species, fleshy and turf algae were combined for overall algal cover. Reviewing entire videotapes for species presence/absence allowed for inclusion of rare species and the creation of a species list for comparisons with earlier studies (Table 2.1; Table 2.2, Fig. 2.3a).

Coral species diversity was evaluated within reefs using Shannon Weaver H' values and compared across reefs using the t -test method (Zar, 1996). To determine change in community structure over time, percent cover, species diversity (H'), species richness (S) and evenness ($J' = H'/H'_{\max}$) were calculated, and when possible, compared to the findings of Dryer and Logan (1978). Their NW reef data were compared with CH Impact reefs and SE reefs were compared with CH Control reefs (Table 2.1; Table 2.2; Table 2.4). Methodologies differed between this and the 1977 study where transect tapes were laid vertically from reef tops to bottoms. For this study, the current methodology of positioning transect tapes horizontally at multiple depths was employed to allow comparison with other contemporary data sets.

Partial Mortality of Corals

The hypothesis that sediment-related damage to scleractinian species would be higher on CH impact reefs than on CH control reefs was tested using *Diploria labyrinthiformis*. This species was chosen to assess damage for three reasons: 1) It is a dominant reef-building coral on the Bermuda platform (Dodge and Vaisnys, 1977, Dodge et. al. 1982). 2) A characteristic dimpled area with partial mortality develops on colony surfaces making damage that may be related to sedimentation easily detectable (Fig. 2.2). 3) *D. labyrinthiformis* is considered a sediment tolerant species (Hubbard and Pocock, 1972) therefore the occurrence of partial mortality related to sedimentation may have implications for other coral species in Castle Harbour. Sediment-related damage on *D. labyrinthiformis* colonies was assessed for each of the 60 video transects using a four-point scale where 0= no damage, 1=surficial sediment; 2=some mortality, some algae; and 3=large area of mortality, mostly algae (Table 2.3). Chi-Square tests for Association were used to evaluate the relationship between depth and degree of damage and location and degree of damage.

Sedimentation Rates

Sediment deposition rates were measured from July 2003 to October 2003. Sediment traps were constructed using 10-cm diameter PVC pipe cut to 27.5-cm lengths, and internally fitted with a 10-cm funnel, and externally fitted with a PVC reducer. The punctured lid of a 250-ml Nalgene bottle was glued to the funnel and trap base providing a watertight seal. The fixed lid allowed for sediment collecting, removal and recapping of collection vessels *in situ*. Traps were designed with a high height to width ratio and fitted with double-layered baffles to prevent re-suspension of collected materials (Rogers, 1990).

Sediment collection traps were placed at shallow (~1.5m), medium (~3.3m), and deep (~5m) depths on each of the study reefs by first surveying each reef to locate areas where they would be most stable. Three sediment traps were secured into cinder blocks at each depth interval on the four CH Impact and Control reefs for a total of 9 traps per reef. Sediment traps were deployed on CH Impact and Control sites over approximately month-long intervals in July and August.

To evaluate the hypothesis that sedimentation rates on the acutely disturbed NS Impact reef would be higher than on the undisturbed NS Control reef and the chronically disturbed CH Impact and Control reefs, sediment traps were deployed on four CH and two NS reefs in September and October. Due to equipment availability traps were deployed at shallow and deep depths only on the 6 study reefs. During the 4 collection periods, traps were periodically scrubbed with bottle cleaners to remove algal growth that might inhibit sediment collection.

At the end of collection intervals, traps were gently tapped to ensure settlement of all collected material into collection bottles. Collected sediments were allowed to settle into collecting bottles and then gently unscrewed and recapped in situ to avoid re-suspension of fine sediments. Traps were re-deployed with new collection bottles in the field.

In the laboratory, collection bottles and contents were rinsed with fresh water to remove salts and filtered using a Buchner funnel and pre-weighed Whatman No. 1 filters. Filters were placed into pre-weighed, labeled foil envelopes and allowed to dry at 70°C until a constant weight. All filters, foil and sediments were weighed to an accuracy of 0.00001g. Sedimentation rates were expressed as mg sediment per cm² per day⁻¹ (Rogers et al., 2001). A three factor ANOVA was used to evaluate sedimentation rates as a function of depth, time and reef (GLM procedure of SAS V8.02) (Table 2.1; Fig. 2.3b).

Sediment Grain Size Analysis and Organic Content

A random selection of 14 dried (4 from NSC and 10 from all other sites) sediment trap samples from the third collection period (September) were soaked overnight in a sodium metaphosphate solution to disaggregate the particles (Buchanan and Kain, 1971). Samples were then washed over a 63 μm sieve and the fines portion was reserved. Fine samples were centrifuged to remove water and allowed to dry in a 70°C oven until constant weight. Coarse portions were allowed to air-dry in a climate controlled room. Further grain size analysis of the coarse portion proved unreliable due to further aggregation of dried samples. Grain size was compared between the NSC site and all other sites using a two-tailed *t*-test.

Organic content was determined by combusting ground, dried, fine and coarse sediments in a 450°C oven for 2 hours. Prior to combustion samples were weighed and placed in pre-weighed crucibles. After combustion samples were allowed to cool to room temperature, re-weighed and the difference between pre and post combustion weights was determined indicating the organic portion. Organic content was compared between the NSC site and all other sites using a two-tailed *t*-test.

Flow Rate Analysis

Flow was measured with pairs of clod cards (Doty, 1971) on CH reefs using the three depths evaluated for coral cover and sedimentation rates for a total of 18 flow measurements per reef. Flow data was collected in July, August and November 2003.

Plaster of Paris (calcium sulfate) was mixed with water according to manufacturer's instructions and poured into equal sized rectangular, round-bottomed, ice-cube trays, agitated vigorously until trapped air was removed (i.e. bubbles no longer appeared) and allowed to harden

overnight to produce clods. Clods were then removed from trays and allowed to dry in a climate-controlled environment for several days. They were weighed periodically until an average (stable) weight was observed. Using a mixture of 7:1 cement to plaster of Paris as an adhesive, clod cards were created by fixing the clods to the unglazed side of a 10 X 10 cm ceramic tile. Over a period of days, clod cards were weighed until an average (stable) weight was obtained. Using plastic cable ties, pairs of clod cards were fastened to fire bricks. Each pair of tiles was labeled to identify reef location, transect location and depth of deployment. At each CH reef, a team of divers placed appropriately labeled bricks in proximity to, but not blocked by correspondingly labeled sediment cinder blocks, to measure flow within the sediment collection area. All clod cards were deployed within a 40-minute time span to ensure uniform experimental conditions. After 48 hours, clod cards were collected in the same order as deployed and returned to the lab. Clod cards were rinsed in fresh water to remove salts, allowed to dry in a climate controlled environment for several days, and weighed periodically until stable finished weights were established.

Clod cards represent a dimensionless measure of flow (Doty, 1971). To determine flow in cm/s from clod weight loss, a controlled experiment was conducted from October to November 2003 to generate a flow calibration curve. Bilge pumps were powered by set voltages to provide a range of flows through plexi-glass flow chambers. Voltage was checked with a voltmeter and flow chambers were submerged into 20-gallon tanks containing flowing ambient seawater and allowed to run until trapped air was released. A previously established flow to voltage ratio was used to control water movement through the chambers (Lipschultz, unpublished data). Two replicate clod cards were placed in separate chambers at set flows of 1.39, 4.18, 7.42 and 8.49 cm/s (2.5, 5, 7.5 and 10 volts) for 48-hour periods for a total of 16

controlled clod cards. After 48 hours, clod cards were removed, rinsed in fresh water and allowed to dry in a climate-controlled environment and weighed until an average (stable) weight was obtained. Flow chambers and tanks were cleaned and voltage calibrated before each run of cards. Average percent weight lost for each pair of clod cards was recorded and plotted against flow, and a calibration curve was calculated using the best-fit line function in Microsoft Excel. The equation of this line was then used to calculate flow in cm/s for percent weight lost for each field-deployed clod. Differences in flow as a function of depth, time and reef were compared with a 3 factor ANOVA (GLM procedures of SAS V 8.02) (Table 2.1, Fig. 2.3c).

Turbidity Analysis

Light attenuation was measured as an index of turbidity using Secchi disk readings next to CH Impact and Control reefs from September to October of 2003 (n=14). A Secchi disk attached to a line with cm/meter increments was lowered over the side of a boat facing the sun to avoid shadows that would bias depth readings. Once out of sight, the disk was slowly raised until visible and the depth was recorded. Readings were duplicated to ensure accuracy and were taken at Control and Impact sites within 15-minute intervals to avoid time-of-day bias. Results were compared using paired difference *t*-tests in SAS v 8.02 (Table 2.1).

RESULTS

Coral Community Structure

Highest average percent coral cover was observed at CHCW deep (7.42%), and lowest average percent cover was observed at CHIW medium depth (1.50%) (Fig. 2.3a, Table 2.1). Within reefs, percent cover was not significantly different over all depths combined (S, M, D)

except on CHCW [$P = 0.012$] where deep transects had significantly higher cover than shallow and medium depth transects (Fig. 2.3a, Table 2.1). Among reefs, percent coral cover was significantly higher at medium and deep depths on Control reefs than on Impact reefs [$P < 0.0001$]. Shallow depth coral cover was not significantly different across the four CH study reefs. Average coral cover on Impact reefs (2.28%) was significantly lower than on Control reefs (5.29%) [$P < 0.0001$]. Algae cover on Control reefs was significantly lower than on Impact reefs [$P = 0.0001$] (Fig. 2.3a, Table 2.1). Highest algae cover was measured at medium depths on the Impact sites (94%). Lowest algae cover was found at medium depths on the Control sites (84%) (Table 2.1).

H' indices for shallow Impact (0.705) and Control (1.667) [$P < 0.001$] and deep Impact (1.145) and Control (1.518) [$P = 0.003$] sites were significantly different. Medium depth Impact and Control sites yielded H' values of 1.939 and 1.814, indicating diversity values were not significantly different [$P = 0.146$]. Total Impact (1.691) and total Control (1.748) indices were not significant different (Table 2.1). Evenness (J') values at CH Control reefs were shallow (0.759), medium (0.707) and deep (0.659). CH Impact reefs yielded J' indices of 0.362, 0.882 and 0.551 for shallow, medium and deep depths respectively (Table 2.1).

On CH Impact reefs at shallow depth, *D. labyrinthiformis* was the dominant species (82%). At medium depths *D. labyrinthiformis* (29%) and *M. decactis* (19%) were dominant with *M. decactis* (69%) dominant at deep transects. On CH Control reefs, shallow depths were dominated by *D. labyrinthiformis* (38%) and *Porites astreoides* (23%), and medium depths by *M. decactis* (39%) and *D. labyrinthiformis* (25%). Deep CH Control sites were dominated by *M. decactis* (50%) and *Madracis mirabilis* (25%). For all depths combined *D. labyrinthiformis* ranked first (40.73%) on CH Impact reefs and second (20.61%) on CH Control reefs. *Madracis*

decactis ranked second on CH Impact reefs (28.93% coral cover) and first on CH Control reefs (38.79% coral cover) (Table 2.2).

Species richness values (S) obtained for CH Impact reefs were 7 at shallow, 9 for medium and 8 for deep depths. On CH Control reefs, S values were 9, 13 and 10 for shallow, medium and deep transects respectively. Presence/absence (P/A) data, a means of accounting for bias against rare species (Aronson et al., 1994), yielded values of 12, 15 and 13 species for shallow, medium and deep CH Impact sites, and values of 14, 15 and 14 species for the same depths on CH Control reefs. Combined P/A values for all depths on CH Impact and Control reefs were 15 and 16 respectively (Table 2.1).

Partial Mortality of Corals

On the 4 Castle Harbour study reefs, the greatest number of *D. labyrinthiformis* (*D. lab*) colonies were found at shallow depths (111), while 78 and 37 colonies were found at medium and deep depths respectively. CHCE had a total of 78 *D. lab* colonies followed by 52 colonies at CHCW, 48 at CHIE and 40 at CHIW. On all but one reef (CHCW) more *D. lab* were damaged to a degree of one or more than not damaged. Combined Impact reefs had marginally significantly more damaged corals (59%) than combined Control reefs (48%) [$P = 0.05$]. A Chi-Square test for association showed no relationship between depth and degree of damage [$P = 0.09$] (Table 2.3).

Sedimentation Rates

On CH reefs, sedimentation rates ranged from lowest, $0.017 \text{ mg cm}^{-2} \text{ day}^{-1}$ in July at CHIW shallow to highest, $3.136 \text{ mg cm}^{-2} \text{ day}^{-1}$ in October at CHCE deep. Within CH reefs,

sedimentation rates differed significantly by depth [$P < 0.0001$] and by time [$P < 0.0001$]. Sedimentation rates increased over the four collection periods (Flood, 2004). No significant difference in sedimentation rates was observed among the CH reef sites [$P = 0.53$] (Table 2.1, Fig. 2.3b). On both CH and NS reefs sedimentation rates were lower on reef tops than on reef bottoms. NS and CH sediment data were compared for the months of September and October, showing significantly higher sediment deposition on CH reefs and the NS Impact reef than on the NS Control reef [$P = 0.005$]. No significant difference in sedimentation rates was found between the CH reefs and NSI [$P = 0.1098$]. The highest NS sedimentation rate was $2.599 \text{ mg cm}^{-2} \text{ day}^{-1}$ on NSI shallow in September and the lowest was $0.563 \text{ mg cm}^{-2} \text{ day}^{-1}$ on NSC shallow depth in October (Table 2.1, Fig. 2.3b).

Grain Size Analysis and Organic Content

Percent fine-grained sediment ($<63 \text{ um}$) was significantly lower in the NSC samples (33 – 46%) [$P = 0.0003$] when compared to the other 10 samples (58.24 - 82.82%). A significantly higher amount of organic material was found in both the coarse and fine sediments of the four NSC samples [$P = 0.002$, $P = 0.003$]. Total organic content of NSC samples ranged in value from 8.83 – 5.72%. Lowest organic content was found in the CHCW samples (4.03%). Percent fine-grained material and percent organic content were not significantly different across Castle Harbour [$P = 0.07$, $P = 0.56$].

Flow Rate Analysis

On CH Control sites, flow rate averaged over all depths was significantly higher on CHCE (6.49 cm/s) than on CHCW (4.88 cm/s) (t -test, $\alpha = 0.05$). CH Impact reefs were not

significantly different from each other with lower mean flows of 3.50 cm/s (CHIW) and 3.43 cm/s (CHIE) (Table 1, Fig. 3c). Average flow on Impact sites was significantly lower than that of average Control sites [$P < 0.0001$]. Within reefs, flow was significantly higher at shallow depth than at medium and deep depths [$P < 0.0001$] and was lowest at deep depths. Flow rates compared among reefs by depth were also significantly different [$P = 0.0018$] where highest mean flow recorded was 7.84 cm/s at shallow depth for combined Control sites and lowest mean recorded flow was at combined deep Impact sites (2.33 cm/s). Flow increased distal to the impacted area (Fig. 2.3c).

Turbidity Analysis

Secchi disk readings were significantly different among CH sites [$P = 0.0325$] with the greatest light values and thus least turbidity recorded at the Impact sites. Values ranged from 3.20 m to 8.10 m (Table 2.1).

DISCUSSION

This study was the first to analyze coral community structure in Castle Harbour in 30 years, and some 60 years post dredge and landfill. Findings indicated that coral community structure had changed considerably in that time. The change in percent cover was most apparent at the 2 reef sites close to the dredge scar (CHIE, CHIW) where a decrease from 12.40% (Dryer and Logan, 1978) to 2.28% was recorded. Comparatively, coral cover was 20% on the outer platform of North Shore, Bermuda, where no significant decline was observed during 7 years of monitoring (1993-2000) (CARICOMP, 2000a). This data, combined with earlier studies

(Dodge, Logan and Antonius, 1982) on the north shore where coral cover was approximately 16% suggests that decline in coral cover is not a general trend on Bermuda's reefs.

A phase shift in dominant species was observed on both the Impact and Control reefs where *Oculina diffusa*, a branching species, shifted from 1st and 2nd for % coral cover (Dryer and Logan, 1978) to 6th and 8th during this study. A decline in the dominance of branching species could suggest that sediment conditions in Castle Harbour have improved over past conditions, however, *Madracis decactis* and *M. mirabilis*, both branching species, are still prevalent on these reefs (Table 2.2). One possible reason for this change in dominance by *O. diffusa* is the difference in methodologies between this study and that of Dryer and Logan (1978). In the earlier study transects were laid vertically from reef crest to reef bottom and off reef onto sediment surfaces. It was noted during this study that *O. diffusa* often lies out on sediment surfaces several meters from reef structures. The brain coral *Diploria labyrinthiformis*, now dominant on CH reefs ranked 8th in the 1978 study (Dryer and Logan) and *D. strigosa*, previously unrecorded on CH Impact reefs and ranked 15th on Control reefs, shifted to a ranking of 4th and 5th respectively. *Montastraea cavernosa* and *M. franksi* had also become more abundant on CH reefs shifting from ranks of 6th and 11th on Control reefs and absence on Impact reefs (Dryer and Logan, 1978) to ranks of 9th and 8th, and 3rd and 7th respectively (Table 2.2) (Dryer and Logan, 1978). On Caribbean reefs with high rates of sedimentation *M. cavernosa* and *D. strigosa* are notably dominant due to their ability to effectively clear sediments (Bak and Elgershuzien, 1976, Lasker, 1980) and laboratory experiments have shown the efficiency of *D. labyrinthiformis* at removing sediment (Hubbard and Pocock, 1972). In particular, fine sediments (60-250 μ m) act like dense fluids and flow off on *M. cavernosa*, while larger particles remain on colony surfaces inducing the animal to remove them through biological action

(Lasker, 1980). Overall, this shift in species composition suggests Castle Harbour is a coral community adapting to high sedimentation. Given the length of time since the dredge and fill operation this shift to sediment tolerant species suggests adaptation to stress is a relatively slow process involving in this case, more than half a century.

Species richness (S) has remained high with 16 of Bermuda's 22 scleractinian species present, while diversity indices (H') have remained low (Table 1, Table 4). Highest H' indices were calculated for medium depth transects on three of the four study reefs (Table 2.1). This may be a result of the "edge effect", where corals situated on vertical slopes avoid sediment falling directly on reef surfaces (Porter, 1972, Sheppard, 1982). Consistent with this finding is the higher percentage of coral cover at medium depth on the two Control reefs (Table 2.1). Evenness (J') indices have changed at Impact sites where shallow and medium depths showed greater species dominance than in the past and deeper depths show less dominance (Table 2.1, Table 2.4). On Control sites J' values have remained relatively stable over the 30 year period (Table 2.1, Table 2.4).

Algal cover is greater than coral cover on all CH reefs (lowest algae cover was 80%, Table 2.1) and may be a significant factor affecting coral cover. In field experiments growth of individual coral colonies increased when competing algae was removed (Tanner, 1995). Algae cover reduces settlement substrate important to coral larval recruitment (Belliveau and Paul, 2002), sediments trapped within algae facilitate algal overgrowth onto coral colonies (Nugues and Roberts, 2003), and when in direct contact, some algae have acted as a vector for coral disease (Nugues et al., 2004). The complex relationship between corals and algae was first demonstrated when a complete phase shift from high coral cover with low algae cover to the inverse was observed following a series of catastrophic events, including 2 major hurricanes,

occurred on Jamaica's reefs (Done, 1992; Hughes, 1994). However, dominance by algae has been reversed when prior conditions resumed, such as the re-establishment of *Diadema antillarum* (grazing sea urchin) after a die-off in the 1980s (Edmonds and Carpenter, 2001), or a reduction in fishing pressure and subsequent increase in grazing fishes. In CH, there is little fishing pressure and grazing scaridae (parrotfishes) several feet long were often observed during this study and have been noted by other researchers (S.R. Smith, pers. comm.). Low fishing pressure combined with the presence of large grazing fishes should keep algal levels in check in CH thereby reducing the impact of competition with corals, however this has not been the finding of this study.

Sixty years after the dredge and landfill project, sedimentation rates in CH were not statistically different to those near an active shipping channel on the North Shore and were significantly higher than an undisturbed north shore control reef. Under continual sediment stress, reefs will support communities comprised of species well adapted to shed sediment (Rogers, 1990). The shift to dominance by *D. labyrinthiformis*, characterized as sediment tolerant (Hubbard and Pocock, 1972), suggests a reef community adapting to chronic sedimentation. Studies in Florida and the Dominican Republic have shown a phase shift from dominance by scleractinians to gorgonians (soft corals) after sediment loading stress (Marszalek, 1981; Torres et al., 2001). Methodologies used for this study constrain the possibility of quantifying soft corals, but personal observations indicate that soft corals were not very abundant and were notably absent from Impact reef deep transects where sedimentation rates were significantly higher than all other study sites. Sedimentation rates in CH and in the north shore shipping channel (NSI) were lower than findings outside of Bermuda where data suggested sediment was an abiotic control of community structure (Rogers, 1990; Gleason, 1998; Torres et

al. 2001). However, it has been suggested that further research is needed not only on the sediment threshold levels of individual coral species but also for reef ecosystems (Rogers, 1990). Since Bermuda's corals are naturally under temperature stress due to their northern position, they may be more limited in their ability to tolerate sediment when compared with Caribbean conspecifics. Therefore further sediment stress studies using corals on Bermuda's reefs would assist with determining sediment tolerances for these northern-most coral reefs.

Consistent with findings on St Lucia's reefs (Nugues and Roberts, 2003), the proportion of fine sediments ($<63 \mu m$) from sediment trap samples was greatest on reefs with the highest sedimentation rates (CHIE, CHIW, CHCE, CHCW and NSI). This suggests that when fine-grained sediments are present, sedimentation rates will be higher because the smaller the grain size, the more easily suspended the particle, and thus more detrimental to reef communities through increased sedimentation rates. It is probable that disturbance from both the dredging project in Castle Harbour and ship traffic on the north shore have reduced sediment grain size through mechanical breakdown of sediment grains which has in turn increased sedimentation rates. For many coral species these fine-grained sediments have a more smothering effect than coarse sediments (Bak and Elgershuizen, 1976) causing greater colony mortality (Nugues and Roberts, 2003).

Findings of the current study were consistent with those on reefs in St. Croix (Gleason, 1998) where reefs with the lowest sedimentation rates (North Shore Control, NSC) had significantly higher proportions of organic material in both the coarse and fine portions. The organic portion of reef sediments can carry nutrients readily available for consumption by the coral animal (Anthony, 1999) and thus, reefs in areas with lower sedimentation rates will be less stressed by sediments and receive greater nutritional value from sediments present. Values for

percent organic material found in Castle Harbour sediments were consistent with earlier findings (Jickells and Knap, 1984) suggesting sediment conditions in CH have not changed during this time period.

Contrary to expectations, Secchi disk readings indicated less turbidity and thus higher light values at CH Impact reefs than at CH Control reefs. Average Secchi values were similar to earlier findings in CH (Morris, et. al., 1977, Jickells and Knap, 1984) (6m). Overall, these light values were greatly lower than the average of a 6 year data set from the north shore lagoon ($33.6\text{m} \pm 10.3$) (CARICOMP, 2000b) suggesting that suspended sediments from the dredging have chronically reduced light availability to the CH coral community. Additionally, historic accounts cite the clarity of waters in CH, which was very much in contrast to conditions experienced during several years of diving in these waters (pers. obs.).

Flow rates were significantly lower on CH Impact sites than on CH Control sites and were similar in range to those found in other CH studies (Mills, 2004). Given that sedimentation rates were not significantly different across these reefs, the higher flow observed on Control reefs may mitigate sediments effects allowing for the significantly greater percent cover observed on these reefs during the current study and sustained since the last in 1978 (Dryer and Logan). Corals remove sediment via a suite of mechanisms including fluid mucus production (Coffroth, 1990) that in concert with flow, may be significant in clearing colony surface of sediments (Hubbard and Pocock, 1972; Rogers, 1990). Flow provides dissolved nutrients to corals and increases the encounter rate of corals with particles such as zooplankton (Sebens et al 2003). Corals exposed to reduced water flow in field experiments in Hawaii experienced significant reductions in calcification rates, photosynthetic pigments and the production of MAAs (mycosporin-like amino acids) (Kuffner, 2002). MAAs are important UVR absorbing

compounds produced in the coral animal that allow survival in the high ultraviolet radiation environment on coral reefs. A reduction in these compounds would make corals more susceptible to heat stress and ultimately temperature related coral bleaching. Reduced flow on the impact reefs may be partially responsible for the diminished growth rates measured on corals in Castle Harbour by Dodge and Vaisnys (1977), who attributed their findings to high sedimentation from the dredging event.

As expected, sediment related damage to *D. labyrinthiformis* colonies was greater on Impact reefs (59%) (CHIE, CHIW) than on the Control reefs (48%) (CHCE, CHCW) (Table 3). Interestingly, at all depths sampled, on all study reefs, more *D. labyrinthiformis* fell into category 0 (0= no damage), than any other individual category. The majority of damaged colonies fell into category 2 (2=some mortality, some algae) (Table 2.3) supporting the findings of earlier studies where partial mortality was greater than whole colony mortality in terms of loss of living tissue (Hughes and Jackson, 1985). Overall, the least corals fell into category 3, (3=large area of mortality, mostly algae) however, this may be the most difficult category to visually identify due to overgrowth of coral tissue by algae biasing short term studies in favor of lower damage categories. In a 4-year study of sediment related coral damage, data supported the use of partial mortality in some coral species as an indicator of sediment related stress (Nugues and Roberts, 2003). Given that sedimentation rates were not significantly different among CH study reefs, while damage was higher on the Impact than Control reefs, partial colony mortality of *D. labyrinthiformis* may not be a good indicator of sediment related stress in this marine basin. This may be due to the short duration of this study, differences in coral colony size, differences in flow rates among study reefs, or proximity of the Impact reefs to a municipal dump facility.

The phase shift to sediment tolerant species 60 years after the dredge and fill operation suggests that the reefs of CH may be slowly adapting to their sediment regime. However, given the decrease in percent coral cover on the reefs closest to the dredge and fill area factors beyond the scope of this study may be influencing survivorship or recruitment on those reefs. Proximity to an existing municipal waste dumping facility in concert with lower water flow rates may be concentrating contaminants and thus influencing percent coral cover.

Large-scale studies of coral communities have successfully elucidated patterns of variation within and among coral reefs over multiple scales (Murdoch and Aronson, 1999). However, this variation in reef communities cannot be understood without micro scale measurements of abiotic controls such as flow, sedimentation and turbidity/light that govern the patterns observed in large-scale studies. Coupled with coral community structure, abiotic controls suggest for example that the effect of sedimentation and turbidity are mitigated with increased flow on reefs distal to the dredge/fill area (CHCE, CHCW). Measurements of single abiotic alone factors therefore, do not provide sufficient data to understand patterns of coral loss and threats to the coral community. The complex interaction of these environmental factors both within and among reef sites suggests that it may be necessary to measure multiple environmental variables to determine causality for declines in percent coral cover. Similarly, knowledge of species specific flow and sediment tolerances gained through the measurement of multiple environmental variables may provide useful guidelines in restoration projects for the replacement of specific reef corals and placement of artificial reefs.

CHAPTER 3

CONCLUSION

Findings of this study indicated that coral community structure had changed considerably in Castle Harbour since the 1970s. The change in percent cover was most apparent at the 2 reef sites close to the dredge scar where a decrease from 12% (Dryer and Logan) to 2% was recorded. Some 60 years post the dredge and fill operation a phase shift in dominant species was observed on both the Impact and Control reefs where the sediment tolerant brain coral *Diploria labyrinthiformis* now ranks 1st in coral cover. This suggests adaptation to stress in coral reef communities is a relatively slow process involving, in this case, greater than half a century.

On reefs situated in proximity to the dredge and fill operation, percent coral cover and flow rates were lower than those on reefs distal to this area. Conversely, light levels were higher on reefs impacted by the dredge and fill, yet sedimentation rates were equal across the Castle Harbour reefs. Rates of sedimentation in Castle Harbour were not significantly different to those experienced by reefs in an active shipping channel. These findings suggest that sedimentation is chronic in Castle Harbour due to the change in landform as a result of the fill operation.

Large-scale studies of coral communities have successfully elucidated patterns of variation within and among coral reefs over multiple scales (Murdoch and Aronson, 1999). However, this variation in reef communities cannot be understood without micro scale measurements of abiotic controls such as flow, sedimentation and turbidity/light that govern the patterns observed in large-scale studies. Coupled with coral community structure, abiotic controls suggest for example that the effect of sedimentation and turbidity are mitigated with increased flow on reefs distal to the dredge/fill area (CHCE, CHCW). Measurements of single

abiotic alone factors therefore, do not provide sufficient data to understand patterns of coral loss and threats to the coral community. The complex interaction of these environmental factors both within and among reef sites suggests that it may be necessary to measure multiple environmental variables to determine causality for declines in percent coral cover. Similarly, knowledge of species specific flow and sediment tolerances gained through the measurement of multiple environmental variables may provide useful guidelines in restoration projects for the replacement of specific reef corals and placement of artificial reefs.

Table 2.1. Castle Harbour Data Synopsis, 2003: % total coral cover, % total algae cover, S, H' , J' , sedimentation rate and flow rate, where % total coral cover and % total algae cover = averages of 5 transects per depth, sedimentation rate = average over 4 collection periods, and flow = average over 3 measurements, light values n=14. Reefs are listed with increasing distance from Impact area.

Reef	Depth	% Total Coral Cover	S.E.	% Total Algae Cover	S.E.	S coral species	Presence/Absence coral species	H'	J'	Sedimentation Rate $\text{mg.cm}^{-2}.\text{day}^{-1}$	S.E.	Flow cm/sec	S.E.	Secchi Disk m
CHIE	Shallow	2.54	0.49	92	1.68	6	12	0.827	0.462	0.8761	0.23	5.52	0.30	
	Medium	2.27	0.78	95	1.29	9	11	1.836	0.835	0.8244	0.25	2.70	0.12	
	Deep	2.08	0.63	92	1.06	6	10	1.030	0.575	2.0441	0.30	2.07	0.11	
	Reef total	2.29		93		10	14	1.777	0.772	1.3945		3.43		
CHIW	Shallow	2.73	0.60	93	0.61	5	8	0.448	0.278	1.1633	0.26	5.03	0.20	
	Medium	1.50	0.53	94	1.02	9	13	1.905	0.867	1.5269	0.49	2.89	0.21	
	Deep	2.58	0.83	92	2.16	5	11	0.832	0.517	1.8054	0.38	2.60	0.12	
	Reef total	2.27		93		10	15	1.520	0.660	1.5544		3.50		
	Total	2.28 ^a		93 ^b		11	15	1.691 ^c	0.705					5.59 ^e
CHCW	Shallow	2.46	0.58	86	2.69	7	11	1.327	0.682	1.1307	0.23	6.96	0.44	
	Medium	5.08	1.31	88	2.49	9	13	1.428	0.650	0.6418	0.28	4.58	0.38	
	Deep	7.42	0.82	84	1.70	9	13	1.516	0.690	1.9017	0.29	3.11	0.19	
	Reef total	4.99		86		11	14	1.629	0.679	1.4029		4.88		
CHCE	Shallow	4.38	0.74	85	1.70	8	12	1.724	0.829	1.4391	0.29	8.73	0.54	
	Medium	6.96	1.34	80	0.72	12	13	1.845	0.742	0.7798	0.24	6.55	0.38	
	Deep	5.42	1.63	88	2.64	9	13	1.435	0.653	2.0804	0.32	4.22	0.26	
	Reef total	5.59		84		14	16	1.890	0.716	1.6253		6.49		
	Total	5.29 ^a		85 ^b		14	16	1.748 ^c	0.662					4.88 ^e
NSC	Shallow	-				-	-	-	-	0.8375		-		
	Deep	-				-	-	-	-	1.5336		-		
	Reef total	-				-	-	-	-	1.1855 ^d		-		
NSI	Shallow	-				-	-	-	-	1.3365		-		
	Deep	-				-	-	-	-	1.7350		-		
	Reef total	-				-	-	-	-	1.5357		-		
		^a $P < 0.0001$		^b $P = 0.0001$				^c Not significant		^d $P = 0.005$				^e $P = 0.0325$

Table 2.2. Corals measured in Castle Harbour, % total coral cover, % coral cover, importance rank. 1978 data from Dryer (1978), 2003 data this study. NW reefs are comparable to Impact reefs, SE reefs are comparable to Control reefs.

Coral Species	Impact Reefs 2003			Control Reefs 2003			NW Reefs 1978			SE Reefs 1978		
	% Total Coral Cover	% Of Coral Cover	Rank	% Total Coral Cover	% Of Coral Cover	Rank	% Total Coral Cover	% Of Coral Cover	Rank	% Total Coral Cover	% Of Coral Cover	Rank
<i>Diploria labyrinthiformis</i>	0.93	40.73	1	1.09	20.61	2	0.28	2.26	8	0.21	2.63	8
<i>Madracis decactis</i>	0.66	28.93	2	2.05	38.79	1	0.85	6.85	3	1.33	16.65	2
<i>Montastraea cavernosa</i>	0.15	6.46	3	0.10	1.94	9	-	-	-	0.32	4.01	6
<i>Stephanocoenia michelinii</i>	0.13	5.90	4	0.13	2.42	7	0.03	0.24	9	0.19	2.38	9
<i>Diploria strigosa</i>	0.13	5.90	4	0.31	5.82	5	-	-	-	0.01	0.13	15
<i>Madracis mirabilis</i>	0.09	3.93	6	0.85	16.00	3	6.68	53.86	1	0.84	10.51	4
<i>Montastrea franksi</i> **	0.06	2.53	7	0.11	2.06	8	-	-	-	0.07	0.88	11
<i>Siderastrea radians</i>	0.04	1.97	8	0.04	0.73	10	0.01	0.08	10	0.11	1.38	10
<i>Oculina diffusa</i>	0.04	1.97	8	0.16	3.03	6	2.44	19.67	2	3.11	38.92	1
<i>Oculina varicosa</i>	0.02	0.84	10	0.03	0.61	11	-	-	-	-	-	-
<i>Isophyllia sinuosa</i>	0.02	0.84	10	0.03	0.61	11	0.64	5.16	5	1.02	12.77	3
<i>Porites astreoides</i>	*	-	-	0.37	7.03	4	0.34	2.74	7	0.27	3.38	7
<i>Agaricia fragilis</i>	*	-	-	*	-	-	0.68	5.48	4	0.39	4.88	5
<i>Porites porites</i>	-	-	-	0.01	0.12	14	0.44	3.55	6	0.03	0.38	13
<i>Favia fragum</i>	*	-	-	0.01	0.24	13	0.01	0.08	10	0.05	0.63	12
<i>Siderastrea siderea</i>	-	-	-	-	-	-	0.00	0.02	11	-	-	-
<i>Meandrina meandrites</i>	-	-	-	*	-	-	-	-	-	0.02	0.25	14
<i>Dichocoenia stokesii</i>	*	-	-	-	-	-	-	-	-	0.00	0.04	15
Total	2.28	100		5.29	100		12.40	100		7.97	100	

* Observed in presence/absence video transect review (see methods).

** *M. franksi* was previously misidentified as *M. annularis* in Bermuda.

Table 2.3. Partial mortality of *Diploria labyrinthiformis* in CH 2003 by reef and depth. 0= no damage, 1=surficial sediment; 2=some mortality, some algae; and 3=large area of mortality, mostly algae. Combined Impact reefs had marginally significantly more damaged corals (59%) than combined Control reefs (48%) [$P = 0.05$]. A Chi-Square test for association showed no relationship between depth and degree of damage [$P = 0.09$].

Reef	Depth	Total <i>D. labyrinthiformis</i>	Degree of Damage:			
			0	1	2	3
CHIE	Shallow	33	11*	7	5	10
	Medium	11	4	4	3	0
	Deep	4	3	0	1	0
	Total	48	18	11	9	10
CHIW	Shallow	27	9*	6	11	1
	Medium	8	5	0	2	1
	Deep	5	4	1	0	0
	Total	40	18	7	13	2
CHCW	Shallow	26	20*	1	5	0
	Medium	16	11	1	3	1
	Deep	10	4	0	5	1
	Total	52	35	2	13	2
CHCE	Shallow	25	8*	11	5	1
	Medium	41	19	4	15	3
	Deep	12	5	0	6	1
	Total	78	32	15	26	5

Table 2.4. Percent coral cover, H' , and J' data from Dryer (1977). Dryer used a rope ladder draped vertically from reef apex to bottom using 0.5m rungs to mark quadrats. His data is presented in 0.5m discrete depth intervals. For this study current methods were used to allow direct comparison with contemporary studies. NW reefs are comparable to CH Impact reefs (2003) and SE reefs are comparable to CH Control reefs (2003).

	Shallow			Medium			Deep	
	0.5-0.99m	1.0-1.49m	1.5-1.99m	3.0-3.49m	3.5-3.99m	5.0-5.49m	5.5-5.99m	
NW Reefs								
% Coral Cover	-	4.70	14.61	34.86	16.63	5.73	16.20	
H'	-	1.24	1.46	0.98	1.09	1.21	0.97	
J'	-	0.60	0.67	0.55	0.61	0.68	0.70	
SE Reefs								
% Coral Cover	7.24	5.43	5.20	8.00	7.92	11.07	5.27	
H'	1.03	1.68	1.53	1.46	1.91	1.02	1.48	
J'	0.74	0.94	0.79	0.64	0.77	0.57	0.82	

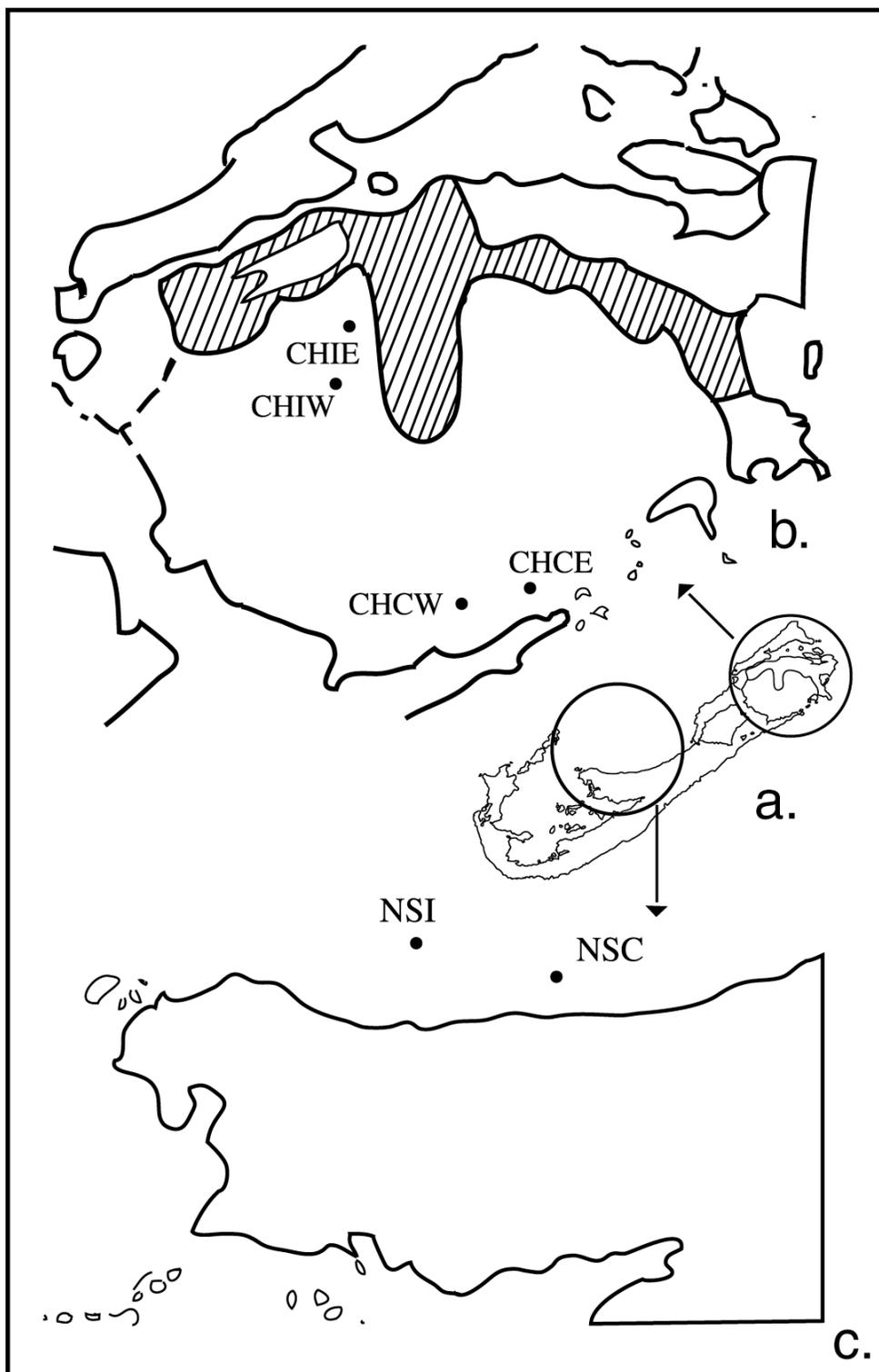


Fig. 2.1. a. Bermuda. b. Castle Harbour and study reefs. Hatched area represents land-fill resulting from the 1941 dredge and fill operation. CHIE = Impact East, CHIW = Impact West, CHCW = Control West, CHCE = Control East. c. North Shore study reefs. NSC = Control reef, NSI = Impact reef.

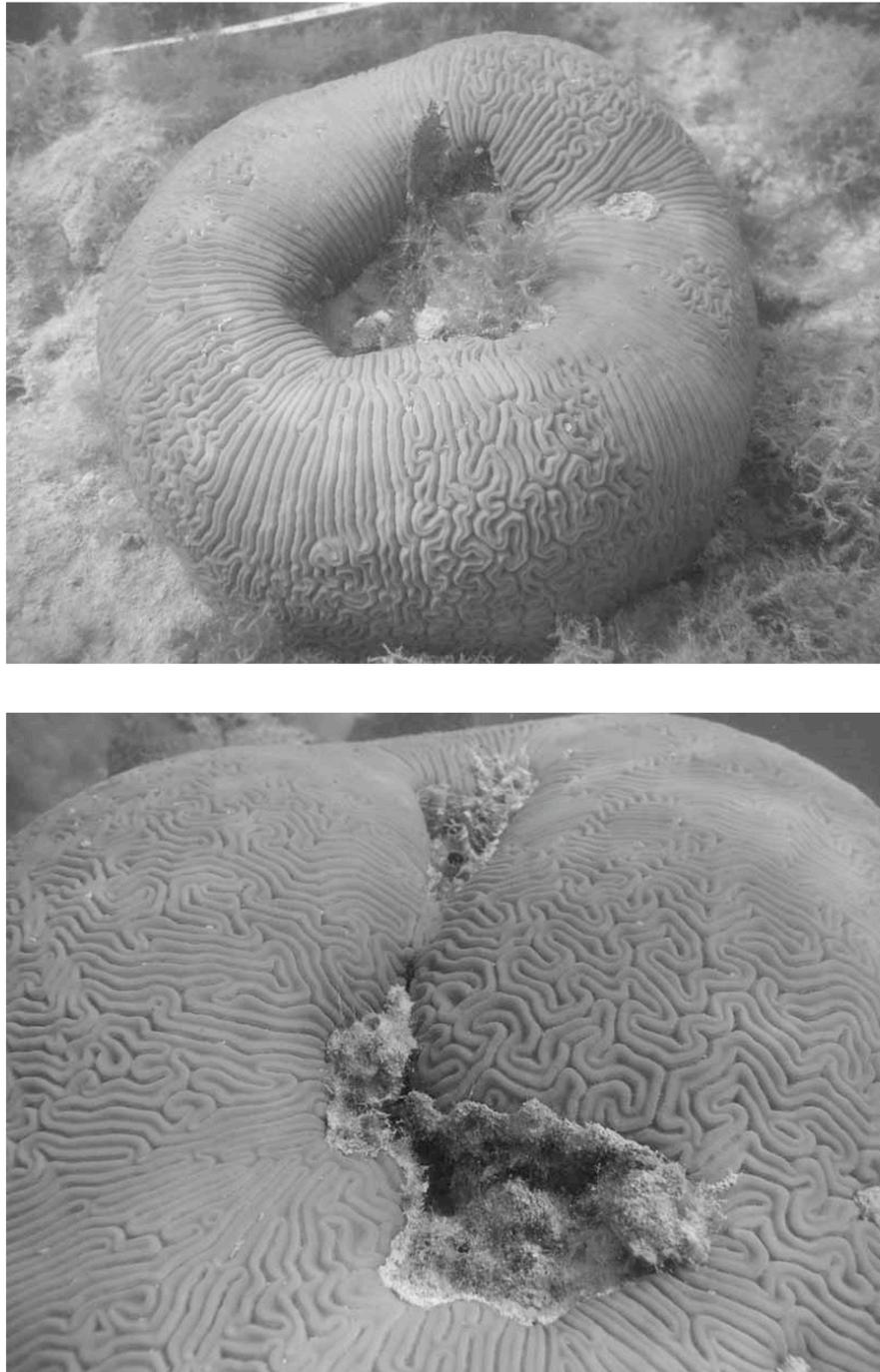


Fig 2.2. *Diploria labyrinthiformis* colonies with characteristic dimpling related to sediment damage. These colonies would be assigned a value of 2 on the 4-point damage scale. Photographs taken on Impact reefs, CH, Bermuda 2003 by Mathew Strong.

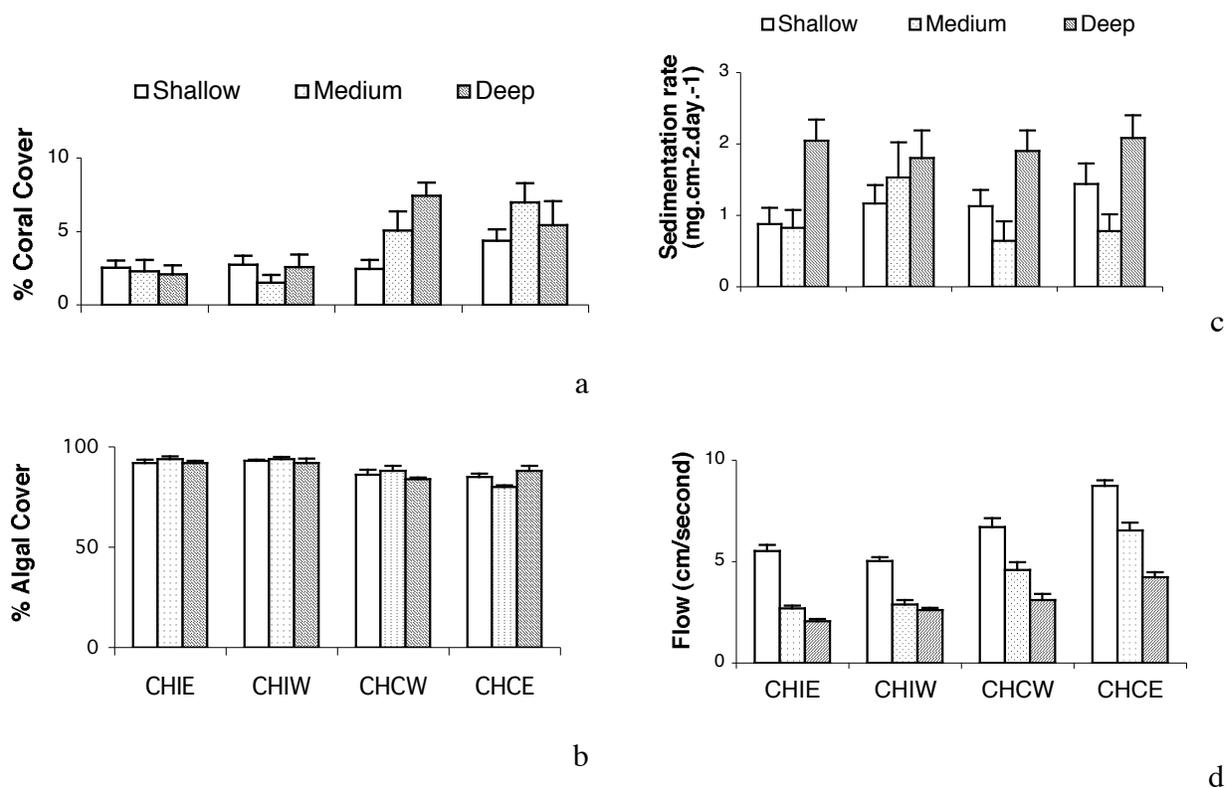


Fig. 2.3. a. Percent coral cover. Average coral cover for Impact sites was significantly lower than Control sites [$P < 0.0001$]. Among reef values significantly different at medium and deep sites [$P < 0.0001$]. Within reef values significantly different on CHCW only [$P = 0.012$]. b. Percent algae cover. Algae cover on Control reefs significantly lower than on Impact reefs [$P = 0.0001$]. c. Sedimentation rates. Within reef sedimentation rates significantly different [$P < 0.0001$]. No significant difference in sedimentation rates was observed among CH reefs [$P = 0.53$]. d. Flow rates. Within reef flow and combined flow on Impact sites compared to combined Control sites significantly different [$P < 0.0001$]. All data from Castle Harbour, Bermuda, 2003. All graphs show reefs in order of increasing distance from Impact area. (mean +1 S.E.).

REFERENCES

- Abdel-Salam, H.A., Porter, J.W., 1988. Physiological effects of sediment rejection on photosynthesis and respiration in three Caribbean reef corals. Proceedings of the 6th International Coral Reef Symposium. 2, 285–292.
- Agassiz, A., 1895. A visit to the Bermudas in March, 1894. Bull. Mus. Comp. Zool, 26, 209–281.
- Anthony, K.R.N., 1999. Coral suspension feeding on fine particulate matter. Journal of Experimental Marine Biology and Ecology. 232, 85-106.
- Aronson, R.B., Edmunds, P.J., Precht, W.F., Swanson, D.W., Levitan, D.R., 1994. Large-scale, long-term monitoring of Caribbean coral reefs: Simple, quick, inexpensive techniques. Atoll Research Bulletin. 421, 1-19.
- Bak R.P., Elgershuizen, J.H.B.W., 1976. Patterns of oil-sediment rejection in corals. Marine Biology. 37, 105–113.
- Bak, R.P. 1978. Lethal and sublethal effects of dredging on reef corals. Marine Pollution Bulletin. 9, 14–16.
- Belliveau, S.A., Paul, V.J., 2002. Effects of herbivory and nutrients on the early colonization of crustose coralline and fleshy algae. Marine Ecology Progress Series. 232, 105-114.
- Block, D.G., 1969. Kindley Air Force Base, Bermuda – The first twenty-five years. Information Division, Kindley Air Force Base, Bermuda.
- Brown, B.E., Le Tissier, M.D.A., Scoffin, T.P., Tudhope, A.W., 1990. Evaluation of the environmental impact of dredging on intertidal coral reefs at Ko Phuket, Thailand, using ecological and physiological parameters. Marine Ecology Progress Series. 65, 273-281.

- Buchanan, J.B., Kain, J.M., 1971. Measurement of the physical and chemical environment. In: Holme, N.A., McIntyre, A.D. (Eds.), *Methods for the Study of Marine Benthos*. In: IBP Handbook No. 16. Blackwell Scientific Publications, Oxford and Edinburgh, pp. 30-58.
- Burns, K.A., Ehrhardt, M.G., MacPherson, J.M., Tierney, J.A., Kananen, G., Connelly, D., 1990. Organic and trace metal contaminants in sediments, seawater and organisms from two Bermuda harbours. *Journal of Experimental Marine Biology and Ecology*. 138, 9-34.
- CARICOMP, 2000a. Status and temporal trends at CARICOMP coral reef sites. In: *Proceedings of the 9th International Coral Reef Symposium 1*, 23-27.
- CARICOMP, 2000b. The Caribbean coastal marine productivity program (CARICOMP) database: potential for data mining and comparisons of Caribbean-wide datasets. *Proceedings of the 9th International Coral Reef Symposium 2*, 901-908.
- Chornesky, E.A. 1989. Repeated reversals during spatial competition between corals. *Ecology*. 70(4), 843–855.
- Coffroth, M.A., 1990. Mucous sheet formation on poritid corals: an evaluation of coral mucus as a nutrient source on reefs. *Marine Biology*. 105, 39-49.
- Dodge, R.E., Logan, A., Antonius, A., 1982. Quantitative reef assessment studies in Bermuda: A comparison of methods and preliminary results. *Bulletin of Marine Science*. 32(3) 745-760.
- Dodge, R.E., Vaisnys, J.R., 1977. Coral populations and growth patterns: Response to sedimentation and turbidity associated with dredging. *Journal of Marine Research*. 35(4), 715–730.
- Dollar, S.J., Grigg, R.W., 1981. Impact of a Kaolin clay spill on a coral reef in Hawaii. *Marine Biology*. 65, 269–276.

- Done, T.J., 1992. Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247, 121-132.
- Doty, M.S., 1971. Measurement of water movement in reference to benthic algal growth. *Botanica Marina*. 14, 32-35.
- Dryer, S. 1977. Reef Ecology and Sediments, Castle Harbour, Bermuda. Unpublished M.S. thesis. Department of Geology, University of New Brunswick, Canada.
- Dryer, S., Logan, A., 1978. Holocene reefs and sediments of Castle Harbor, Bermuda. *Journal of Marine Research*. 36(3), 339–425.
- Edmunds, P.J., Carpenter, R.C., 2001. Recovery of *Diadema* leads to reduced macroalgal cover and increased abundance of juvenile corals on a Caribbean reef. *Proceedings of the National Academy of Sciences USA* 98: 5067-5071
- Flood, V.S. 2004. The effects of Chronic Sedimentation on the reefs of Castle Harbour, Bermuda. Unpublished M.S. thesis. Department of Geology, University of Georgia, Athens, Georgia, USA.
- Gleason, D.F., 1998. Sedimentation and distribution of green and brown morphs of the Caribbean coral *Porites astreoides* Lamark. *Journal of Experimental Marine Biology and Ecology*. 230, 73–89.
- Hanna, S.S. 1997. The new frontier of American fisheries governance. *Ecological Economics*. 20, 221- 233.
- Hubbard, J.A.E.B, Pocock, Y.P., 1972. Sediment rejection by recent scleractinian corals: a key to palaeo-environmental reconstruction. *Geologische Rundschau*. 61, 598-626.

- Hughes, T.P., Jackson, J.B.C., 1985 Population dynamics and life histories of foliaceous corals. *Ecological Monographs*. 55, 141-166.
- Hughes, T.P., 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science*. 265, 1547-1551.
- Jickells, T.D., Knap, A.H., Smith, S.R., 1986. Trace metal and nutrient fluxes through the Bermuda inshore waters. *Rapp. P.-v. Reun. Cons. Int. Explor. Mer* 186, 251-262.
- Jickells, T.D., Knap, A.H., 1984. The distribution and geochemistry of some trace metals in the Bermuda coastal environment. *Estuarine, Coastal and Shelf Science*. 18, 245-262.
- Kuffner, I.B., 2002. Effects of ultraviolet radiation and water motion on the reef coral, *Porites compressa* Dana: a transplant experiment. *Journal of Experimental Marine Biology and Ecology*. 270, 147-169.
- Lasker, H.R., 1980. Sediment rejection by reef corals: The roles of behavior and morphology in *Montastrea cavernosa* (Linnaeus). *Journal of Experimental Marine Biology and Ecology*. 47, 77-87.
- Magguran, A.E., 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey, USA. 179pp.
- Marszalek, D.S., 1981. Impact of dredging on a subtropical reef community, southeast Florida, USA. *Proceedings of the 4th International Coral Reef Symposium*. 1, 147-153.
- Mills, M.M., Lipschultz, F., Sebens, K.P., 2004. Particulate matter ingestion and associated nitrogen uptake by four species of scleractinian corals. *Coral Reefs*, 23, 311-323.

- Morris, B., Barnes, J., Brown, F., Markham, J., 1977. The Bermuda Marine Environment. A report of the Bermuda Inshore Waters Investigations 1976-1977. Special Publications of Bermuda Biological Station for Research. 15, 120pp.
- Muller-Parker, G., D'Elia, C.F., 1997. Interactions between corals and their symbiotic algae. In: Birkeland, C. (Ed.), *Life and Death of Coral Reefs*. Chapman and Hall, pp. 96-113.
- Murdoch, T.J.T., Aronson, R.B. 1999. Scale-dependent spatial variability of coral assemblages along the Florida reef tract. *Coral Reefs*, 18, 341-351.
- Murdoch, T.J.T., Aronson, R.B., *Digital Video Methodology – Lab Techniques*. Dauphin Island Sea Lab, Alabama, 5pp.
- Nugues, M.M., Smith, G.W., van Hooijdonk, R.J., Seabra, M.I., Bak, R.P.M., 2004. Algal contact as a trigger for coral disease. *Ecology Letters*. 7, 919-923.
- Nugues, M.M, Roberts, C.M., 2003. Partial mortality in massive reef corals as an indicator of sediment stress on coral reefs. *Marine Pollution Bulletin*. 46, 314–323.
- Nugues, M.M, Roberts, C.M., 2003. Coral mortality and interaction with algae in relation to sedimentation. *Coral Reefs*. 22, 507-516.
- Pastorok, R.A., Bilyard, G.R., 1985. Effects of sewage pollution on coral-reef communities. *Marine Ecology Progress Series*. 21, 175–189.
- Pitt, J., Flood, V.S., Venn, A., Smith, S.R., 2004. The introduction to this special publication. *Marine Pollution Bulletin*. In press.
- Porter, J.W., 1972. Patterns of species diversity in Caribbean reef corals. *Ecology*. 53(4), 745–748.
- Rogers, C.S., 1990. Response of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*. 62, 185–202.

- Rogers, C.S., Garrison, G., Grober, R., Hillis, Z., Franke, M.A., 2001. Coral Reef Monitoring Manual for the Caribbean and Western Atlantic. Virgin Islands National Park, St. John, USVI. 50pp.
- Sebens, K.P., Helmuth, B., Carrington, E., Agius, B. 2003. Effects of water flow on growth and energetics of the scleractinian coral *Agaricia tenuifolia* in Belize. *Coral Reefs*. 22, 35-47.
- Sheppard, C.R.C., 1982. Coral populations on reef slopes and their major controls. *Marine Ecology Progress Series*. 7, 83-115.
- Sterrerr, W.E., Wingate, D.B., 1981. Wetlands and marine environments. In S.J. Hayward, V.H. Gomez and W.E. Sterrer (eds.) *Bermuda's Delicate Balance*. Bermuda National Trust, pp. 107-122.
- Tanner, J.E., 1995. Competition between scleractinian corals and macroalgae: An experimental investigation of coral growth, survival and reproduction. *Journal of Experimental Marine Biology and Ecology*. 190(2)151-168.
- Tomascik, T., Sander, F., 1987. Effects of eutrophication on reef-building corals III. Reproduction of the reef-building coral *Porites porites*. *Marine Biology*. 94, 77-94.
- Torres, R., Chiappone, M., Geraldles, F., Rodriguez, Y., Vega, M., 2001. Sediment as an important environmental influence on Dominican Republic reefs. *Bulletin of Marine Science*. 69(2), 805–818.
- Verrill, A.E., 1902. The Bermuda Islands: Their scenery, climate, productions, physiography, natural history and geology, with sketches of their early history and the changes due to man. *Trans. Conn. Acad. Arts and Science*. 11, 413–956.

Webster, G.W., Smith, S.R., 2000. Reduced juvenile coral populations on reefs affected by sewage discharge in Bermuda. In: Proceedings of the 9th international coral reef symposium 2, 1041-1046.

Zar, J.H., 1996. Biostatistical Analysis. Prentice Hall, New Jersey, USA, 662pp.

APPENDICES

Appendix A. Sedimentation Rates for all reefs. Data was collected in Castle Harbour for 4 months. Data was collected on North Shore for 2 months. * = No data collected for that period.

Castle Harbour Impact West							
Trans	Depth	July	Aug.	Sept.	Oct.	Ave.	S.E
1	5	0.021	1.409	1.037	2.494	1.240	0.510
1	10	0.010	1.057	-	-	0.533	0.524
1	15	0.108	1.057	1.605	1.106	0.969	0.313
2	5	0.001	1.956	1.314	2.553	1.456	0.547
2	10	2.576	2.928	-	-	2.752	0.176
2	15	1.359	1.815	2.509	3.891	2.393	0.552
3	5	0.030	0.473	1.050	1.622	0.794	0.346
3	10	0.556	2.035	-	-	1.295	0.740
3	15	0.122	3.029	0.977	4.088	2.054	0.912
Castle Harbour Impact East							
1	5	0.307	1.971	0.397	*	0.669	0.442
1	10	1.390	1.522	-	-	1.456	0.066
1	15	0.648	3.115	1.170	3.057	1.998	0.638
2	5	0.035	1.714	1.290	2.161	1.300	0.458
2	10	0.040	0.986	-	-	0.513	0.473
2	15	1.063	2.594	2.036	1.605	1.824	0.325
3	5	0.041	0.278	0.911	1.409	0.660	0.310
3	10	0.297	0.710	-	-	0.504	0.206
3	15	0.593	2.317	2.707	3.625	2.311	0.635
Castle Harbour Control West							
1	5	0.052	0.772	1.504	1.920	1.062	0.412
1	10	0.093	0.615	-	-	0.354	0.261
1	15	0.212	2.078	2.117	2.211	1.654	0.482
2	5	0.020	1.036	0.834	2.083	0.993	0.424
2	10	0.396	0.520	-	-	0.458	0.062
2	15	0.150	1.066	2.769	3.216	1.800	0.719
3	5	0.046	1.736	1.785	1.781	1.337	0.430
3	10	0.225	2.002	-	-	1.114	0.888
3	15	1.836	3.069	2.108	1.989	2.251	0.279

Castle Harbour Control East							
Trans	Depth	July	Aug.	Sept.	Oct.	Ave.	S.E
1	5	0.045	3.546	1.835	1.069	1.624	0.738
1	10	0.104	1.540	-	-	0.822	0.718
1	15	1.081	2.037	2.502	1.659	1.820	0.301
2	5	0.704	1.035	2.362	2.076	1.544	0.400
2	10	0.489	0.531	-	-	0.510	0.021
2	15	0.562	1.175	3.006	4.505	2.312	0.897
3	5	0.299	2.136	0.956	1.208	1.149	0.381
3	10	0.706	1.308	-	-	1.007	0.301
3	15	1.209	2.075	1.908	3.245	2.109	0.422
North Shore Impact							
1	5	-	-	2.576	1.087	1.831	0.745
1	15	-	-	1.577	1.160	1.368	0.209
2	5	-	-	2.621	1.144	1.882	0.739
2	15	-	-	2.994	0.893	1.944	1.050
3	5	-	-	*	0.591	-	-
3	15	-	-	1.867	1.919	1.893	0.026
North Shore Control							
1	5	-	-	1.729	0.459	1.094	0.635
1	15	-	-	2.583	0.505	1.544	1.039
2	5	-	-	*	0.851	-	-
2	15	-	-	3.273	0.549	1.911	1.362
3	5	-	-	0.891	1.095	0.993	0.102
3	15	-	-	1.657	0.635	1.146	0.511