BULLETIN OF MARINE SCIENCE, 75(2): 295–320, 2004

LARGE-SCALE ECOLOGICAL IMPACTS OF DEVELOPMENT ON TROPICAL ISLANDS SYSTEMS: COMPARISON OF DEVELOPED AND UNDEVELOPED ISLANDS IN THE CENTRAL BAHAMAS

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ABSTRACT

The relationship between density of development and the health of nearshore marine habitats is explored through spatial and temporal comparisons of patch reef environments in the central Bahamas. Nearshore patch reefs are important fish habitats, and tend to have high, but variable, coral cover and benthic diversity in the Bahamian archipelago. Twelve patch reef stations were established off developed and undeveloped islands in the central Bahamas. Environmental parameters were measured over an 18-mo period to examine seasonal, tidal, and diurnal variability. Water quality measurements were not significantly different between developed and undeveloped sites for temperature, salinity, dissolved oxygen, chlorophyll-*a*, total nitrogen and total phosphorus. Only turbidity measurements were significantly different among sites, attributed to storm events. Ecological surveys recorded macroalgae species, stony coral species, coral cover, and coral vitality. Significant differences in species composition between developed and undeveloped stations were seen, with a higher coral diversity, lower coral cover, and higher incidence of coral lesions on developed patch reefs. A 53-yr comparison of nearshore environments from aerial imagery showed significant loss of patch reefs and seagrass areas with increasing development density. Results stress the importance of comparison reefs in marine protected areas for evaluating impacts of coastal development on nearshore marine habitats.

This paper is one in a series resulting from a workshop held at the Caribbean Marine Research Center (December 2001) to evaluate the importance of back reef systems for supporting biodiversity and productivity of marine ecosystems. This paper specifically addresses the potential impacts of coastal development on nearshore patch reef environments by spatial and temporal comparisons of heavily developed ("developed") and less-developed ("undeveloped") islands in the central Bahamas. The Bahamian archipelago is made up of shallow-water carbonate limestone environments with few surface water resources; a critical feature is the continuous solution of the limestone rock, and consequent permeation of seawater beneath all the islands (Sealey, 1994). The marine and terrestrial habitats adjacent to the shoreline interact ecologically in terms of nutrient flux through rainfall run-off, seepage of ground water, and detrital material moving on and off the islands. Most people in the Bahamian archipelago live within 2 km of the sea, and both countries that occupy the islands (The Bahamas and the Turks and Caicos Islands) share a common culture as well as economic interest in the coastal and marine resources.

The typical pattern of development on these carbonate islands requires completely clearing the site of all vegetation, and leveling the rocky terrain, with fill if necessary. Threats to nearshore marine environments, particularly patch reefs, occur on several levels. The most severe threat is the physical elimination of reefs for the alteration and restructuring of the shoreline to accommodate marina, harbor, and residential development. A second threat to these reefs comes from the acute and chronic sedimentation generated when coastal vegetation is removed, and the soil/sand exposed to erosion by rain during construction. Often exotic plants are used in landscaping, and native coastal plants are

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removed permanently, leaving little or no vegetation buffer between buildings and the sea. Lastly, a threat exists, though poorly documented in the Bahamas specifically, from nutrient seepage from cesspit systems very close to the sea, or in contact with ground water. With the exception of downtown Nassau and some large resorts, the common means of wastewater treatment and disposal is the use of "soak-aways" or cesspit systems constructed onsite (Cant, 1997). All onsite disposal systems installed on limestone islands are shown to enrich nearshore water with inorganic nutrients and some amount of organic matter (U.S. EPA, 1983, 1991).

Human activities on land inevitably increase nutrient inputs to coastal waters from deforestation, wastewater, fertilizer, and other sources (Bell, 1992). Human population growth in the Bahamian archipelago is one of the highest in the insular Caribbean, with a 10-yr intercensal growth rate of 19% for the Bahamas (Department of Statistics, 2002), and 41.7% for the Turks and Caicos Islands (UNEP, 2002). The population of the Bahamas is projected to increase from 303,000 in 2000 to 357,000 in 2010. Seventy percent of the population in the Bahamas live on New Providence Island. Although the population is small in comparison to the islands of the Greater Antilles, population size is similar to eastern Caribbean island nations. The small island nature of the archipelago places all development in close proximity to nearshore reef environments. The Bahamas is not unlike the Florida Keys (Hoffmeister, 1974), where the process of eutrophication has been studied intensively. Major pathways of nutrient input to waters of the Florida Keys include onsite sewage disposal systems (Lapointe et al., 1992), and submarine groundwater discharge (Lapointe and Matzie, 1992). A major difference between the Florida Keys and the central Bahamas is circulation. The Bahamian islands are not adjacent to the peninsula of south Florida, and have not been targeted for any significant fill between islands for causeway construction (See Lott et al., 1996 for historical overview of island fill in the Florida Keys).

Considerable concern exists over the loss of live coral and the decline of coral reefs caused by macroalgae proliferation in the tropics (e.g., Dustan and Halas, 1987; Hallock et al., 1993; overview by McCook et al., 2001). Coral reef ecosystems are very sensitive to environmental perturbations for several reasons: 1) key reef-building organisms such as corals have very narrow physiological tolerances, 2) interactions of key species (plant-herbivore, algae-coral) are easily disrupted by human-induced perturbations, and 3) the toxic effects of introduced materials are enhanced because of tropical water temperatures and higher metabolic rates (Pastorak and Bilyard, 1985). The stress of eutrophication or nutrient-enrichment on coral reefs likely contributes to this macroalgae proliferation, and appears to be related to the proximity of coastal development as a source of pollution, particularly sewage (Bilyard, 1985; Marszalek, 1987; Pastorak and Grigg and Dollar, 1990). Throughout developed areas of the tropics, nutrient input from human sources constitutes one of the greatest threats to coral reefs, often resulting in a chronic eutrophication process (Mee, 1988). Indeed, this threat may be even greater in the Bahamian archipelago because, despite having a large area of shallow-water banks, fisheries production is in fact tied to habitats very close to islands along the platform margin (see Stoner et al., 1994; Colin, 1995; Sluka et al., 1996; Lipcius et al., 1997). How can nearshore habitats be monitored and evaluated to detect impacts from development? Clark and Green (1988) summarized several criteria to be used in pollution assessment, including the importance of selecting one or more sites as controls (relatively non-impacted), and the documentation of nuisance physical and biological variables from seasonal, tidal, or diurnal cycles.

The present study evaluates criteria for the selection of control sites for nearshore patch reefs based on their proximity to coastal development. With coastal development, nearshore patch reefs can be physically destroyed (loss of habitat) or degraded by sediment and/or nutrient enrichment (habitat degradation or phase-shifts). Habitat degradation should be detected by changes in both environmental parameters (physical and chemical properties of the water column and sediments) and ecological parameters (benthic species composition and coverage). No islands in the archipelago can be considered "undeveloped" in the purest sense (Jackson et al., 2001) as historical changes in land cover and vegetation, as well as extinctions and extirpations, have accounted for unknown ecological changes over the past two millennia. For this paper, "undeveloped" is less-developed, and at the lowest level of contemporary human occupation and use in the central Bahamas. Both the undeveloped and developed patch reef stations are in areas of restricted fishing; undeveloped patch reefs are within the Exuma Cays Land and Sea Park, a marine fisheries reserve, and the developed patch reef stations are within the no-fishing limits adjacent to settlements.

This study examined three questions: 1) Are spatial comparisons made between patch reefs adjacent to developed and undeveloped islands valid, and are there appropriate "reference sites" within a larger ecological system (e.g., banks)? 2) What environmental and ecological parameters are most useful in characterizing the condition of reefs based on proximity to coastal development in the central Bahamas? and 3) What is the nature of temporal changes in reef environments as development density increases (e.g., Montagu Bay off New Providence) given a detailed history of aerial photography and historical records? The answers are critical to developing both a better ecological understanding of nutrient flux in the coastal zone as well as management guidelines for development practices within the archipelago.

Study Area

The central Bahamas includes the eastern half of the Great Bahama Bank, and is comprised of about ten main islands and many smaller cays and rocks extending along the platform margin of the bank (Fig. 1). The bank is bounded by the western Atlantic to the east, and is penetrated by a submarine trough, probably of tectonic origin (Exuma Sound). Most of the bank area is very shallow (mean depth of 5–10 m). The selection of patch reef stations was based on previous studies of the reefs as grouper habitat, and physical similarities in size, proximity of islands, and exposure to prevailing winds. The twelve patch reefs selected were within 5 km of the islands of New Providence (developed) and Warderick Wells, Halls Pond, and Bell Island (undeveloped; Table 1; Fig. 2). All patch reefs were located on the leeward sides of islands, somewhat protected from direct wave and wind action. The islands themselves are located along the Great Bahama Bank platform margin, the Exuma Cays facing the western edge of Exuma Sound, and New Providence facing the southern edge of the Northeastern Providence Channel. Several previous studies have reported on the local oceanography, and most notably the tidal-generated currents adjacent to islands and tidal inlets; tidal currents can be quite strong, as high as 150 cm s^{-1} (Lang et al., 1988; Stoner et al., 1994; Colin, 1995; Lipcius et al., 1997). Initial observations of the sites showed well developed, dome-type patch reefs.

Dome-type patch reefs have a diversity of dominant biota and exhibit great variability in topographic complexity (Jones, 1977). Mature patch reefs in the Bahamas are often dominated by large colonies of the species *Montastraea annularis* (Ellis and Solander, 1786), *Montastraea cavernosa* Linnaeus, 1767, *Siderastrea sidereal* (Ellis and Solander, 1786), *Colpophyllia natans* (Houttuyn, 1772), and *Diploria clivosa* (Ellis and Solander, 1786) (Sluka et al., 1996). The patch reefs selected were previously investigated as a habitat for juvenile groupers (Sluka et al., 1994, 1999) and the

Figure 1. Map of the central Bahamas with the location of New Providence Island and the northern Exuma Cays. Bathymetric contours represent 200 m and define the platform margin of the Great Bahama Bank.

patch reefs' benthic species composition had been characterized in terms of coral and sponge cover (Sullivan and Chiappone, 1992). Small patch reefs in sheltered, nearshore environments of the central Bahamas were shown to be important fisheries habitats, and were highly variable in coral species present as well as overall coral cover. All patch reefs tended to have higher coral cover than other reef and non-reef hard bottom habitats (Sluka et al., 1997). The twelve patch reefs were small, ranging from 98–660 m^2 (size measured by two perpendicular survey tapes stretched along the sides of the patch, area reported in square meters), with an average size of 350 m^2 (Table 1).

Materials and Methods

The methods used can be divided into three sections: measurement of environmental parameters (water quality and sediment); measurement of ecological parameters (species composition and cover, coral lesions); and temporal image analysis of 50-yr changes to the Montagu Bay environment as development density increased fourfold.

Environmental Parameters.—Measurement of water quality and sediment parameters adjacent to the patch reef stations was aimed at first characterizing the natural variability of these parameters for nearshore patch reefs, and second, evaluating the usefulness of the Exuma Cays as an undeveloped comparison site to New Providence (heavily developed). Variability in water quality on the patch reef stations was likely attributed to tidal cycles, diurnal cycles, season, and distance from shore. Water quality assessment involved surveying the water column directly above the patch reefs (Fig. 2). Water quality sampling was carried out over a 2-wk period in each of February 1998 and October 1998 (1 wk at developed island stations, and 1 wk at undeveloped island stations). Water quality samples were taken via Niskin bottles deployed at the reef sites at 1-m depth. Salinity, temperature, and dissolved oxygen were measured in situ with a YSI probe (Yellow Springs Instruments, Model 85, oxygen electrode calibrated daily). Sample bottles were placed in a cooler and returned to shore for turbidity measurements via a LaMotte turbidity me-

Table 1. Summary of patch reef stations with location, area, depth, and brief description. Twelve patch reefs were selected for sampling, six adjacent to a heavily developed island, New Providence, and six adjacent to undeveloped islands in the Exuma Cays Land and Sea Park, central Bahamas.

Site name	Station number	Patch reef area (m^2)	Latitude	Longitude	Depth range at low tide (m)	Distance from shore (m)
Montagu Bay off New Providence Island (developed)						
Lighthouse	DEV1	98	N 25° 02.65′	W 77° 15.61′	2–4 m	50
Triplets	DEV2	100	N 25° 03.02′	W 77° 16.71′	1–3 m	230
Midchannel	DEV3	425	N 25° 03.35′	W 77° 16.02′	1–3 m	650
Wreck	DEV4	490	N 25° 04.52′	W 77° 16.55′	1–4 m	2,600
Porgy Rocks 2	DEV5	575	N 25° 03.54′	W 77° 14.51′	3–4 m	4,700
Porgy Rocks 1	DEV6	660	N 25° 03.79′	W 77° 14.57′	4–6 m	5,200
Exuma Cay Land and Sea Park (undeveloped)						
Bell South	UNDEV1	180	N 24° 18.02′	W 76° 33.44′	1–3 m	10
Big Eye	UNDEV2	297	N 24° 23.97′	W 76° 38.15′	1–4 m	40
Hall's Pond	UNDEV3	250	N 24° 22.02′	W 76° 35.45′	2–5 m	150
Emerald	UNDEV4	99	N 24° 23.04′	W 76° 37.76′	1–3 m	450
Malabar	UNDEV5	440	N 24° 21.98′	W 76° 35.42′	1–3 m	900
Channel Rocks	UNDEV6	550	N 24° 17.38′	W 76° 33.36′	3–5 m	1,200

ter (Model 2008, calibrated daily with 0.5 NTU calibration standard). Five hundred-ml of each sample was then filtered through a GF/F filter, and the filter was subsequently labeled and frozen for chlorophyll-*a* determination. At the University of Miami, filters were processed for chlorophyll-*a* content as per Szmant and Forester (1996). Filters were placed into vials with 10-ml of 20% tetrahydrofuran and 80% methanol (D'Elia et al., 1983). Samples were mixed, refrigerated for 4 hrs, and then centrifuged. A flourometer was used to determine chlorophyll-*a* concentration of the supernatant, and values were used to calculate micrograms per liter of seawater (Lorenzen, 1996). Unfiltered seawater (250 ml) was collected and frozen for laboratory analysis of water column nutrients. Total nitrogen (TN) and total phosphorus (TP) were determined by the South Florida Environmental Research Center at Florida International University. TN was measured by a Nitrogen Anlyzer (Jones and Boyer, 2002) and TP was determined using a dry ashing hydrolysis technique. Data are reported in micromoles. Sediment samples were taken from the "halo" adjacent to the patch reefs by using a PVC core. Sediment from ~25-cm depth from five random locations around the patch reef was collected and frozen. Thawed sediment samples were mixed. Subsamples were sieved for grain size distribution (Stoddart, 1978). Sediment (100 g) was dried, and then ground with an agate mortar and pestle. Samples were analyzed for TN with a Carlo Erba Model 1106 Elemental Analyzer (Szmant and Forrester, 1996).

Water quality values tend to be skewed to low concentrations, particularly in oligotrophic tropical waters. Values do not follow a normal distribution, thus a more appropriate means to evaluate natural variability of parameters is through examining median values, as measures of central tendency. Outliers (<5th and >95th percentiles) were excluded; thus the 5th and 95th percentiles are the minimum and maximum values given (Christian et al., 1991). Differences in values were tested between developed and undeveloped patch reef sites, using the Wilcoxon Ranked Sign test ($P = 0.05$).

Ecological Parameters.—Species presence-absence surveys were used to inventory the dominant and conspicuous benthos on the patch reef stations. Surveys consisted of 1-hr searches each for benthic macroalgae and stony corals based on standardized checklists from previous surveys in the Bahamas (Sullivan and Chiappone, 1992, 1993). Macroalgae identification was reviewed using Littler and Littler (2000). The algae and coral data were analyzed using similarity coefficients and clustering strategies to evaluate similarities in species composition among several

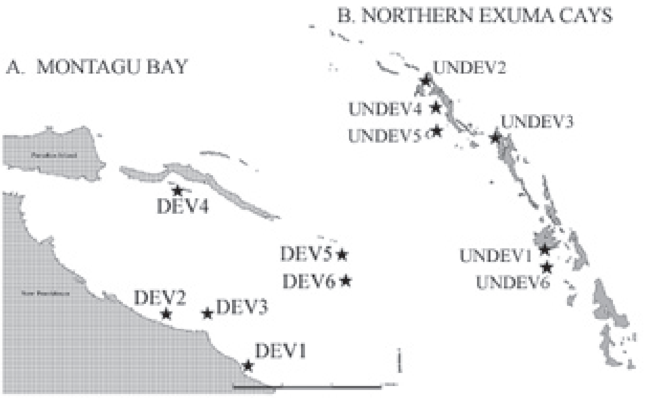

Figure 2. Map of the developed (A) and undeveloped (B) patch reef stations in the central Bahamas. Developed patch reef stations were located in Montagu Bay, New Providence. Undeveloped patch reef stations were located in the Exuma Cays Land and Sea Park.

survey locations. The Jaccard coefficient was used in pair-wise comparisons between patch reefs (Pielou, 1977; Hubalek, 1982). This matrix was used to construct a dendogram based on cluster analysis of similarity values. The dendograms were used to identify patterns of species that could be indicative of ecological change.

One-m^2 quadrats were used to inventory the coral cover and incidence of lesions for reef-building corals. Preliminary surveys were carried out to determine effective sample sizes for the coral vitality surveys on patch reefs. Pilot study results indicated that surveys of 20, 1-m^2 quadrats captured 78–85% of the total colonies larger than 7 cm in maximum diameter on the small patches. Within the quadrats, corals were identified to species and measured for diameter or length and width to the nearest 0.5 cm. Colony size measurements were used to calculate the planar size (cm^2) of each colony, these measurements were used to calculate coral cover (with a maximum of 10,000 cm^2 per quadrat). The recording of coral lesions was a modification of Dustan (1993). Data were analyzed by presenting vitality as a percentage of all coral colonies surveyed with lesions, defined as all conditions except "unblemished" and "almost unblemished".

IMAGE ANALYSIS OF TEMPORAL TRENDS.—The purpose of the temporal trends analysis was to understand landscape scale changes in a bay adjacent to a developed island. Montagu Bay was historically dominated by three types of hard-bottom habitats: A) patch reefs dominated by large boulder corals, B) hard bar or hard bottom co-dominated by corals, octocorals and sponges, and C) nearshore hard bottom or rocky platform habitats dominated by corals and sponges. Montagu Bay and the adjacent northeastern shore of New Providence were selected as the image analysis site because of the historical record of nearshore coral reefs in the area, the uniformity in the type of development (all single family homes with onsite sewage disposal), and the available historical data.

The Montagu Bay study site was 443.8 ha of seafloor and coastal zone (land). The bay was bounded by New Providence Island to the south, Paradise (Hogg) Island to the northwest, Athol Island to the north, and Porgy Rocks to the northeast (Fig. 2). This bay has a strong tidal circulation through Nassau Harbour to the west, and through the channel between Paradise and Athol Island. The bay contains many reefs that have been used historically and today for tourism (snorkeling, SCUBA diving, and glass-bottom boats). The reefs are well documented both in aerial photographs, and early underwater photographs. The classification of the benthic habitats was based on previous benthic surveys and mapping the central Bahamas (Sluka et al., 1999; Chiappone et al., 2000). The classification was based on the hierarchical habitat classification in Cowardin et al. (1979).

Two sets of aerial photography were selected: 1) 1943 photography taken by a Canadian survey company in high-resolution black/white film at a scale of 1:30,000, and 2) 1995 photography taken by a U.S. survey company also in black/white film at a scale of 1:10,000. Both photo sets provided an excellent view of reefs and shallow marine habitats. Images were scanned, orthocorrected, and assembled in mosaics in a GIS database (ESRI ArcInfo). Photo-mosaics were examined for both the density of development (number of houses within 500 m of the shoreline) and mapping benthic habitats. Stereo pairs of the photographs were used to aid in photo-interpretation. Benthic habitats were identified as one of 13 classes, these classes were grouped for change detection into three broader categories based on substrate and lifeform coverage: 1) Bare or algal-covered sand/mud bottom, 2) Seagrass habitats on sand or mud, and 3) Reefal and hard bottom habitats. Bare or sparsely covered sand or mud bottom included nearshore mud bottom adjacent to mangrove wetlands, mud bottom with bioturbation (shrimp) mounds, algae-dominated mud bottom, and dredged “pits”. Seagrass habitats included sparse, patchy, or dense seagrass beds. Hard bottom communities included nearshore rocky platform, hard bar (non-reefal hard bottom), and patch reefs. The 1995 image was ground-truthed, and the benthos classified based on verification in field surveys. Change detection was accomplished by comparison of the two maps, then identification of the areas that changed habitat classes. Analysis included comparing the total area of coverage of a habitat as well as the number of polygons (habitat units) that changed between the respective years for the physical loss of reef habitats.

RESULTS

ENVIRONMENTAL PARAMETERS.—Water quality data are summarized in Table 2; temperature, salinity, dissolved oxygen, turbidity, TN, and TP are shown in pair-wise comparisons, grouped by season and tidal cycle. Median values are presented for all developed and all undeveloped reefs, for season and tide. These water quality parameters show no significant difference between developed and undeveloped reefs with one exception. The only significant differences between the developed and undeveloped sites occurred in turbidity ($P = 0.05$). Turbidity measurements were significantly higher off undeveloped reefs in February. Seasonal and tidal variability of parameters was much greater than diurnal changes. Patterns and extent of seasonal and tidal variation were similar between developed and undeveloped patch reef stations.

Temperature on nearshore patch reefs varied as much as a 4°C over the tidal or diurnal cycle. Temperatures were very high in October of 1998, with long-term temperature loggers recording a maximum summer (June 1988–October 1998) temperature of 34.4°C on developed reefs and 34.8°C on undeveloped reefs. Salinity was likewise high at all the patch reefs, ranging between 36.2 and 40.9.

Dissolved oxygen levels measured at all stations were high and reflected surface mixing and tidal circulation in shallow water at both developed and undeveloped stations. Dissolved oxygen levels were higher during the winter, when the water temperature was also lower. Levels of dissolved oxygen were not different between sunrise and sunset.

Overall, chlorophyll-*a* concentrations were lower with less variation during February (0.00–0.83 mg L^{-1}) compared to October (0.04–4.36 mg L^{-1}). Total nitrogen at patch reefs ranged from 0.00–11.49 μM during February and from 1.96–16.59 μM during October. TN was also slightly higher during low tide compared to high tide. TP concentrations were very low, ranging from 0.00–0.18 μM in October, and 0.00–0.46 μM in February. Variation in TP was greatest at low tide during February.

Table 3 presents the water quality parameters grouped for reefs near developed and undeveloped sites, based on distance from shore during the February sampling. The distance from shore represents a linear distance from island shoreline, but also distance out onto the banks (away from the platform margin), thus farther “offshore” does not

Table 2. Water quality parameters for 12 patch reefs adjacent to developed and undeveloped coasts. Water quality sampling was carried out over 2 wks in February 1998 and 2 wks in October 1998. Median, maximum, and minimum values (exclusive of outliers) are given for temperature, salinity, dissolved oxygen, turbidity, chlorophyll *a*, total nitrogen, and total phosphorus. (**) indicates significant differences between developed and undeveloped reefs.

		Temperature	Salinity	Dissolved oxygen	Turbidity	Chl *a*	Total N	Total P
		(ºC)	(ppt)	(mg L^{-1})	(NTU)	(µg L^{-1})	(µM)	(µM)
SEASONAL VARIABILITY-FEBRUARY								
All developed	Median	21.6	38.3	6.4	0.16 **	0.06	4.89	0.05
High and low tide	Max	23.8	39.2	7.1	0.3	0.18	9.61	0.37
	Min	20.9	36.2	5.9	0.0	0.00	0.25	0.00
	n	130	130	130	70	52	60	60
All undeveloped	Median	21.15	39.1	6.4	0.8	0.22	3.50	0.06
High and low tide	Max	24	39.6	7.1	4.6	0.83	11.49	0.46
	Min	19	38.5	5.9	0.0	0.01	0.00	0.00
	n	120	120	120	89	57	60	60
SEASONAL VARIABILITY-OCTOBER								
All developed	Median	30.25	40.5	4.9	0.1	0.01	6.93	0
High and low tide	Max	31.4	40.9	6.4	0.4	4.56	13.83	0.17
	Min	28.2	37.8	4.1	0.0	0.04	1.96	0.00
	n	100	100	100	70	58	58	58
All undeveloped	Median	29.9	39.6	4.7	0	0.09	6.86	0
High and low tide	Max	31.2	40.1	5.0	0.5	0.12	16.59	0.17
	Min	29.4	39.1	3.9	0	0.04	3.24	0
	n	90	90	90	90	60	53	53
TIDAL VARIABILITY (WITHIN SEASON)								
All developed	Median	21.4	38.2	6.06	0.2	0.08	5.04	0.04
February	Max	21.5	38.6	6.14	0.3	0.17	9.19	0.37
Low	Min	21.2	38	5.88	0.1	0.01	0.78	0
	n	30	30	30	30	30	30	30
All developed	Median	22.2	38.5	6.45	0.1	0.04	4.75	0.06
February	Max	23.8	39	6.57	0.3	0.18	9.61	0.33
High	Min	21.5	37.8	6.26	0.0	0	0.25	0
	n	30	30	30	30	28	30	30

infer proximity to oceanic (deeper) water. There were no significant differences in water quality parameters based on distance from shore.

Thirty sediment samples were processed from both developed and undeveloped patch reef stations. Sediment composition did not vary significantly between developed and undeveloped reefs; for both areas the sediment adjacent to reefs was made up of mostly sand (0.5 mm fraction), ranging from 54–73% of sample. The smallest fraction from both areas was rubble (4.75 mm), ranging from 8–20%. Rubble was entirely made up of shell fragments. Nitrogen content of the sediments was similar between sites, ranging between 20–57% dry weight in the 60 samples.

Ecological Parameters.—More macroalgae species were found on developed patch reef stations (mean = 16.2 ± 5.6) compared to undeveloped patch reef stations (mean = 9.3 ± 1.7), but these differences were not significant ($t_{[10,.05]} = 0.088$). Significantly more stony corals species were found on developed patch reef stations (mean = 21.5 ± 1.2) compared to undeveloped patch reef stations (mean = 14.0 ± 2.9; $t_{[10,.05]} = 9.59$). There

Table 2. Continued.

		Temperature (°C)	Salinity (ppt)	Dissolved oxygen (mg L^{-1})	Turbidity (NTU)	Chl *a* (µg L^{-1})	Total N (µM)	Total P (µM)
All undeveloped	Median	21.2	39.1	6.4	1.4	0.30	3.6	0.06
February	Max	24	39.6	7.1	3.6	0.83	9.78	0.26
Low	Min	19	38.7	6.3	0	0.11	0.88	0
	n	40	40	40	40	29	30	30
All undeveloped	Median	21.7	39.2	6.3	0.4	0.12	3.31	0.04
February	Max	23.5	39.4	6.85	4.6	0.79	11.49	0.46
High	Min	19	38.9	5.91	0	0.01	0	0
	n	40	40	40	40	29	30	30
All developed	Median	30.4	40.5	5.22	0.0	0.09	6.45	0
October	Max	31.4	40.8	6.36	0.1	4.56	12.32	0.03
Low	Min	30.0	37.8	4.11	0.0	0.04	1.96	0
	n	35	35	35	35	29	28	28
All developed	Median	29.2	40.5	4.6	0.1	0.11	7.58	0
October	Max	29.8	40.9	5.3	0.4	0.13	13.83	0.17
High	Min	28.2	39.5	4.2	0.0	0.08	4.62	0
	n	35	35	35	35	29	30	30
All undeveloped	Median	29.8	39.6	4.6	0.0	0.09	6.57	0
October	Max	30.3	40.1	5.0	0.5	0.12	10.89	0.16
Low	Min	29.5	39.1	3.9	0.0	0.04	4.65	0
	n	45	45	45	45	30	23	23
All undeveloped	Median	30	39.5	4.7	0.0	0.08	7.14	0
October	Max	31.2	39.7	4.9	0.2	0.11	16.59	0.17
High	Min	29.4	39.3	4.6	0.0	0.04	3.24	0
	n	45	45	45	45	30	30	30

was no significant difference in the number of sponge species recorded on undeveloped and developed patch reefs (t$_{[10,.05]}$ = 0.818; Table 4).

Figure 3 illustrates the cluster analysis of presence-absence similarity values for benthic algae species, with a segregation of the developed vs. undeveloped patch reefs. Only 14 algae species were found on reefs from both sites. Macroalgae composition on the patch reef stations is variable from patch to patch, with the highest similarity between DEV3 and DEV4, with 52% of algae species shared.

More species of stony corals were found on the patch reefs in Montagu Bay, but the cluster analysis did not segregate the patch reefs by developed and undeveloped stations (Fig. 4). Patch reef stations that were clustered with macroalgal species composition were not clustered based on stony coral species present. Percent coral cover was significantly different between developed patch reef stations (mean = 17.8% ± 4.7) compared to undeveloped patch reef stations (mean = 24.2% ± 12.1; based on cm^2 m^{-2} coral cover t$_{[10,.05]}$ = 0.701). The percent of all coral colonies showing lesions was significantly higher for developed patch reef stations (mean = 30.3% ± 9.8) compared to undeveloped patch reef stations (mean = 16.2% ± 5.4; based on number of lesion colonies t$_{[10,.05]}$ = 0.481; Table 4).

The species composition of macroalgae was quite different between the developed and undeveloped reefs. Only 14 species out of 46 were found on both developed and

Table 3. Water quality parameters for 12 patch reefs at varying distance from islands in the central Bahamas. Stations are grouped by distance from shore. UNDEV1, UNDEV2, DEV1, and UNDEV4 were <500 m from shore, DEV2, UNDEV4, DEV3, and UNDEV5 were 650–900 m from shore. UNDEV6, DEV4, DEV5, and DEV6 were over 1000 m from shore. Water quality sampling was carried out over 2 wks in February 1998. Median, maximum, and minimum values (exclusive of outliers) are given for temperature, salinity, dissolved oxygen, turbidity, chlorophyll *a*, total nitrogen, and total phosphorus.

		Temp (°C)	Salinity (ppt)	Dissolved oxygen (mg L^{-1})	Turbidity (NTU)	Chl *a* (mg L^{-1})	Total N (μM)	Total P (μM)
Distance from shore								
All reefs within 500 m								
	Median	21.6	39.1	6.36	0.29	0.11	3.2	0.05
	Max	24	39.6	6.85	3.42	0.83	10.85	0.39
	Min	19	37.6	5.88	0.01	0.01	0	0
	n	77	77	77	54	39	40	40
Reefs 650–900 m								
	Median	21.4	38.9	6.38	0.23	0.06	5.19	0.06
	Max	22.6	39.4	7.14	4.62	0.37	9.78	0.46
	Min	19.6	36.2	6	0	0	0.88	0
	n	81	81	81	55	36	40	40
Reefs over 1,000 m								
	Median	22.1	39	6.39	0.19	0.08	3.65	0.05
	Max	23.8	39.6	6.85	3.77	0.79	11.49	0.33
	Min	19	38.1	5.92	0.01	0.02	0.25	0
	n	75	75	75	40	34	40	40

undeveloped reef stations. No species were found on all 12 patch reefs, though *Halimeda tuna* (Ellis and Solander) and *Amphiroa fragilissima* (Linnaeus) were found on all developed patch reefs (Table 5). Some alga species only found on developed reefs included *Schizothrix* spp., *Rhipocephalus phoenix* (Ellis and Solander), *Caulerpa cuppressoides* Agardh, *Dictyosphaeria cavernosa* (Forskaål), and *Galaxaura oblongata* (Ellis and Solander). Species found only on undeveloped patch reefs included *Microdictyon marinum* (Bory), *Turbinaria turbinata* Barton, and *Caulerpa ventricillata* Agardh. Stony coral species were much more widely distributed between developed and undeveloped reefs (Table 6). Some coral species were found on all 12 patch reefs: *Agaricia agaricites agaricites* (Linnaeus), *Porites porites porites* (Pallas), *Siderastrea radians* (Pallas), and *M. annularis*. Many species were only missing from one or two of the 12 reefs, and common in both areas: *Millepora alcicornis* Linnaeus, *Siderastrea siderea* (Ellis and Solander), *Porites asteroides* Lamarck, *Diploria labyrinthiformis* Linnaeus, *Favia fragum* (Esper), *Meandrina meandrites meandrites* Linnaeus, and *Montastraea cavernosa* Linnaeus.

The coral vitality surveys revealed the differences between patch reefs of developed and undeveloped islands. For *M. annularis,* most colonies in Montagu Bay had more lesions per colony (Fig. 5A) and covered a larger area of the colony. Most of the lesions were identified as algal overgrowth in Montagu Bay. In the Exumas, most of the lesions on *M. annularis* were classified as damage to tissue only (predation). The most common coral to both sites was *A. agaricites,* a lettuce coral. This coral species showed the greatest difference in number of lesions per colony between the two sites (Fig. 5B). The

Table 4. Summary of number of species, percent coral cover, and percent of all coral colonies with lesions from 12 patch reef sites in the central Bahamas. Species present were recorded from entire patch reef (ranging in size from 98–660 m^2). Coral cover and percent of all coral with lesions was evaluated from the measurement and inspection of coral colonies from 20, 1-m^2 permanent quadrats.

Site name	Station number	# of macro-algae species	# of stony coral species	# of sponge species	% coral cover	% of all coral colonies with lesions (n = sample size)	
Reefs adjacent to coastal development							
Lighthouse	DEV1	16	20	12	15.1	18.2	(n = 303)
Triplets	DEV2	23	21	14	23.4	38.0	(n = 332)
Midchannel	DEV3	22	23	18	23.1	25.8	(n = 299)
Wreck	DEV4	13	23	22	11.9	22.8	(n = 307)
Porgy Rocks 1	DEV5	15	21	12	18.6	44.4	(n = 178)
Porgy Rocks 2	DEV6	8	21	12	14.6	32.4	(n = 222)
Reefs adjacent to undeveloped islands							
Bell South	UNDEV1	10	12	20	24.9	10.5	(n = 429)
Big Eye	UNDEV2	6	13	14	26.3	17.3	(n = 510)
Hall's Pond	UNDEV3	9	16	14	22.3	12.8	(n = 450)
Emerald	UNDEV4	10	11	8	15.9	11.5	(n = 477)
Malabar	UNDEV5	11	13	14	10.1	23.7	(n = 312)
Channel Rocks	UNDEV6	10	19	24	45.5	21.1	(n = 360)

majority of the lesions recorded were bleaching of *Agaricia* coral on both developed and undeveloped patch reef stations**.** Lesions consisting of algal overgrowth, bleaching, fresh tissue damage, or predation and sediment damage accounted for up to 70% of the colony area for developed patch reef corals.

Image Analysis of Temporal Trends.—Over 52 yrs the housing density along the 10.5 km shoreline of Montagu Bay increased from 1.5 houses ha^{-1} in 1943 to 5.7 houses ha^{-1}. Aerial imagery showed 327 houses in 1943 compared to 1270 houses in the same

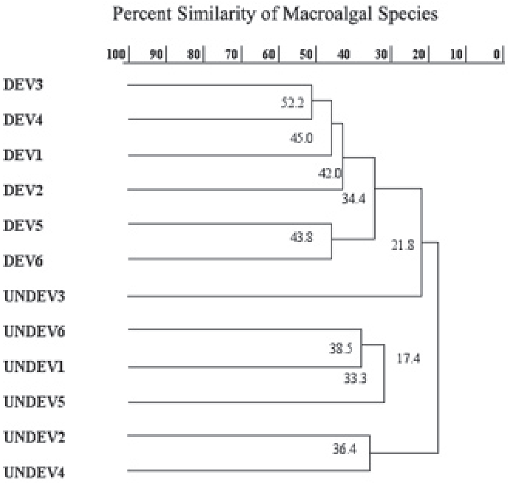

Figure 3. Cluster analysis (Q-mode) of presence-absence similarity values for benthic algae on six patch reefs in Montagu Bay and six patch reefs in the northern Exuma Cays, Bahamas. Values were calculated using the Jaccard coefficient and clustered using a group-average sorting strategy.

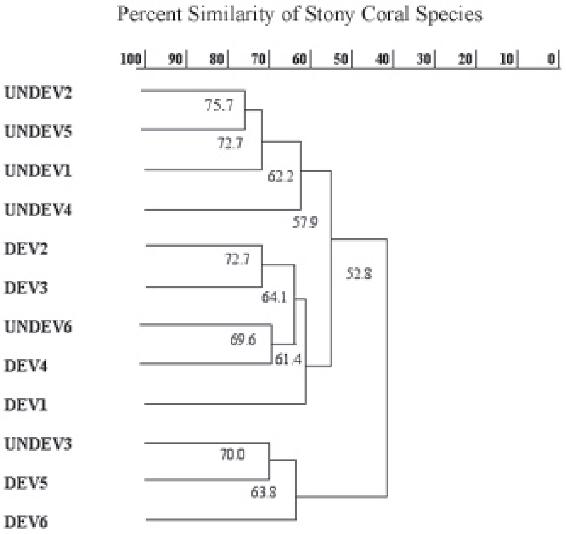

Figure 4. Cluster analysis (Q-mode) of presence-absence similarity values for stony corals on six patch reefs in Montagu Bay and six patch reefs in the northern Exuma Cays, Bahamas. Values were calculated using the Jaccard coefficient and clustered using a group-average sorting strategy.

area in 1995. All houses have onsite wastewater disposal with the exception of one package plant and injection well at a condominium complex. One hundred percent of the linear extent of the shoreline changed from 1943–1995; shoreline alterations came from dredging canals, filling of coastal wetlands, and seawall construction. Between 1943–1995, 2.9 ha of land were added on New Providence with the filling in of a mangrove wetland, and building the shoreline out with seawalls. Spatial change analysis showed 47% of the marine benthic habitats changed from 1943–1995 (Figs. 6,7). Changes were analyzed for major shifts in three habitat categories: 1) bare or algal-covered sand/mud bottom, 2) seagrass habitats, and 3) reefs and hard-bottom habitats. The area of mud or algal-covered bottom increased, while the area of seagrass and hard-bottom habitats decreased (Table 7). The number of patch reefs in the bay decreased from 214 to 133. The total number of seafloor polygons decreased overall within the 50-yr time span from 280 to 216 habitat units. Disturbed seagrass areas (with visible propeller scars, dumping and anchor damage) increased from 0.39 to 15.76 ha. In 1943, propeller scars were seen very close to docks and anchorages, but in 1995, scars impacted much of the shallow seagrass in the western areas of the bay. Dredged pits and spoil areas were not visible in 1943, but covered 0.33 ha in 1995. The tidal channel reef visible in 1943 aerial images, and documented with underwater photographs did not exist in 1995; much was cleared and physically removed for a navigation channel.

Seagrass areas showed the most extensive changes, with a 24.1% loss in area of dense seagrass habitats (Table 7). The entire bay lost coral habitat, both in the loss of patch reefs, and in the loss of coral and sponge dominated hard-bottom habitats (locally called "hard bar"). Along the southeastern extent of Montagu Bay, hard-bottom habitats changed from sponge-coral-octocoral co-dominated to algal-dominated.

An analysis of habitat change over 52 yrs illustrated some important trends in the Montagu Bay environment (Fig. 8). For each of the three categories, each polygon or habitat unit was examined to evaluate the nature of change over time. Polygons identified

Table 5. Macro-algae species checklist with species present on 12 patch reef stations in the central Bahamas. Six patch reefs were adjacent to developed coastlines, and six were adjacent to undeveloped coasts. Surveys were carried out in 1 hr.

Algae	DEV1	DEV2	DEV3	DEV4	DEV5	DEV6	UNDEV1	UNDEV2	UNDEV3	UNDEV4	UNDEV5	UNDEV6
Species	Lighthouse	Triplets	Midchannel	Wreck	Porgy 1	Porgy 2	Bell South	Big Eye	Hall's Pond	Emerald	Malabar	Channel Rock
CHLOROPHYTA												
Acetabularia calyculus		1										1
Acetabularia crenulata		1							1			
Anadyomene stellata					1							
Avrainvillea longicaulis		1										
Batophora oerstedii			1									
Caulerpa cupressoides		1	1	1								
Caulerpa racemosa											1	
Caulerpa taxifolia	1											
Caulerpa verticillata							1					
Derbesia sp.	1	1										
Dictyosphaeria cavernosa												
Dictyosphaeria cavernosa		1	1									
Halimeda goreauii	1	1	1	1	1							
Halimeda opuntia		1	1	1						1		
Halimeda tuna	1	1	1	1	1	1	1		1			
Microdictyon marinum							1	1		1	1	1
Penicillus capitatus	1		1	1								
Penicillus dumetosus		1										
Rhaphocephalus phoenix	1	1	1	1								
Udotea flabellum	1											
Valonia macrophysa	1		1		1					1		
Ventricaria ventricosa		1	1	1	1						1	

Table 5. Continued.

Algae	DEV1	DEV2	DEV3	DEV4	DEV5	DEV6	UNDEV1	UNDEV2	UNDEV3	UNDEV4	UNDEV5	UNDEV6
Species	Lighthouse	Triplets	Midchannel	Wreck	Porgy 1	Porgy 2	Bell South	Big Eye	Hall's Pond	Emerald	Malabar	Channel Rock
PHAEOPHYTA												
Dictyota humifusa	1		1	1	1	1	1		1			1
Dictyota cervicornis												
Dictyota dichotoma			1	1				1		1		
Dictyota divaricata			1				1	1			1	
Lobophora variegata		1	1		1	1	1	1		1	1	1
Padina sanctae-crucis		1	1		1		1			1	1	
Rosenvingea intricata							1					
Sargassum hystrix			1		1							
Sargassum polyceratium									1			
Sargassum pteropleuron										1		
Turbinaria tricostata			1									
Turbinaria turbinata								1		1		
RHODOPHYTA												
Amphiroa fragilissima	1	1	1	1	1	1			1	1	1	1
Amphiroa rigida					1	1						
Cladophoropsis macromeres	1		1				1				1	1
Coelothrix irregularis	1	1	1	1	1	1	1			1		1
Galaxaura oblongata					1							

Table 5. Continued.

Algae	DEV1	DEV2	DEV3	DEV4	DEV5	DEV6	UNDEV1	UNDEV2	UNDEV3	UNDEV4	UNDEV5	UNDEV6
Species	Lighthouse	Triplets	Midchannel	Wreck	Porgy 1	Porgy 2	Bell South	Big Eye	Hall's Pond	Emerald	Malabar	Channel Rock
Hydrolithon boergesenii		1							1			1
Kallymenia limminghii		1	1									
Laurencia intricata	1	1							1			1
Laurencia poitei		1			1				1			
Neogoniolithon spectabile	1	1		1		1						
Peysonnelia sp.								1				1
Titanoderma prototypum									1		1	
BLUE-GREEN ALGAE												
Szhizothrix spp.	1	1	1	1	1	1						
SEAGRASSES												
Thalassia testudinium	1	1									1	
Syringodium filiforme											1	
TOTAL SPECIES	16	23	22	13	15	8	10	6	9	10	11	10

Table 6. Stony coral species checklist with species present on 12 patch reef stations in the central Bahamas. Six patch reefs were adjacent to developed coastlines, and six were adjacent to undeveloped coasts. Surveys were carried out in 1 hr.

	DEV1	DEV2	DEV3	DEV4	DEV5	DEV6
Species list	Lighthouse	Triplets	Midchannel	Wreck	Porgy 1	Porgy 2
STONY CORALS						
Acropora cervicornis						1
Agaricia agaricites	1	1	1	1	1	1
Agaricia fragilis			1			
Bartholomea annulata	1	1		1	1	1
Colpophyllia natans		1	1			1
Condylactis gigantea	1	1	1			1
Dichocoenia stokesi	1	1	1	1	1	
Diploria clivosa		1	1	1	1	1
Diploria labyrinthiformis	1	1	1	1	1	1
Diploria strigosa						
Discosoma sanctithomae	1	1		1	1	1
Eusmilia fastigata	1	1	1	1	1	1
Favia fragum	1	1	1	1		1
Isophyllastrea rigida						
Isophyllia sinuosa	1	1	1	1		
Lebrunia danae		1	1	1	1	1
Leptoseris cucullata	1				1	
Madracis formosa				1	1	1
Madracis mirabilis						
Manicina areolata	1	1	1	1		
Meandrina meandrites						
Millepora alcicornis	1	1	1	1	1	1
Millepora complanata	1		1		1	
Montastraea annularis	1	1	1	1	1	1
Montastraea cavernosa	1		1	1	1	
Mussa angulosa				1	1	
Mycetophyllia danaana	1		1	1		
Mycetophyllia ferox					1	1
Mycetophyllia lamarckiana			1	1		
Porites astreoides	1	1	1	1	1	1
Porites branneri						
Porites porites	1	1	1	1	1	1
Scolymia lacera		1	1		1	1
Siderastrea radians	1	1	1	1	1	1
Siderastrea siderea		1	1	1	1	1
Stephanocoenia intersepta	1	1		1		1
Total species	20	21	23	23	21	21
CORALLIMORPHS / AHERMATYPES / ANTIPATHARIANS						
Palythoa caribaeorum			1			
Ricordea florida		1	1	1		
Total species	0	1	2	1	0	0

Table 6. Contiued.

Species list	UNDEV1 Bell South	UNDEV2 Big Eye	UNDEV3 Hall's pond	UNDEV4 Emerald	UNDEV5 Malabar	UNDEV6 Channel Rock
STONY CORALS						
Acropora cervicornis						
Agaricia agaricites	1	1	1	1	1	1
Agaricia fragilis						
Bartholomea annulata						
Colpophyllia natans				1		
Condylactis gigantea						
Dichocoenia stokesi				1		1
Diploria clivosa		1	1		1	1
Diploria labyrinthiformis	1	1	1		1	1
Diploria strigosa						
Discosoma sanctithomae						
Eusmilia fastigata	1	1	1			1
Favia fragum	1	1	1	1	1	1
Isophyllastrea rigida						1
Isophyllia sinuosa						
Lebrunia danae						
Leptoseris cucullata						
Madracis formosa			1			
Madracis mirabilis						1
Manicina areolata	1	1		1	1	1
Meandrina meandrites			1			1
Millepora alcicornis	1	1	1		1	1
Millepora complanata			1			
Montastraea annularis	1	1	1	1	1	1
Montastraea cavernosa	1	1	1	1	1	1
Mussa angulosa						1
Mycetophyllia danaana						
Mycetophyllia ferox			1			
Mycetophyllia lamarckiana						
Porites astreoides		1	1	1	1	1
Porites branneri	1					
Porites porites	1	1	1	1	1	1
Scolymia lacera						
Siderastrea radians	1	1	1	1	1	1
Siderastrea siderea	1	1	1	1	1	1
Stephanocoenia intersepta					1	1
Total species	12	13	16	11	13	19
CORALLIMORPHS / AHERMATYPES / ANTIPATHARIANS						
Palythoa caribaeorum						
Ricordea florida						
Total species	0	0	0	0	0	0

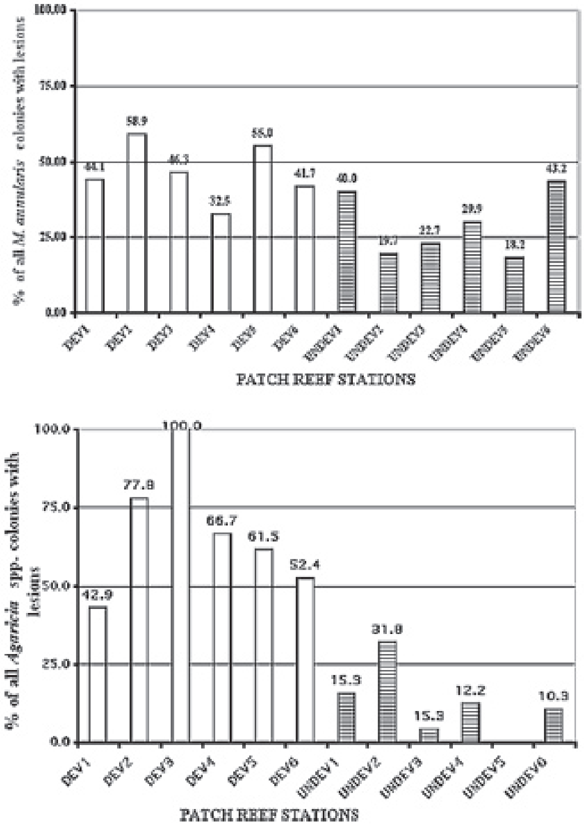

Figure 5. (A) Mean number of lesions per colony on *Montastraea annularis* on the six developed patch reef stations and six undeveloped patch reefs in the central Bahamas (B) Mean number of lesions per colony for *Agaria agaricites* on same six developed patch reef stations and six undeveloped patch reef stations in the central Bahamas.

in aerial imagery are shown in Figures 6 and 7, and these habitat units vary in size. In addition to looking at area percent change, the change analysis of habitat units indicates how benthic habitats have changed over time. For the bare sand/mud or algal-bottom habitats, 57% of the polygons changed to land or dredge spoils, 9% remained within this category, and 33% changed to seagrass habitats. For all seagrass habitats, 12% of the polygons changed to land or dredge spoils, 12% changed to bare sand/mud or algal bottom habitats, 38% remained seagrass habitats, and 38% changed to hard-bottom habitats. For reefal and hard-bottom habitats, 10% changed to bare mud/sand or algal bottom habitats, 63% changed to seagrass habitats, and only 25% remained hard-bottom habitats. For patch reefs that changed to seagrass communities, these areas were observed to be rubble-strewn seagrass beds with scattered coral heads; patch reefs were either buried in sand, or physically broken up as navigation hazards. Most changes occurred in the western half (inner half) of the bay, with high conservation of reefs and benthic habitats in the eastern (outer half) of the bay.

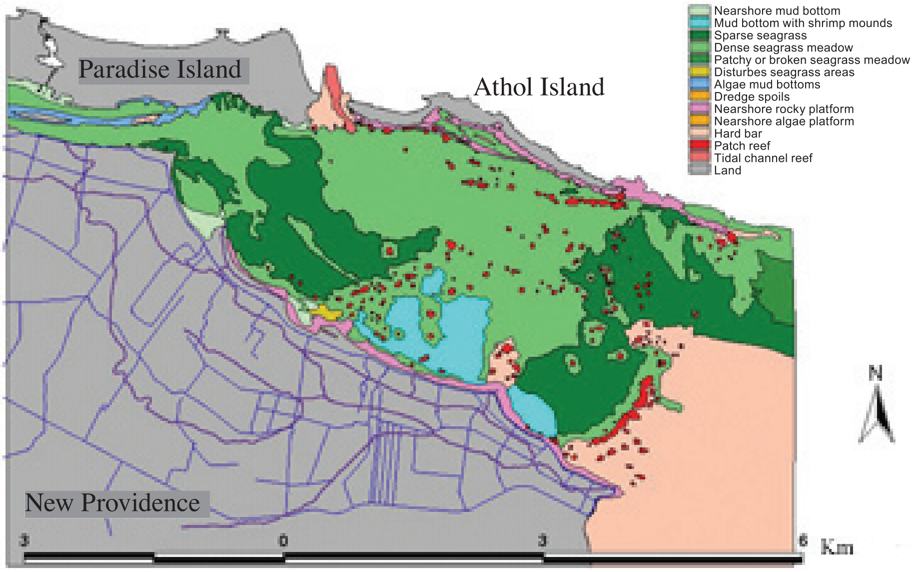

Figure 6. Map of the distribution of marine benthic habitats in Montagu Bay based on 1943 aerial photography used in the image analysis of temporal trends.

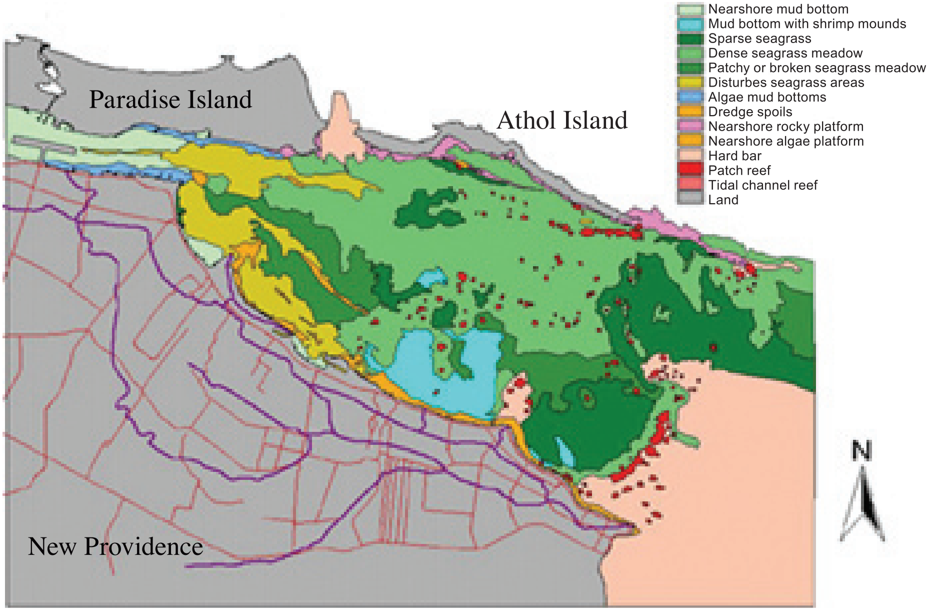

Figure 7. Map of the distribution of marine benthic habitats in Montagu Bay based on 1995 aerial photography and ground-truthing used in the image analysis of temporal trends.

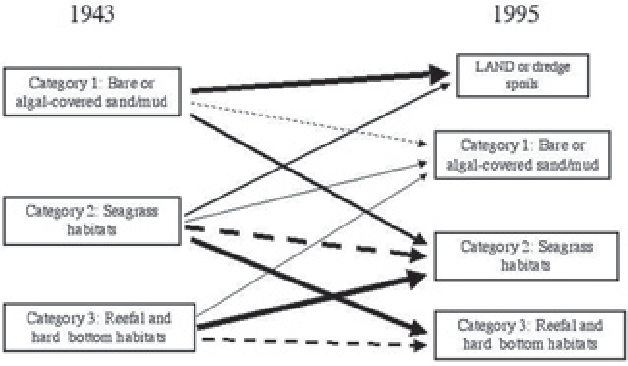

Figure 8. Change in benthic habitats of a tropical marine bay adjacent to a heavily developed island (Montagu Bay). 280 benthic habitat polygons from image analysis of 1943 were categorized based on changes mapped from 1995 aerial imagery. Three broad habitat categories were used: bare and algal-covered sand/mud; seagrass habitats; or reef and hard-bottom habitats. Lines indicate the direction and magnitude of change over the 52 yrs. Most sand/mud habitats were converted to land; most seagrass habitats were converted to hard bottom; and most reef habitats were converted to seagrass. Dashed lines indicate changes within the same habitat category.

Discussion

The results initially looked somewhat surprising. How could patch reefs adjacent to a densely populated island be so similar in water quality conditions and ecological character to patch reefs off undeveloped islands? Paul et al. (1995) documented the ease at which fecal bacteria can move from cesspits in the Florida Keys to nearshore waters and canals. Onsite sewage disposal on carbonate islands contributes nutrients, organic material and pathogens to nearshore waters (U.S. EPA 1983, 1991). Nutrient loading would appear to be significant to developed patch reef stations based on coastal housing density. Where do nutrients go? Ecological phase shifts that are catalyzed by human activities are complex and are manifested in abrupt changes triggered by catastrophic events such as the impacts of Hurricane Gilbert on Jamaican reefs as described by Hughes (1984). Although the phase shifts on reefs represent profound ecological change, it is often difficult to identify the early indicators of this shift or the contribution of causal mechanisms (e.g., trophic shifts, algal overgrowth).

The results suggest two things. First, spatial comparisons made between patch reefs adjacent to developed and undeveloped islands should be valid and appropriate as reference sites. The patterns of variability in water quality parameters between sites were not significantly different, and showed strong seasonal changes. Without undeveloped shorelines, it will be difficult to assess the changes from chronic eutrophication, or to begin to develop ecological criteria for coastal restoration and mitigation programs. The patch reefs, though variable in coral cover and diversity, appear to be good sampling units, and provide valuable comparisons. Marine parks have been reviewed for their importance as marine fisheries reserves (PDT, 1990; Bahamas park, Chiappone and Sullivan Sealey, 2000), but an even more critical role may be for marine parks as comparison sites to understand changes in coastal ecology. Simple water quality sampling programs can help determine the control sites that have a similar range and variability on environmental parameters.

In the central Bahamas, only the Exuma Cays Land and Sea Park has large islands and is sufficiently isolated to utilize its reefs for comparisons to Nassau.

Secondly, there may be no single parameter or single taxa group that can characterize the shifting mosaic of a coral reef, but stony corals remain critical to reef identity both in the status of individual colonies, and the status of coral habitats (Brown and Howard, 1985; Wittenburg and Hunte, 1992). The value of historical changes to reefs and coral habitats is essential in the evaluation of current condition and trends. Montagu Bay appeared in 1943 as an incredible coral environment, with over 200 patch reefs, and large areas of hard-bottom coral habitats. In light of the historical loss of coral habitat, the lower coral coverage today on developed patch reef stations becomes more significant. There are fewer coral colonies, less coral habitat, and smaller populations of coral now in Montagu Bay than in 1943. These changes may not be linked to nutrient enrichment from cesspits alone, but also to a combination of sediment movement and coastal zone alterations associated with construction and development of the island. The increasing density of houses on or near the coastline introduces two ubiquitous stresses on patch reef systems: 1) chronic eutrophication from "soak-away" onsite sewage disposal systems, and 2) the loss of native coastal vegetation and wetland buffers to limit sediments and nutrients from run-off. The indirect impact of chronic nutrient enrichment on a variety of coral reef organisms has been documented (Pastorak and Bilyard, 1985; Birkeland, 1988), but the ecology of eutrophication is not clear. Coral mortality is likely due to a variety of causes, not only the stimulation of algal growth (McCook et al., 2001).

The central Bahamas is unique in its shallow-water banks system, and the oceanographic dynamics at the bank margins. Patch reefs often develop in channels adjacent to the platform margin, and experience strong tidal circulation (Sealey, 1994). Circulation around the islands has been a key focus in fisheries recruitment studies (Ray and Stoner, 1995) and may be a key variable in maintaining good water quality for nearshore reefs, despite development. The absolute nutrient load combined with the coastal circulation determines the severity and extent of nutrification. Restricted embayments are more sensitive to nutrient loading or chronic eutrophication (U.S. EPA, 1991). The effects of coastal eutrophication have been well documented in the tropics, such as the Great Barrier Reef (Bell, 1992; Bell and Elmetri, 1995); Hawaii (Smith et al., 1981; Laws and Redalje, 1982; Maragos et al., 1985); Barbados (Tomascik and Sander, 1985, 1987a,b; Hunte and Wittenburg, 1992); and the Florida Keys (Tomasko and Lapointe, 1991; Lapointe et al., 1994). Strong circulation around islands at the platform margin of the Bahamas suggests a higher tolerance to eutrophication and less obvious indications of change.

Taken as a single assessment, the differences between developed and undeveloped patch reef stations are not striking. Macroalgae species present were different between reefs, but not linked to proximity to development (Fig. 3). The most similar patch reefs (DEV1, DEV2, DEV3, and DEV4) share calcareous green algal species, and differ in species of frondose red and brown algae (e.g., *Laurencia* spp. and *Dictyota* spp.). Undeveloped patch reef stations had fewer algal species, and especially fewer calcareous green algae (e.g., *Halimeda* spp., *Udotea* spp., *Penicillus* spp.). On the developed patch reefs more pockets of sand and sediment accumulated, appropriate for the growth of these green calcareous species (more typically found in seagrass beds, or sparsely vegetated sand bottom communities of the central Bahamas). The three least similar patch reefs in macroalgae species present (UNDEV3, DEV5, and DEV6) were reefs closest to the platform margin, and were the least protected of all 12 patch reefs stations. These same three patch reefs formed a separate cluster for stony coral species present (Fig. 4).

Stony coral species presence did not segregate developed from undeveloped patch reef stations, nor did the reefs segregate by size or distance from shore (with the exception of the three previously mentioned).

The visual differences between developed and undeveloped patch reefs are attributed to algae coverage. Reefs adjacent to developed shorelines had a distinctly "fuzzy" appearance. Developed patch reef stations not only supported more calcareous green algae but also species such as *Schizothrix* spp., C. *cupressoides*, *D. cavernosa*, *B. oerstedii*, and *K. limminghii (*found only on developed patch reef stations). More brown algae species were found on undeveloped patch reefs, especially rooted *Sargasum* species. These algal species differences are not an indication of eutrophication. Eutrophication represents the combination of nutrient enrichment, increased sedimentation, and introduction of toxins due to human activity (Pastorak and Bilyard, 1985; Tomascik and Sander, 1985; Rogers, 1990). A higher percentage of lesions for all coral colonies is interpreted as a higher likelihood for loss of coral cover (Hallock and Schlager, 1986; Porter and Meier, 1992). Coral cover remains one of the most commonly evaluated ecological parameters on reefs, yet is at best only an indirect indicator of algal overgrowth and eutrophication (Grigg 1995; McCook et. al., 2001).

Water quality parameters were not different between developed and undeveloped patch reef stations, suggesting that these two areas are very similar environments. Seasonal variability of patch reefs is perhaps the most troublesome. Measurements were made in October, typically a hot wet month, and February, typically a cool dry month. Most consistent in the seasonal trends were temperature records: the median temperatures for October and February 1998 differed by 9°C. Rainfall, in contrast to temperature, was highly variable across the central Bahamas from location to location, and from year to year. Rainfall for the central Bahamas overall was below average for 1998, but there were heavy rains in February, 1998 (13.2 cm total rainfall for the February 1998 compared to 2.4 cm in 1997; Sealey, 1999). Seasonal changes in temperature and rainfall impact surface water salinity. Salinity can be high (40.5 median salinity for October) on the shallow banks of the Bahamas when evaporation is high. The greater variation and slightly lower salinity values during February were the result of low temperatures (low evaporation) and high rainfall.

Large storms such as cold fronts or hurricanes may impact the undeveloped and developed patch reef stations in a similar manner, but with a 128 km distance between these stations, rainfall variability is likely the greatest environmental difference. In any monitoring effort between developed and undeveloped patch reef stations, meteorological records of air temperature and rainfall would be very important components for comparing stations.

Nutrient levels measured on nearshore patch reefs in the central Bahamas are lower than TN and TP recorded for nearshore middle and lower Florida Keys, stations in the water quality monitoring program of the Florida Keys National Marine Sanctuary (Jones and Boyer, 2002). Nearshore Florida Keys surface water stations have a median TN of 13.35 μM, and a maximum value of 85.88 μM (n = 478). This is twice as high as recorded in this study and represents quarterly sampling events. TP was also higher, with a median value of 0.020 μM, and a maximum of 0.62 μM (n = 478). In the central Bahamas, TN was higher in October than in February, but TP was higher in February. These results suggest that the Bahamas should be characterized as extremely oligotrophic (LaPointe et al., 1994) and water column nutrients are therefore poor indicators of chronic eutrophication.

Sediment plays an important role in the reef community by trapping organic materials (such as detritus) and releasing nutrients. Smaller sediment particles will be able to trap more nutrients, and possibly become anoxic. Where there had been dredging, very small sediment particles (0.125 mm) dominated the sediment samples. This was not the case for in situ sediment adjacent to the developed patch reef stations. Sediment movement buried small patch reefs in the inner reaches of Montagu Bay, but existing patch reefs did not show elevated sediment nutrients or reduced grain size.

Most of the change over 52 yrs was the loss of small patch reefs from sedimentation; and the physical removal of material during coastal development projects. The physical restructuring of the shoreline and sea floor had a large impact on the Montagu Bay environment. Major changes in sedimentation occurred as a result of jetty construction and beach erosion. Analysis of temporal changes to nearshore patch reefs indicates a major impact of sedimentation and movement of sediments associated with construction projects (Fig. 8). Historical aerial photographs show that the major erosion and sedimentation events occurred with major construction projects in and near Montagu Bay from 1961 to the present. The physical restructuring of the shoreline was massive – 100% of the shoreline along Montagu Bay from 1943–1995 was altered. The physical loss and change of habitats, particularly seagrass and reef habitats, can have a profound impact on coral populations, as well as the ecological function and fisheries production of the bay as a whole (Eggleston, 1995; Sluka et al., 1996). Image analysis for temporal trends in nearshore patch reefs is a critical procedure for in understanding long-term function of individual patch reef monitoring stations.

ACKNOWLEDGMENTS

The following people are gratefully acknowledged for their assistance: M. Chiappone, E. Schmitt, J. Kelly, A. Lowe, K. Pronzati, and T. Hollis (field work); N. Sealey (boat support and editing); R. Wright, and T. Benham (GIS support); A. Szmant (chlorophyll and sediment sample analyses); R. Lightbourne, Capt. W. Munro, and P. Balfe (historical photograph and interviews), and Department of Archives, Nassau, Bahamas. Funding for the fieldwork was provided by the U.S. Environmental Protection Agency (X825122-01-0), Jeniam Foundation, the Nature Conservancy, and University of Miami. Permission to conduct research was granted by the Bahamas National Trust and Department of Fisheries, Government of The Bahamas. This paper is funded in part by a grant from the Caribbean Marine Research Center (CMRC Project #CMRC-00-1XNR-03-01A) National Oceanic and Atmospheric Administration (NOAA) Undersea Research Program, US Environmental Protection Agency, and Environmental Defense. Views expressed herein are those of the author and do not necessarily reflect the views of CMRC, or any supporting agencies.

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