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Coastal impact ranking of small islands for conservation, restoration and tourism development: A case study of The Bahamas

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ABSTRACT

An 11-year project to characterize, then assess, the health of coastal environments of The Bahamas ranked a total of 238 sites on ten different islands. Satellite images and aerial photography were used to characterize coastal types (e.g. substrate, geomorphology and wave energy to describe beaches, mangroves, or rocky shores), and then field assessments ranked four types of anthropogenic impacts that influence ecosystem function and coastal system services. The ranking of coastal health was based on physical alterations, destructive use of the coastal zone, coastal development and occurrence of Invasive Alien Species (IAS). The characterization and assessment methods were developed to serve as a rapid survey of coastal stability, biological diversity and quality of wildlife habitats. A system of coastal ranking is presented using numerical scores for four impact criteria along with terrestrial plant surveys to examine the intactness of the coastal environment. Some locations (Exuma and Great Guana Cay) were repeatedly monitored over time. Scores ranged from "0" for no human impacts or invasive coastal plants to "20" for highly altered with dredging, coastal development and loss of native vegetation. The mean impact rank for all sites across all islands was 5.7 ± 4.3, which indicates "Medium" ranks for at least two of the four human impact criteria. Only one uninhabited island (Cay Sal) had all coastal impacts scores of "None". Over 77% of all the sites surveyed had abundant occurrences of Invasive Alien Species (IAS) coastal plants. The Australian Pine (*Casuarina equisetifolia*) was the more pervasive and the most widespread IAS in the coastal environment, and its abundance increased in all sites that were re-surveyed over time. Degradation of coastal function can signal greater risks to coastal property, flooding events or loss of wildlife populations. The coastal impact ranking protocol presented here helps identify target areas for conservation as well as identify areas with the greatest feasibility for coastal restoration.

1. Introduction

Islands are, by their nature, only pieces of a larger whole. Ecologists have come to understand the nature of islands by their isolation, size, and susceptibility to large-scale disturbances. Islands are often studied as groups or archipelagos for biogeographic studies, but national boundaries usually limit studies of development impacts to local scales. The past two decades have produced important research on island ecology in the tropical Atlantic that illustrates the integration of ecological function across land-sea boundaries, and the connectivity between islands (Barbier et al., 2011; Kemp and Boynton, 2012). Coastal processes across the land-sea interface control sediment, nutrients and run-off characteristics, particularly in hot, dry climates with few surface water resources (Ray and McCormick-Ray, 2004). Physical alterations to the shoreline or changes in coastal land use will impact coastal processes, especially altering adjacent marine communities (Sealey, 2004). The loss of biological diversity, erosion of beaches and loss of mangrove areas can impact ecosystem function, particularly shoreline stabilization (see summary in Nagelkerken, 2009).

Humans receive valuable ecosystem services from coastal and estuarine ecosystems, including shoreline stabilization, protection of property, fisheries production and supporting biological diversity, but these services are lost with over-exploitation of coastal resources and loss of habitat (Jackson et al., 2001). Coastal ecologists are paying greater attention to both the role of native plants in maintaining coastal ecosystem stability (McGlathery et al., 2007), and to ecosystem service damage resulting from human

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disturbance, particularly through the introduction of Invasive Alien Species (IAS) (Gedan et al., 2011). Threat of eutrophication may be especially insidious in oligotrophic tropical islands, where very small thresholds of nutrient enrichments may cause "phase shifts" or irreversible ecological changes to near shore reefs (See discussions by Aronson et al., 2003; Hughes, 1994; Fabricius, 2005; and Lapointe et al., 2004. Nowhere may these land-sea nutrient fluxes and ecosystem services be more important that in the extreme oligotrophic environments of the Bahamian archipelago (see Buchan, 2000, for ecosystem overview).

In The Bahamas, the characteristic turquoise, clear waters and oligotrophic conditions are maintained by intact coastal plant communities, the absence of surface water discharge, as well as the limited and episodic nutrient input to near shore marine communities (Sealey, 2006; Buchan, 2000). The structure of the carbonate limestone banks with small islands and cays aligns much of the reefal habitat in close proximity to islands. The relationship between biological production (ecosystem function) and diversity has become a central focus of ecosystem management (see review by Loreau et al., 2001).

Changes in coastal environments have not been systematically tracked and documented, and human alterations to the coast are rarely limited to a single activity. The coastal development impacts on near shore marine habitats only amplify the barriers to successful reproduction, recruitment and growth of coastal species, including corals, invertebrates and fishes. How can these changes in the landscape ecology of coastal environments, including species extirpation, habitat loss and fundamental shifts in nutrient dynamics with water quality change be tracked and characterized?

The aim of this study was to determine the comparative "intactness" or a proxy for community stability based on a ranking system of coastal environments over numerous islands ranging from very low to high population densities. The survey was motivated by two questions; first, what was happening to the coastal resources throughout the country outside of national parks and protected areas? Second, how do coastal developments and alterations affect coastal plant diversity? Patterns of coastal use and degradation were determined from a combination of coastal plant surveys and an impact ranking system designed to rapidly identify key areas appropriate for coastal protection, restoration, remediation, or continued monitoring for land-based sources of pollution.

2. Materials and methods

2.1. Bahamian islands study sites and Reference Conditions

In order to gain an overview of the state of the coastal environment and develop a protocol to uniformly assess human impacts, 238 sites at 11 islands of varying size and population density were visited between 2002 through 2012 (Table 1). LandSat images using coastal classification guidelines (Cowardin et al., 1979; CMECS, 2012) were employed to develop a stratified random sampling allocation scheme which incorporated all coastal types (beaches, mangroves and rocky shore) with road access. Topographic maps (produced by the Department of Lands and Surveys, Government of The Bahamas (DLS)) were used in the field; these sectional maps were based on United Kingdom Overseas Survey Department photography taken between 1967 and 1972. Historical aerial photographs were obtained from DLS and private collections from 1972 for selected areas of Andros and Great Guana Cay, Abaco, and 1942 aerial photographs were available for Great Exuma. Google Earth Pro was used to view historical imagery of islands from 1990 to present to verify that historical alterations to the coastal environs were dated as occurring after a known dated imagery. This survey also did not include the large ports in Nassau, New Providence and Freeport, Grand Bahama.

Because the historical use of coastal resources is often poorly known, a coastal impact ranking system was used to develop the criteria for determining "Reference Condition" as defined by wetland and stream ecologists (Stoddard et al., 2006). Surveys consisted of two parts: 1) Classification of the coastal environment, and 2.) Coastal ranking and assessment.

2.2. Classification of coastal environments

Classification of a coastal survey site included 1.) a description of coastal habitat classification, 2.) documentation of the visible coastal zonation from the waterline to upland vegetation, and 3.) a survey of coastal plants using a standard checklist along a transect of the coastal environment.

Coastal environments were described in terms of sediment type, and wave and wind energy using existing definitions and terminology (Table 2). The classification included a description of coastal vegetation using existing plant community and coastal wetland

Table 1
Overview of the islands surveyed in the Bahamian archipelago. 11 islands were surveyed, varying in area, history and population density.

Island	Area (square kilometers)	Population (2010)	Communities and history	Years surveyed in this study
North Andros	4700	6267	Many small communities, heavy reliance on fishing and farming; Several US Navy Military Installations along the coast	1
South Andros	1257	1119	Many small communities, heavy reliance on fishing	1
Cat Island	388	1503	Many communities and several small resorts. This island has lost population since 1960.	1
Eleuthera – South	518	2711	Nearby communities include Deep Creek, failed resort development, Rock Sound is nearest airport	1
Eleuthera – Windermere	8	320	Resort residential community near the community of Palmetto Point and Governor's Harbour	1
Abacos – Great Guana Cay	14	472	Great Guana Cay settlement and three large private home developments	5
Exuma	264	7314	George Town as first capital of the Bahamas, many settlements, resorts and private vacation homes	7
Inagua	1544	911	Site of largest modern solar salt production (Morton) and Mathew Town. Active settlement for 285 years	2
Long Island	448	3024	Resort, farming and formerly used for salt production. Includes Deadman's Cay and Clarence Town	1
New Providence	210	248 948	Most populous island, Capital city of Nassau, largest harbour. Population center of the country, with limited public access to coast	1
Cay Sal Cay	4	0	Un-inhabited	1

Table 2
Matrix illustrating the basic classification of coastal environments of the Bahamian archipelago based on sediment type and wave energy. The location of an island on the carbonate bank system can determine wind and wave energy conditions along the shoreline.

Wave energy (right) Sediment type (below)	High and Medium energy shoreline	Low energy shoreline
Rocky shores consolidated carbonate sediments	**HIGH relief rocky shores and cliffs** Cliffs along the ocean side of islands. Eleuthera, Long Island, and Cat Island are best examples	**LOW relief rocky shores** "Iron shore" or rocky shores along relatively protected coasts. Much of the developed shore of New Providence was once low-relief rocky shores.
Soft sediment shores sand or muds	**Beaches and their associated dunes** Beaches and beach strand communities can be shrub-dominated, or herb-dominated with varying widths and heights of dune systems. Often beach strand shorelines have low-lying wetlands just inland of the dunes.	**Coastal wetlands and mangrove areas** Most islands have mangrove wetlands along low-energy (bank) coasts. Mangroves can be both coastal and inland, associated with creeks, saline ponds or blue holes.

classifications for the insular Caribbean (Areces- Mallea et al., 1999; Cowardin et al., 1979). Terms and descriptions of coastal geology and rock formation were based on the unique carbonate geology of the Bahamas bank system (Carew et al., 1994) and standard coastal classification nomenclature (CMECS, 2012).

Shorelines were characterized as "rocky" with consolidated limestones, "beaches" with mobile, unconsolidated limestone, and "mangroves" indicating low energy with the depositing of fine muds or unconsolidated sands with emergent halophytes (mangroves). Some beaches included exposed beach rock or small rocky tombolo, but the classification of the shorelines considered the larger scale characteristics (over 1 km) of the coastal environment as dominated by rocky shores and cliff or dominated by beaches (see distribution of coastal types in Table 3A).

The prevailing winds in The Bahamas are from the east (southeast in the northern Bahamas, and east-northeast in the southern Bahamas); thus low-energy coastal environments include the western shorelines of islands protected from prevailing winds, and sheltered by large areas of the shallow banks. Low-energy coasts can also occur in protected lagoons, bays or mangrove creeks anywhere on an island. Medium energy shorelines occur along the north or eastern shores of islands, with some protection from offshore reef crests or cays. High-energy coastal environments are mainly narrow bands along the platform margin of banks with precipitous walls at the platform margin, and steep cliffs or rocky headlands (Bird, 2000). A checklist was used to record the zones along a coastal transect from the waterline to upland communities (or human development); the zones were identified as beach face, beach pioneer zone, sparse mangroves (<60% aerial coverage); dense mangroves (>60% canopy coverage), fore dune, back dune, rocky platform, swale or ephemeral wetland, cliff, inter-dune area, coastal coppice, coastal ridge or human-altered landscapes (including roads). The Caribbean vegetation classification (Areces-Mallea et al., 1999) is hierarchical, and provides simple guidelines for designation of vegetation structure by height and canopy cover. The coastal vegetation communities can be identified to the formation level with assessment of vegetation structure and type, and the identification of dominant plant species. A standard check-list of coastal plants was developed using *The Flora of the Bahamian Archipelago* (Correll and Correll, 1982). Plants were surveyed along a transect approximately 100 m along the shore, with a second transect established inland a minimum of 50 m, but up to 170 m until roads, upland dry evergreen formation, back dune, or swale was reached. Coastal transects varied in length with coastal geomorphology (Cambers, 1998) to survey up to sufficient elevation or distance outside of a defined "coastal zone" used in recommended setbacks. Plant species were recorded by examining grasses, herbs, vines, shrubs and trees within 5 m of the transect line, and the

Table 3
Summary of all coastal types (A) and coastal rankings (B) by island. The table shows the distribution of sites by coastal type and overall ranking. A total of 238 surveys were completed at 229 sites over 10 years from 2002–2011; this includes repeated visits to survey sites on Great Exuma, and Guana Cay, Abaco. 12% of the sites were ranked with "None", or no anthropogenic coastal impacts; 23.5% ranked as "Low"; 33% ranked as "Medium"; 22% ranked as "High"; and 9.5% of the sites ranked as "Severe" in coastal impacts.

		North Andros	South Andros	Cat island	Eleuthera – South	Eleuthera – Windermere	Abacos, Great Guana Cay	Exuma	Inagua	Long island	New Providence	Cay Sal bank	Total
A. Distribution of survey sites by coastal type and island.													
Number of Survey Sites		50	16	11	33	6	16	38	25	33	7	3	238
Coastal type	Beach	26	8	8	19	4	8	13	15	15	3	1	120
	Rocky shore	21	6	3	12	0	8	21	10	16	4	2	103
	Mangrove	3	2	0	2	2	0	4	0	2	0	0	15

		North Andros	South Andros	Cat island	Eleuthera – South	Eleuthera – Windermere	Abacos, Great Guana Cay	Exuma	Inagua	Long island	New Providence	Cay Sal bank	Total	Percent OF total
B. Distribution of survey sites by coastal rank and island.														
Number of survey sites		50	16	11	33	6	16	38	25	33	7	3	238	
Ranking	None	11	0	0	13	0	0	0	2	0	1	1	28	11.7%
	Low	11	0	3	5	2	8	9	5	11	0	2	56	23.5%
	Medium	17	3	8	8	3	5	6	12	14	3	0	79	33.2%
	High	10	10	0	3	1	3	10	6	8	1	0	52	21.8%
	Severe	1	3	0	4	0	0	13	0	0	2	0	23	9.7%

occurrence of each species along the transect was identified within vegetation zones (e.g. fore dune or pioneer zone as listed above). Overall abundance of plants were assessed by areal coverage (Occasional < 10% coverage; Common = 10–70% coverage; and Abundant > 70% coverage).

Along each transect, vegetation zones encountered were further documented with site photos. Periodic voucher plant specimens were collected (pressed) and returned to the lab for identification, and collected specimens reside at Fairchild Tropical Garden (Miami, Florida, USA) Bahamas collection. The developed checklist is not a comprehensive inventory, but a list of 171 species that are known to characterize the coastal environment or indicate the maturity of regrowth of coastal plant communities. The plant species list was developed with assistance from the Institute of Regional Conservation (Miami, FL, USA).

2.3. Rapid assessment and ranking of anthropogenic impacts on coastal environments

After classification by field surveys, a review of historical aerial photographs was conducted. Human impacts were evaluated and ranked using four criteria: 1) Physical restructuring (i.e. cutting through) of the shoreline by dredging canals and marinas, or reclaimed seabed and filled areas; 2) Destructive use of the coastal environment with vegetation loss from sand mining or dumpsites; 3) Coastal development and vegetation replacement, and 4) Volunteer invasion of alien plants from seed dispersal mechanisms (Harvey and Woodroffe, 2008). For all of the ranking criteria, impact categories of none, low, medium, high, and severe corresponded to alteration percentages of 0–1%, 2–10%, 11–50%, 51–70%, and greater than 70%, respectively. All four criteria were evaluated with scores from 0 (no impacts) to 4 (severe impacts). The overall score of human impacts to the coastal environment is a compilation of these four separate parameters with extra weight given to physical alterations (this score was doubled), giving a maximum score of 20. Physical alterations such as dredging or marina constructions were considered the most destructive to island hydrology and most expensive impact category to restore or mitigate.

The final ranking score for any given site could range from 0 (no impacts)–20 (severe impacts in each of the four criteria including a doubling the score for the first criteria, *Physical Restructuring*). Physical restructuring of the shoreline (e.g. dredging, filling, marine or canal construction) would represent the greatest challenge in terms of cost and resources to restore or mitigate. Often, aerial photographs or satellite images can be used to determine the extent of physical restructuring. However, historical, anthropogenic changes such as the construction of marinas, boat basins

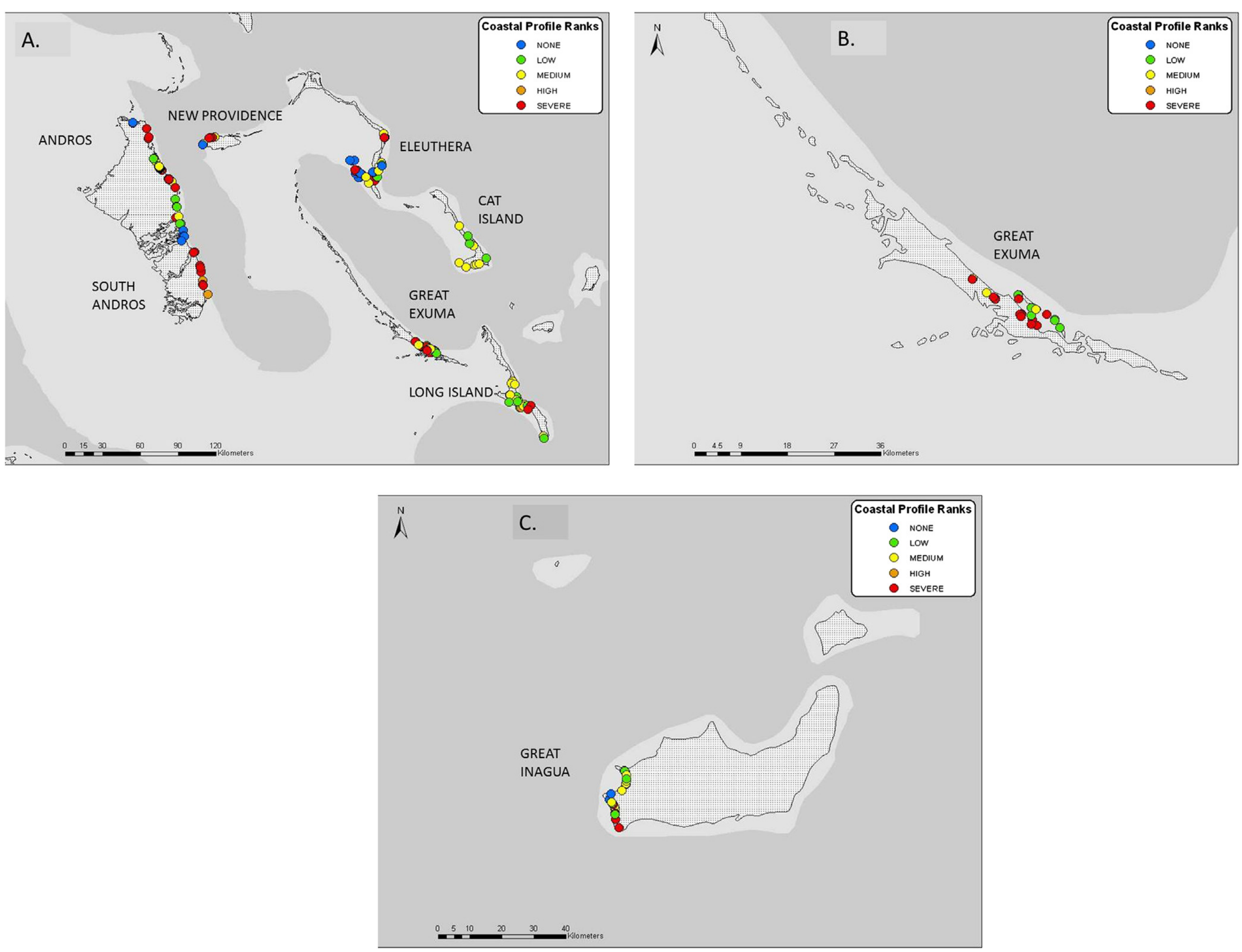

Fig. 1. Location map of the coastal survey sites in the central Bahamas (exclusive of Abaco, Inagua and Cay Sal) illustrates the distribution of severe, high, medium and low ranked sites. 1A illustrates the spatial extent of the survey sites in the central Bahamas; 1B shows details of site locations on Exuma, and 1C shows site locations for Great Inagua.

causeways, and coastal roads, or dune removal, require field surveys to groundtruth the extent of alterations that may be obscured by vegetation overgrowth.

In addition, the coastal ranking looked at the presence and abundance of nine invasive alien species (IAS) of coastal plants as threats to the health of coastal environments (identified in the Invasive Species Strategy, Bahamas Environment, Science and Technology Commission, Government of The Bahamas, 1996). Often, these IAS were propagated by sea-borne or wind-borne seeds to the coastal environment. The Australian Pine (*Casuarina equisetifolia*) and the Beach Naupaka (*Scaevola taccada*) are considered particular threats to the stability of the coastal environment and wildlife habitat quality (e.g. by compromising nesting habitat for sea turtles), and are known to compete with native plants (French et al., 2011; Wheeler et al., 2011). As the sea-borne seeds of these two species can invade even intact and otherwise unaltered coastal environments, a synoptic view of their distributions around the archipelago provided an important component to the IAS rank.

The combined impact assessment produced a final overall coastal ranking score designed to indicate the ease of remediation. The score also indicated a level of risk for coastal erosion, loss of wildlife habitat or loss of near shore marine habitats via eutrophication. The numerical scores were interpreted as “None” (0); “Low” (1–2); or “Medium” (3–7); “High” (8–11) and “Severe” (>12 with a maximum of 20). The “Low” and “Medium” impact scores

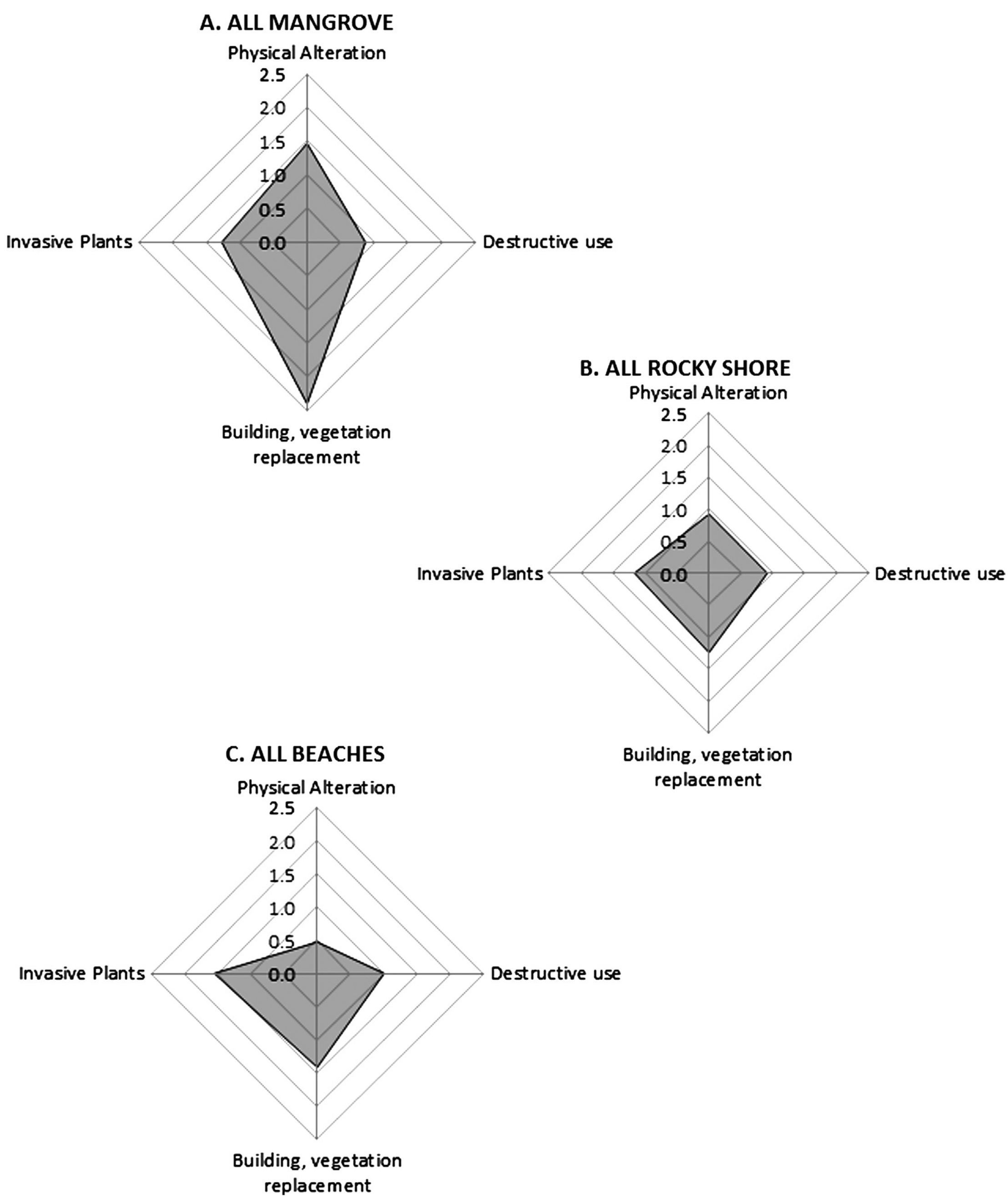

Fig. 2. Radar Plots by coastal type illustrating the contribution of the four ranking factors to the overall coastal impact rank for all islands. A. Mangrove coasts from all islands; B. Rocky Shores from all islands, and C. Beaches from all islands. Each coastal type has a unique pattern of coastal alterations.

represent areas that can be improved by local stewardship actions, such as invasive plant removal, or some modest coastal restoration measures. "High" and "Severe" impact scores would call for larger-scale and higher-cost remediation measures, such as backfilling dredged canals, physical re-structuring of the shoreline environment, beach replenishment and removing causeways.

Coastal ranking scores were examined using radar or "spider" charts to look at the occurrence of each of the four ranking criteria on a separate axis. The radar charts are intended to illustrate the patterns of threats to the coastal environment from island to island. Two islands were re-surveyed over time to look at temporal changes in coastal ranking and coastal plant diversity. Great Exuma was surveyed seven times from 2004 to 2012 to re-examine four sites; one of these sites was being actively restored (Victoria Pond). Great Guana Cay, Abaco was surveyed from 2004 to 2008 to re-examine four sites; one site was left undisturbed (Joe's Creek) and the other sites were actively developed as a resort residential community (see Sealey and Cushion, 2009).

2.4. Coastal plant species assemblages and diversity assessment

Plant lists by site were analysed in Primer-E multivariate statistical software (Plymouth Marine Laboratory, UK) to examine similarity in coastal plant species assemblages between sites and for sites over time (Exuma and Great Guana Cay). Changes in plant species assemblages were examined over time, and between sites for beaches and rocky shores. Coastal plant species assemblages are the product of environmental conditions, herbivory pressure and human disturbance. The objectives were to determine the extent and occurrence of common coastal plants, and to describe the plant-coastal disturbance relationships.

Previous work has shown some changes in terrestrial plant assemblages vary between islands for dry evergreen formations (Larkin et al., 2012), particularly along latitudinal (temperature) gradients. Thus, this study's survey sites were aggregated by island, shore type and coastal human impact ranking. Sites surveyed over time on two islands (Exuma and Great Guana Cay) were examined separately. These species assemblages were analysed in Primer-E multivariate statistical software (Plymouth Marine Laboratory, UK) to examine similarity in coastal plants within and between islands, within and between shore types (beaches, rocky shore or mangroves) and lastly, by coastal impact rank. Ideally, the dataset would be used to identify species that can primarily discriminate between intact or "reference" areas contrasted to impacted areas. Three aspects of plant species assemblages were explored: diversity indices, hierarchical clustering with analysis of similarity within and between islands and ranks (ANOSIM), and identification of those species primarily discriminating between sites (SIMPER).

Diversity indices reported for each site included **S** (total number of species), **d** (Margalef's index for species richness), and **H′** (Shannon–Wiener diversity index). We hypothesized that intact coastal environments with few impacts should have higher plant diversity and vegetation coverage and that more impacts would decrease plant diversity. Hierarchical clustering of species assemblages by site were carried out by pre-treatment (fourth-root transformation of coverage classes), and constructing a matrix based on site-by-site Bray Curtis similarity comparisons. Coastal plant species assemblages were separated by islands and analyzed by coastal impact rank. The analysis of similarity tests (ANOSIM) were carried out on the resemblance matrix of coastal plant species assemblages to test the null hypothesis that there are no assemblage differences between groups of sites with different coastal ranks. The null hypotheses tested were: 1) there are no differences in coastal plant species in the coastal environments between sites with different coastal impact ranks, and 2.) over time, there will be no changes in coastal plant species regardless of coastal rank on a given island.

Lastly, coastal sites that were significantly different on a given island were analyzed using SIMPER to list the species that contribute to differences between the sites (e.g. what coastal plants are likely to be found at sites with low coastal impact ranks as compared to sites with high or severe coastal impacts?).

3. Results

The survey focused on coastal environments throughout the archipelago primarily impacted by human settlements since 1940. The surveyed sites included both private and public ownership, and all survey sites were within 1 km of road access. Thus, the surveys reflect island-specific patterns of coastal environment use throughout the country. Other than the two islands (Great Exuma and Great Guana Cay) selected for repeated sampling, most islands were visited during a single year, with the exception of Great Inagua. Great Inagua is a very large island, with unique vegetation that required two field seasons to survey. Fig. 1 illustrates the spatial extent of the survey sites in the central Bahamas (Fig. 1A), details of site locations on Great Exuma (Fig. 1B) and Inagua (Fig. 1C). A master list of all sites with the coastal characterization and ranking is given in Appendix 1.

3.1. Site selection and coastal impact ranks

Table 3B provides summary information on the final rankings for each island. Every island except Cay Sal had high and severe

Table 4
Summary of 203 coastal sites from ten islands with complete coastal plant surveys from 2002 to 2012. The number of survey sites on each island, number of coastal zones (e.g. beach face, pioneer, fore dune, back dune, mangroves, rocky shore, wetland or flooded swale, cliff or bluff, inter-dune area, coppice, coastal ridge, and human altered landscape.). The total number of plant species was recorded for all sites on each island is listed, with the most coastal plant species found on Inagua, the least on New Providence. All islands had sites with Invasive alien species, with 100% of sites on New Providence with IASs.

	North Andros	South Andros	Cat Island	Eleuthera – South	Eleuthera – Windermere	Abacos, Great Guana Cay	Exuma	Inagua	Long Island	New Providence
Number of sites	29	16	11	36	6	14	23	33	29	6
Number of coastal zones	11	10	9	11	10	9	11	11	11	7
Number of coastal plant species	111	115	99	120	96	101	110	122	108	57
Percent Invasive Species (number of IAS out of all species recorded)	9%	8%	6%	5%	4%	7%	5%	5%	6%	11%
Sites with invasive species	93%	94%	100%	81%	100%	100%	70%	73%	69%	100%
Sites with >1 invasive species	72%	88%	73%	33%	83%	79%	35%	42%	38%	100%
Sites with >2 invasive species	45%	63%	45%	11%	33%	50%	13%	18%	10%	67%
Sites with >3 invasive species	34%	13%	18%	0%	0%	29%	9%	3%	7%	17%
Sites with human altered landscapes in transects	28%	56%	45%	36%	50%	43%	17%	70%	55%	100%

ranked sites. Southern Eleuthera and Andros Islands had the highest percentage of "None" and "Low" anthropogenic coastal impact scores. Across all islands and coastal types, 11.7% of the sites were ranked with "None" or no anthropogenic coastal impacts; 23.5% ranked as "LOW"; 33.2% ranked as "Medium"; 21.8% ranked as "High"; and 9.7% of the sites ranked as "Severe" in coastal impacts. Low human population densities on islands did not appear to be a consistent indicator for healthy and intact coastal environments.

The type of coastal alterations varied with coastal type (Fig. 2). Radar plots were used to illustrate the average ranking for each of the four ranking criteria, and the patterns of coastal alteration that varied between coastal types. Mangrove shorelines (fringing mangroves, and mangrove creeks) overall had the highest impact ranks. Mangrove shorelines were more frequently filled for buildings, marinas or causeways. Rocky shores had the least impacts overall, and these shorelines included cliffs, rocky platforms, and coasts exposed to high wave energy. All four components of coastal alterations occurred on rocky shores, but at a lower frequency than mangrove coasts. Beaches were most often impacted by the presence of buildings or roads on the dune, and the dominance of coastal plant IAS. Surprisingly,

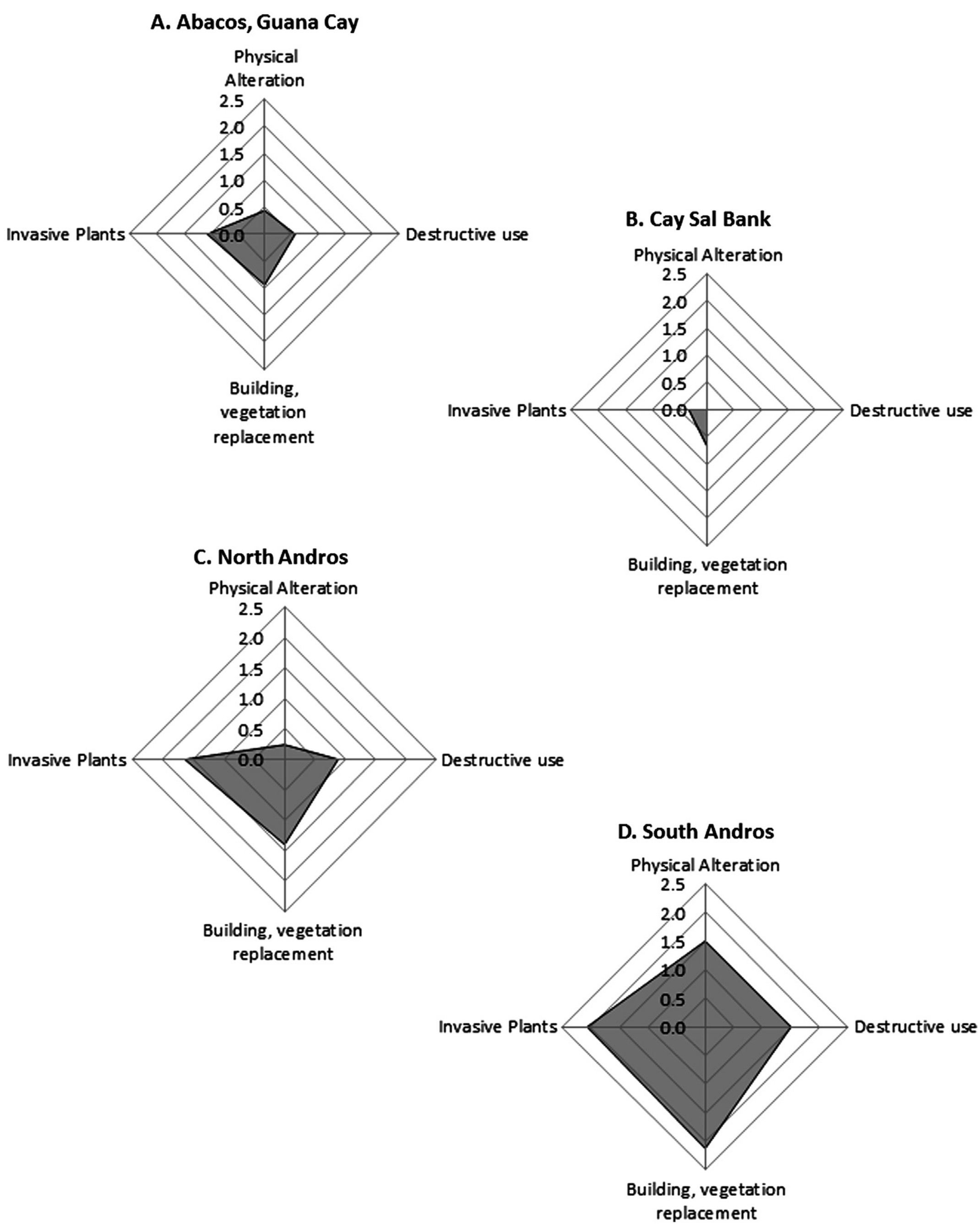

Fig. 3. Radar plots illustrating the contribution of the four ranking criteria to overall ranks for each island. A. Great Guana Cay, Abaco (resort residential island); B. Cay Sal Bank (now uninhabited); C. North Andros; D. South Andros; E. South Eleuthera; F. Eluethera Windemere Island (resort residential island); G. New Providence (most populous island and capital); and H. Exuma (fasting growing population).

throughout all sites across the archipelago, 89% of coasts had some level of invasive plants, primarily *C. equisetifolia* in the coastal environment (77.8% of all sites, broken down by island in Table 4). All beaches with high and severe impacts were dominated by *C. equisetifolia*.

Overall, the coastal impact ranking method provided a good overview of the types of human disturbances that occur between islands and on different shore types. The types of activities impacting the coastal environment varied among islands (Fig. 3). Great Exuma had the greatest percentage of "High" and "Severe" ranked sites. The radar plots for Great Guana Cay (Fig. 3A) and Cay Sal (Fig. 3B) illustrate the ubiquitous occurrence of IAS plants on even remote islands. The largest islands, North and South Andros (Fig. 3C and D), illustrate the challenge of historical changes to the coastal environment. South Andros has a number of sites that were dredged or altered prior to 1967, but have not been continuously disturbed since then. North Andros and Cat Island have extensive IAS plants along the shoreline with the

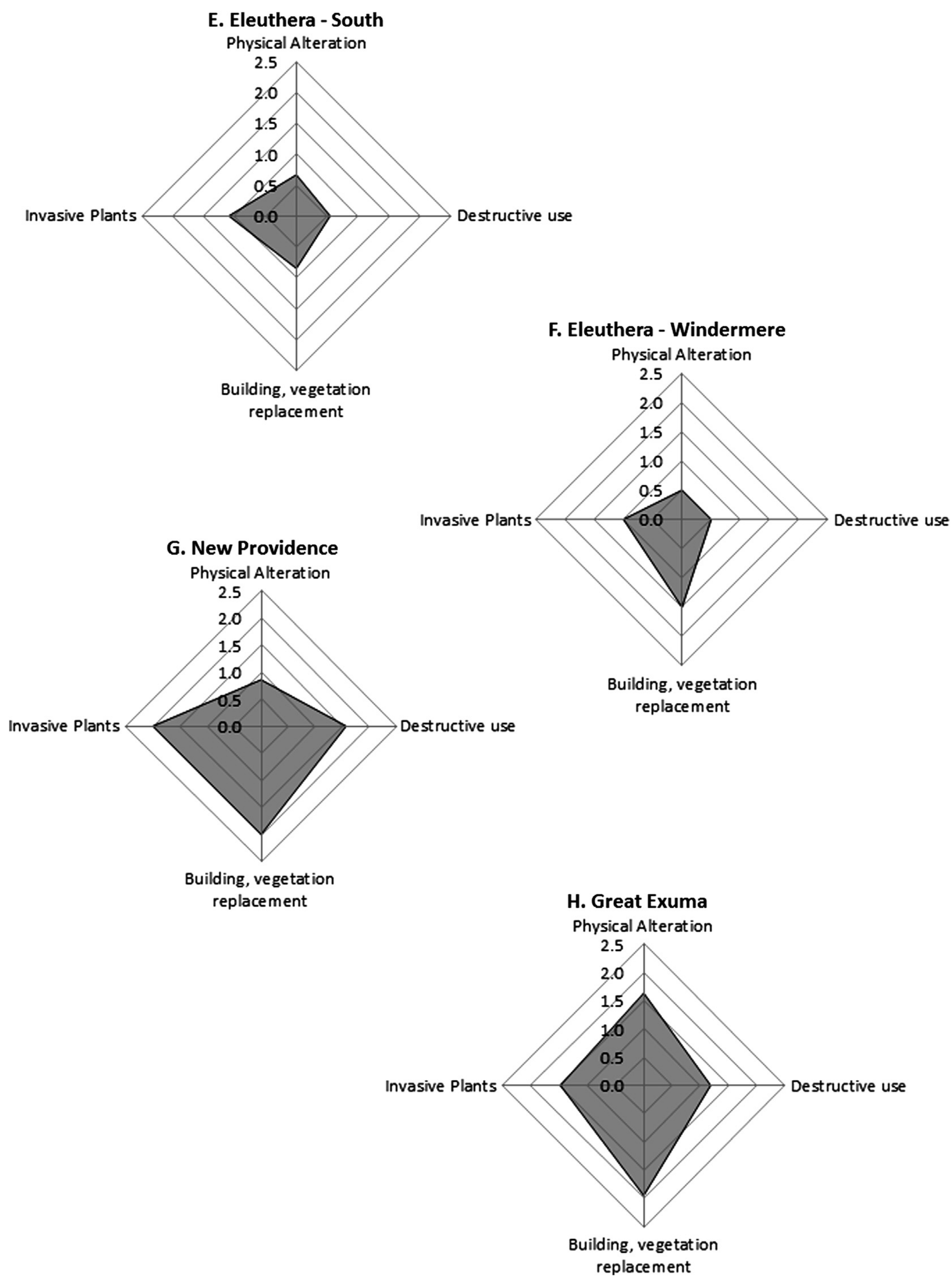

Fig. 3. (*continued*).

construction of roads and buildings on the dune or very close to the shoreline. In both cases, the radar plot shows the polygon expanded on the axes indicating “Invasive Plants”, and “Building, Vegetation Replacement” impacts. Eleuthera Island had some of the healthiest coastal environments, occurring near both local settlements (South Eleuthera) and tourism development (Windemere Island) (Fig. 3E and F). The two islands with some of the most altered coastal environments include New Providence (outside Nassau) and Great Exuma (Fig. 3G and H). New Providence was impacted by buildings and roads in the coastal environment. The large natural harbour in Nassau would account for less physical destruction to the shoreline of the rest of the island of New Providence. Great Exuma shows more physical coastal alteration than New Providence (but as of 2013, these trends are changing with dredge-and-fill development on New Providence).

3.2. Coastal impact ranks and coastal plant diversity

The final check-list of coastal plant species used in the surveys is included in Appendix 2. There are differences in the number of coastal plants found on different islands, with the fewest species found on New Providence. New Providence has the highest number of IAS in the coastal environment, with the highest frequency of occurrence (at 100% of the survey sites). An initial examination of the coastal plant species surveys resulted in five sites discarded as outliers. These sites included areas of incomplete plant surveys, or unusual circumstances that precluded ranking under the methods described. In general, there was a negative relationship ($R^2 = 0.0785$, $p = 0.0003$) between coastal plant diversity and coastal impact rank (Fig. 4). The number of coastal plant species is weakly linked to coastal impact ranking (Fig. 4A), and tends to be higher for lower impact ranks. However, there is stronger relationship between diversity indices, particularly Margelef's index of evenness (Fig. 4B) and Shannon–Weiner Index (Fig. 4C) and coastal ranks which capture abundance (coverage) of plant species.

The most significant change in coastal plant diversity occurs in “Severe” ranked coasts, regardless of shore type (Table 5). Although the diversity of coastal plant communities is slightly higher along rocky shores, there is no significant difference between shore types (ANOVA, $f = 0.174$). However, there are significant differences between ranks (Severe ranked rocky shores and beaches, one way ANOVA, $p = 0.025$, $f = 9.356$). Invasive Alien Species (IAS) are increasing in occurrence and abundance in coastal habitats throughout The Bahamas. The most common 25 plants included three invasive alien plant species; along with the dominance of *C. equisetifolia*, fellow exotic species Jumbay (*Leucaena leucocephala*) occurred in 46% of all the sites, and Beach Naupaka (*S. taccada*) occurred in 30% of all survey sites. These invasive species were found on all islands surveyed, and represent a national threat to coastal stability and biological diversity. As summarized in Table 6, the most abundant 20 native plants include primarily tree and shrub species that stabilize the coastal zone, and the range of

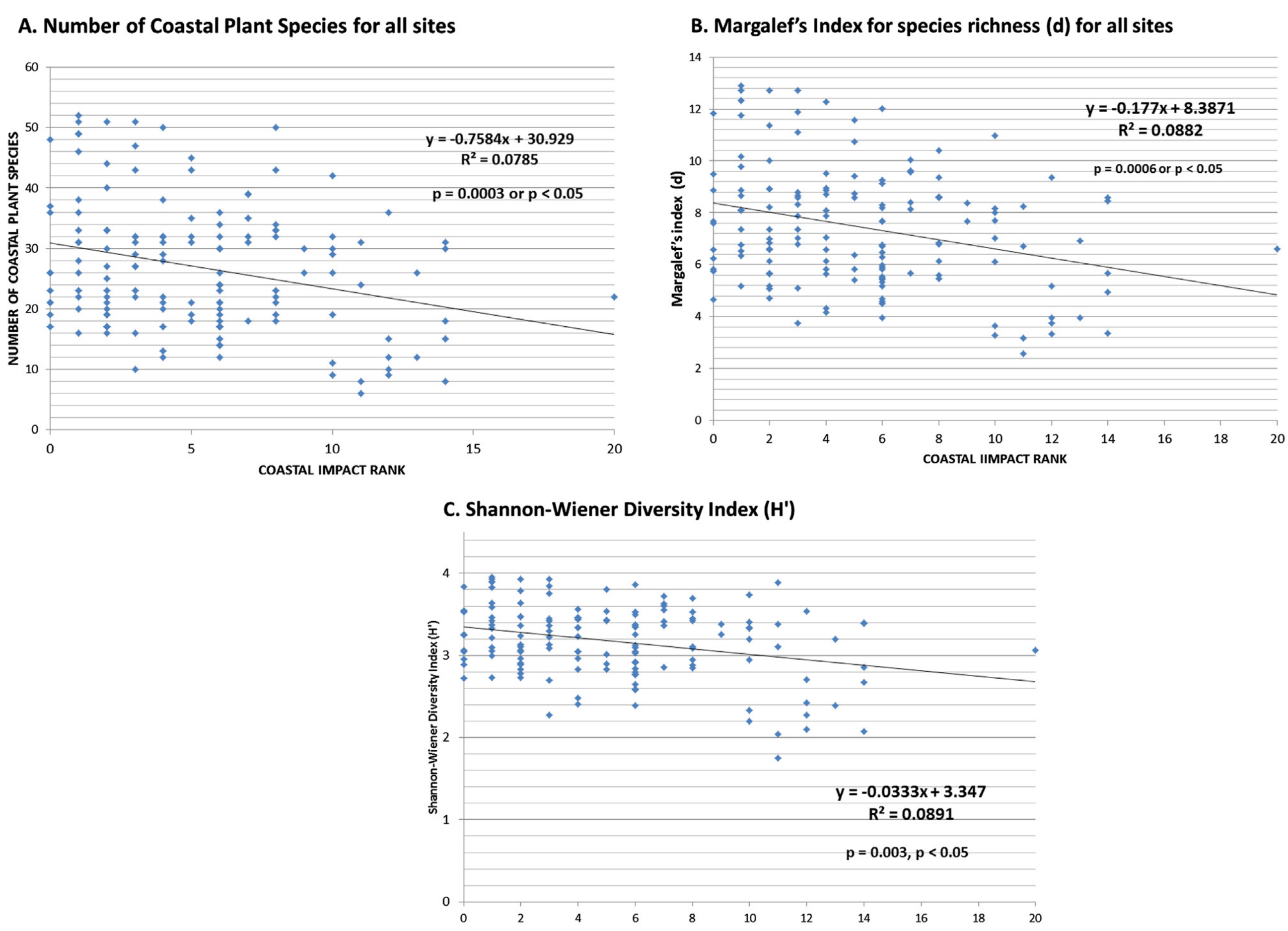

Fig. 4. Regression analysis of coastal plant diversity changes with coastal impact ranking. A. Number of plant species surveyed per unit area vs. Coastal rank. B. Margelef's index of evenness (d) vs. coastal rank, and C. Shannon–Wiener diversity index vs. coastal rank.

Table 5
Diversity Indices for Sites by Shore type (Rocky Shores and Beaches) and coastal impact rank. The number of sites for each rank (**N**), mean number of coastal plant species present (**S**); mean Margelef's index of evenness (**d**), standard deviation, mean Shannon–Wiener index (Diversity indices reported for each site included) and standard deviation. There are no significant differences between shore types (pairwise *t*-tests) but there are significant differences between ranks, indicated by "**". (Severe ranked rocky shores and beaches, one way ANOVA, $p = 0.025, f = 9.356$).

Coastal impact rank	N	S	Margelef's index		Shannon–Wiener index	
			d	St Dev	**H′**	St Dev
Rocky shore						
None-Low	21	31.3	8.456	2.794	3.338	0.422
Med	12	26.3	7.468	2.714	3.148	0.485
High	11	29.5	7.949	2.343	3.254	0.459
Severe	8	20.8	5.921**	2.058	2.825**	0.530
Beaches						
None-Low	22	27.4	7.624	1.750	3.240	0.288
Med	41	25.3	7.076	1.844	3.127	0.355
High	11	28.3	7.684	1.918	3.249	0.360
Severe	8	22.5	6.419**	4.001	2.860**	0.727

coastal types and islands in which these species occur make them ideal candidates for coastal restoration planning. Coconut palms (*Cocos nucifera*) were found in 35% of the surveys, and are ubiquitous throughout the coastal environment from both intentional and volunteer propagation.

Coastal type did affect coastal plant communities, and there are distinct assemblages of coastal plants identified with beaches, rocky shore and mangrove shorelines, although there are no differences in terms of diversity between shore types (Table 5). Each site was characterized by island, date surveyed, coastal type, rankings, and the total number of plants counted in the coastal survey transect, including IAS present.

Table 6
Rank order abundance of Coastal Plants occurring at the 203 survey sites. The most frequently occurring coastal plants throughout The Bahamas on all islands and at all sites show that the invasive exotic *Casuarina equisetifolia* occurs at the most locations on the 10 islands surveyed. Another important invasive plant in wetland margins, *Leucaena leucocephala* was seen in 46.3% of the surveys. The plants on this list (exclusive of the bolded invasives) are key shrubs and trees that should be used in coastal restoration planning.

Casuarina equisetifolia	**Australian pine**	77.7
Coccoloba uvifera	Sea grape	74.2
Conocarpus erectus	Buttonwood	63.3
Pithecellobium keyense	Ram's horn	56.3
Sesuvium portulacastrum	Sea purslane/Sea Pickle	53.3
Suriana maritima	Bay Cedar	48.9
Leucaena leucocephala	**Jumby**	46.3
Erithalis fruticosa	Black torch	45.0
Sporobolus domingensis	Seashore Rush grass-Long	41.0
Casasia (Genipa) clusiifolia	Seven-year apple	40.6
Reynosia septentrionalis	Darling plum	39.7
Coccothrinax (Leucothrinax) argenta	Silver top palm	39.3
Metopium toxiferum	Poisonwood	39.3
Rhizophora mangle	Red Mangrove	37.1
Guapira discolor	Narrow-leaf blolly	36.7
Rhachicallis americana	Wild thyme	36.7
Acacia choriophylla	Cinnecord	36.2
Eustachys petraea	Finger grass	36.2
Cocos nucifera	**Coconut Palm**	35.4
Borrichia arborescens	Sea ox eye – dark green	34.9
Corchorus hirsutus	Jack switch	34.5
Scaevola plumieri	Native Inkberry	34.5
Sporobolus virginicus	Seashore rush grass – short	34.5
Jacquinia keyensis	Joe Wood	32.3
Scaevola taccada	**Exotic Inkberry**	30.1
Bursera simaruba	Gum-Elemi, Tourist Tree	29.7

Hierarchical clustering of plant assemblages was carried out for rocky shores and beaches separately. Patterns of beach plant diversity changed with coastal impact ranks. A two-way crossed Analysis of Similarities (ANOSIM) showed clear differences between each coastal impact rank among all islands for rocky shores (Global $R = 0.345$, Significance level of sample statistic: 0.1%). However, there were no significant differences between coastal impact ranks among all islands for beaches. (Global $R = -0.017$; Significance level of sample statistic: 56.8%). Low R-values indicate a lack of separation among the groups and high R values represent good separation. Clarke and Gorley (2001) interpreted R-values >0.75 as well separated; $R > 0.5$ as overlapping, but clearly different and $R < 0.25$ as barely separable at all.

Thus, even if the number of coastal plant species and diversity of a site does not change, the composition of plants in that coastal environment changes with increased human alterations. SIMPER analysis of beaches was used to identify the species that contributed to community changes between none and low coastal impact ranks and severe coastal impact ranks were all IAS (the most common being *C. equisetifolia*) with weedy vines and grasses such as *Ipomoea pes-caprae* and *Eustachys petraea*. Across all islands and all coastal types, a list of species that distinguish none to low coastal impact ranked sites form severe coastal impact ranked sites are listed in Table 7. Low-ranked coastal impact coastal zones were dominated by shrubs and herbs; severe ranked coastal environments were dominated by IAS with weedy vines and grasses. The SIMPER analysis by shoreline type provided coastal plant species lists that could be indicators of reference sites; these indicator species are listed in Table 8. The specific plant assemblages and numbers of plant species are dependent on intact geomorphology along the shoreline, providing the zonation (e.g. fore dune, back dune, swale and interdunal areas) for environmental gradients that support plant diversity.

3.3. Coastal impact ranking changes over time

Changes in sites over time were assessed on one island with an active restoration initiative (Great Exuma) and another island actively being developed as a residential resort (Great Guana Cay, Abaco). Coastal impact ranks over time are presented for two islands in Fig. 5. Two sites on Great Exuma were surveyed initially in

Table 7
Indicator plants identified as characteristic of coastal sites ranked as NONE or LOW contrasted to coastal sites ranked as SEVERE. These plants account for over 50% of the differences between "None to Low" and "Severe" sites (Primer, SIMPER). Plants are listed in order of importance in characterizing the rank, and are used to determine "Reference Sites". "*" indicates Invasive Alien Species (IAS).

All coastal types (beaches, rocky shore and mangroves)	
None to Low ranks	Severe ranks
Conocarpus erectus	*Sesuvium portulacastrum*
Metopium toxiferum	*Scaevola taccada**
Sesuvium portulacastrum	*Ipomoea pes-caprae*
Jacquinia keyensis	*Casuarina equisetifolia**
Borrichia arborescens	*Eustachys petraea*
Erithalis fruticosa	*Leucaena leucocephala**
Coccothrinax (Leucothrinax) argenta	
Rhachicallis americana	
Reynosia septentrionalis	
Suriana maritima	
Guapira discolor	
Casasia (Genipa) clusiifolia	
Coccoloba uvifera	
Borrichia frutescens	
Pithecellobium keyense	

Table 8
Coastal habitat conditions as defined by impact rank for beaches, rocky shore and mangrove shorelines in The Bahamas based on archipelago-wide synoptic surveys of coastal plant diversity and assessment of four types of human disturbances to the area. A summary of sites that NONE to LOW attributed to only IAS presence in low abundance. Sites are described, and characteristics of "Reference Sites" are listed. For all coastal types, the presence of *Conocarpus erectus* (Buttonwood) is a key indicator of coastal condition.

	Beaches	Rocky shore	Mangroves
Reference condition description	Beaches with all zones intact: Pioneer, fore dune, back dune and swale. No volunteer Invasive Alien Plants	Rocky shore with all zones intact: rocky shore, cliff or coastal ridge. Upland water shed intact.	Mangrove with associated water shed, coastal wetlands with associated transition zones and upland communities.
Vegetation structure	Grasslands	Scrub land changing to Shrub thickets	Woodlands to Shrub thickets
Plant diversity (within 500 m^2 transect)	An average of 28 coastal plant species, ranging from 18–48 depending on the height of the dune and hurricane history		An average of 32 species, ranging from 21–54
Plants characteristic of reference sites	*Coccoloba uvifera* *Casasia (Genipa) clusiifolia* *Pithecellobium keyense* *Suriana maritima* *Coccothrinax (Leucothrinax) argenta* *Uniola paniculata* *Scaevola plumieri* *Reynosia septentrionalis* *Sporobolus domingensis* *Borrichia arborescens* *Sesuvium portulacastrum* *Jacquinia keyensis* Scaevola plumieri *Ambrosia hispida* *Iva imbricata* *Mallotonia (Argusia) gnaphalodes*	*Conocarpus erectus* *Coccoloba uvifera* *Sesuvium portulacastrum* *Rhachicallis americana* *Suriana maritima* *Metopium toxiferum* *Guapira discolor* *Pithecellobium keyense* *Jacquinia keyensis Borrichia arborescens Coccoloba diversifolia* *Erithalis fruticosa* *Casasia (Genipa) clusiifolia* *Reynosia septentrionalis*	*Conocarpus erectus* *Rhizophora mangle* *Coccoloba uvifera Pithecellobium keyense* *Sesuvium portulacastrum* *Lantana involucrata* *Metopium toxiferum* *Acacia choriophylla* *Avicennia germinans Cassythia filiformis* *Laguncularia racemosa Erithalis fruticosa* *Corchorus hirsutus* *Borrichia arborescens Reynosia septentrionalis* *Gundlachia corymbosa* *Casasia (Genipa) clusiifolia Passiflora cupraea* *Solanum bahamense*

2004, then annually through 2012 (Fig. 5A). Fowl Cay is an uninhabited cay within the Mariah Harbour Cay National Park. The Cay has some voluntary invasive plants in the fore dune zone (*C. equisetifolia* and *S. taccada*) that increased in abundance until a hurricane in 2011 removed *C. equisetifolia*. The coastal Impact rank remained "LOW", and the number of coastal plants recovered ranged from 32 (2004) to 40 (2011). In contrast to Fowl Cay, Victoria Pond is a mangrove embayment site, and was ranked "High" in coastal impacts. Victoria Pond had only 12 coastal plant species recorded in 2004. In 2009, this site was designated as a National Wetland Restoration Site. Channels were re-opened, invasive plants growing on fill were removed, and red mangroves (*Rhizophora mangle*) were planted to the restored shorelines. The number of coastal plants increased to 36 (2011), though the overall impact rank did not decrease for the site (roads and buildings remained, marinas and docks remained, and some areas of invasive plants remained).

Great Guana Cay, Abaco provided another temporal comparison (Fig. 5B). The northern end of the island was uninhabited in 2004. Active development of a residential resort community started in 2005, with allowances for 15 m coastal buffer zones along the beaches and rocky shores. All sites selected for the temporal study were expected to be "un-impacted" by the development; however, even in intact coastal buffer zones, there was an increase in IAS and a decrease in plant diversity over time. Construction activity resulted in indirect impacts on the coastal impact ranks, even without direct coastal alterations.

4. Discussion

Coastal impact ranking and assessment of changes in the coastal environment have been used in the past to evaluate impacts on marine resources, especially the effects of land-based sources of pollution on coral reefs (See Burke et al., 2001; Burke and Maidens, 2004). The *Reefs at Risk* assessment of the Caribbean especially uses human population density on a regional scale as an indicator of coastal impacts or land-based sources of pollution (Burke and Maidens, 2004). However, for islands such as the Bahamian archipelago, the absence of large human populations does not always equate to healthy coastal environments. Coastal impact ranking needs to be efficient in identifying first, the threat of coastal eutrophication, second, the best candidate sites for restoration or mitigation, and lastly, diversity "hotspots" or important wildlife habitats requiring additional protection and management. Management is the more cost-effective option to restoration (Cambers, 1998).

In the absence of historical or "baseline" information, synoptic surveys on a wide range of coastal sites with a variety of human impacts can be the best way to address "reference" conditions or identify reference sites for establishing restoration or management goals (Stoddard et al., 2006). Reference locations can then be characterized by coastal type characteristic plant species, overall plant diversity and vegetation coverage (Table 8). The coastal impact ranking method then provides the framework for establishing expectations for the ecological conditions of the coastal ecosystem. This can be particularly important in establishing meaningful coastal setbacks and coastal buffer zones that are developed to meet the needs of a given coastal environment.

Coastal plants can be critical indicators of the ability for a site to recover from vegetation removal or coastal alterations. Coastal plants are resilient and can improve coastal condition over time, but native plant re-vegetation alone cannot restore or rehabilitate severely impacted coastlines. Some isolated areas characterized by decades-old disturbances (e.g. within North and South Andros) have recovered coastal plant diversity over time, with the exception of *C. equisetifolia* -dominated beaches. Once dune systems are disturbed by invasion of Australian pine (*C. equisetifolia*), coastal erosion continues and native plant diversity continues to decline (Sealey, 2005). Hooper's Bay, Great Exuma represents the worst possible fate for a coastal habitat: a large scale residential resort development (started in 1999), which involved initially clearing and filling about 30 ha of high relief rocky shore and beach. The project was halted and abandoned in early 2003. Coastal vegetation was removed, the rocky shore altered with fill, and without mitigation. *C. equesetifolia* and *S. taccada* invaded the coastal

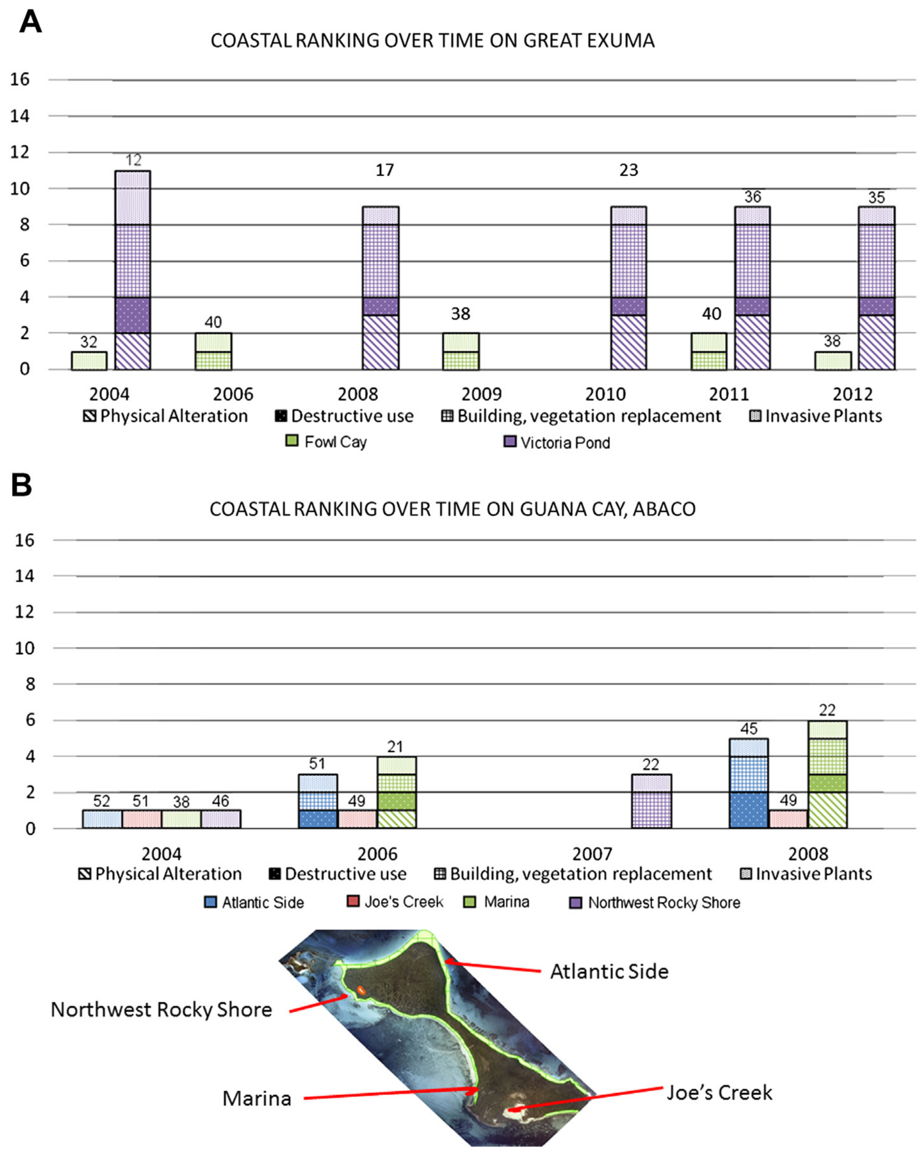

Fig. 5. Temporal changes in coastal rankings on A. Great Exuma, and B. Great Guana Cay, Abaco. Numbers indicate the number of coastal plant species recorded at each site over time.

environment, resulting in significant loss of wildlife habitat, destruction to near shore coral patch reefs, and overall loss of biological diversity in the area. The number of coastal plant species present at the site went from seven in 2003, to 15 in 2004, to 22 by 2006 indicating some recruitment and voluntary re-vegetation of the area, primarily of grasses and herbs. This site illustrated that without mitigation or restoration, the recovery of coastal plant assemblages is slow.

The islands of The Bahamas are unique in their geology and are vulnerable to over-development primarily from alterations to linked nutrient and hydrological cycles. The threats include not only loss of terrestrial species, but also loss of marine species and habitats from land-based sources of pollution (Rabalais et al., 2009). The ability to rank sites based on four impact criteria and a coastal plant checklist can provide a rapid, cost-effective tool for coastal management and planning. The population in the 2010 census was 327 000 people, with over 70% of the population living on the small island of New Providence (Government of The Bahamas, Department of Statistics 2011). The greatest population increase was seen on the island of Exuma, where the population almost doubled in 10 years from 3571 people in 2000 to 7314 in 2010. Coastal impact ranking on Great Exuma at two sites with active management (Victoria Pond UNEP Ecohydrology Demonstration Site and Fowl Cay, Mariah Harbour National Park) illustrated how effective management can improve sites, but IAS are a continuous management issue (Fig. 5A). Other unmanaged Great Exuma survey sites showed how rapidly the nature of impacts can change from destructive use (e.g. sand mining and dumping) prior to 2004 to construction of homes in the coastal environment and on the dune line by 2012 (Appendix 1).

The Government of The Bahamas has recognized the importance of incorporating the best guidelines for sustainable use of small islands where coral reef resources are critical to both the economy and the culture (BEST, 2002, 2005). Best practices in coastal management of islands are designed to: 1.) Stabilize the coastal environment to minimize the costs of mitigating erosion and damage to roads, buildings, and other infrastructure; 2.) Protect coastal biological diversity for both plant and animal species; and 3.) Minimize the flux of nutrients and pollutants from land to near-shore marine environments, specifically to prevent localized eutrophication. Small islands with their associated coral reef resources are threatened by coastal hypoxia (low oxygen) that can only partially be addressed by creation of protected areas, national marine sanctuaries, and aquatic preserves. The changes in coastal land use along with coastal alterations (e.g. dredge and fill development) have created many small hypoxia "hot spots," leading to profound changes in near-shore ecology (Paul et al., 1995). However, there are poorly understood processes that control the fate of organics and nutrients once they enter porous carbonate islands. Healthy, intact coastal systems could support some increases in nutrient flux across the land-sea interface.

High biological diversity in shallow-water marine communities, like coral reefs, is dependent on some intermediate level of perturbation (Connell, 1978; Hughes, 1994). Hurricanes and large tropical storms provide an important disturbance regime for mesoscale sediment or detritus transport on and off of Bahamian islands. At any given point in time, there is likely a mosaic of varying states of disturbance and recovery across an island archipelago essential for the functioning of the wider ecological system. Evaluating the landscape or archipelago-wide scale of habitat complexity is necessary to understand diversity and production through island connectivity (see Reice, 1994; Cowen and Sponaugle, 2009). Globally, the biological diversity of tropical coastal systems is threatened by five general categories of human activity (Nixon, 1995): 1) Overfishing of fishes and invertebrates, 2.) Dredge-and-fill coastal construction, 3.) Filling and land reclamation of coastal wetlands, particularly mangroves, 4.) Pollution and sediment discharge and run-off; and 5.) Introduction of invasive exotic species. Other regional assessments have attempted to characterize each of the above categories, but threats such as over-fishing are not easily assessed or linked to coastal management strategies. The coastal impact ranking presented in this study incorporates many of the above threats in a rapid assessment of coastal ecological integrity to target areas for restoration or conservation.

The Bahamas is a partner in a number of international agreements and treaties that oblige the country to follow international guidelines for coastal protection and setbacks (BEST, 2002). Throughout the insular Caribbean, there are standards for coastal setbacks for each type of coastal environment. Coastal setbacks are defined as a prescribed distance to a coastal feature, such as the line of permanent vegetation, within which all or certain types of development are prohibited (Cambers, 1998). They are designed to leave a buffer of natural vegetation between human development and the shoreline, and are a critical component of coastal zone management, both to protect property, people and the environment. Regional standards for coastal setbacks are already employed in the Environmental Impact Assessment (EIA) process within The Bahamas; thus, this delineation is important to use in the country-wide coastal ecological survey. Government agencies (Bahamas Environment, Science and Technology (BEST) Commission) recommend setbacks though there are few mechanisms for enforcement of coastal setbacks or coastal buffer zones for tourism development. This ranking scheme allows for a tracking of coastal setbacks and buffer zones on islands by assessment of the impact criteria and coastal plant inventories.

In summary, the ecological links between land and sea ecology are well established, especially for tropical islands (Fabricius, 2005; Lapointe et al., 2004; Littler et al., 1992). Coastal Rankings can begin to target priority areas for complimentary marine surveys and water quality monitoring. Coastal impact rankings can be carried out quickly, over large areas, and over different islands to facilitate better management of coastal areas, particularly with the long-term goals of protecting coastal stability and biological diversity. Targeted coastal and marine surveys would be the ideal approach to assess Best Management Practices and to provide a better understanding of the status of coastal environments.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2014.01.010.

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