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CHAPTER 10

Linking Landscape Condition Impacts to Coral Reef Ecosystem Composition for the East End of Saint Croix

Daniel S. Dorfman, Simon J. Pittman, Sarah D. Hile, Christopher F.G. Jeffrey, Alicia Clarke, and Chris Caldow

Abstract

In this land-sea characterization, we endeavored to map spatial patterns of the connections between actions on land and impacts at sea. Specifically, we analyzed 2007 land-cover data, evaluated land-use patterns, and applied a Landscape Development Intensity Index for watersheds adjacent to the East End Marine Park of Saint Croix, US Virgin Islands. We then correlated the distribution of benthic species and coral reef habitats within 300 m buffer watershed impact zones of the landscape development intensity index to identify and explore potential linkages between land-use patterns and ecological impacts on coral reefs. We compared the benthic habitat composition of watershed impact zones within classes of anticipated impacts from land-based sources of pollution. This was done using benthic habitat data both from benthic habitat maps and in-water surveys. The benthic habitat maps indicated a positive correlation between the Landscape Development Intensity Index and seagrass presence and a negative correlation between the index and coral cover. The in situ surveys revealed higher coral cover in medium-impact classes compared with high and low impact. Although the results from comparing benthic habitat maps and in situ surveys are inconsistent, we anticipate that this could be because of the low number and uneven distribution of the in-water surveys. Additionally, we identified watersheds where species known to be susceptible to land-based sources of pollution are located. The process described here is intended to evaluate potential linkages between landscape condition and marine ecosystem condition. We expect that the methods described here could be employed to track the impacts of land-based sources of pollution on benthic habitats and species composition in the nearshore environment.

Introduction

Coral reefs are among the most diverse and productive ecosystems on Earth. In many locations they are the economic engine of the marine environment, providing a wide range of ecosystem goods and services, including food, as well as supporting recreation and tourism activities, and coastal protection from storm and wave action. It is estimated that the total annual economic value of coral reef services to the United States is US$3.4 billion (Brander and Van Beukering 2013), with coral reefs of the US Virgin Islands valued at approximately US$187 million annually (Van Beukering et al. 2011).

The United States and its territories are home to thousands of acres of coral reefs that stretch from remote, relatively untouched areas in the Pacific Ocean to densely populated regions in the Caribbean Sea and Atlantic Ocean. With their vibrant colors and array of fish, sea grass, and invertebrates, coral reef ecosystems are the foundation of many unique and special places throughout the country. In the US Virgin Islands, there are two coral reef national monuments, a national park, and several territorial marine protected areas, including the East End Marine Park on the island of Saint Croix, to enhance protection of coral reef ecosystems.

Despite their economic, biological, and cultural significance, coral reefs in the US Virgin Islands and those across the globe face a myriad of threats and stressors, such as storms, thermal stress from elevated water temperature, diseases, and land-based sources of pollution (Rogers and Beets 2001). Research indicates that multiple threats and stressors interact to negatively impact coral reefs, and poor water quality from runoff reduces the resilience of corals to disturbance from thermal stress (Carilli et al. 2009; Ban et al. 2014).

Coastal development and land-based sources of pollution, such as runoff, are a major concern to marine resource managers in the US Virgin Islands and other small islands, where steep terrain results in direct and rapid transport of runoff into coastal waters after rainfall events (Smith et al. 2008; Waddell and Clarke 2008). In these environments, unpaved "dirt" roads in the watershed were identified as a major source of sediment onto reefs (Begin et al. 2014).

These land-sea connections are of particular interest to coastal resource managers of the Saint Croix East End Marine Park, where the upland development of watersheds poses a primary threat to the health of adjacent marine ecosystems. This concern is documented in the management plan for the East End Marine Park (The Nature Conservancy 2002). The Saint Croix East End Marine Park, established in 2003 as the first multiuse marine park managed by the US Virgin Islands Department of Planning and Natural Resources, encompasses nearly 39,000 acres of underwater habitats and protects the largest island barrier reef system in the Caribbean. Geographical patterns of predicted erosion suggest that the eastern half of Saint Croix is more seriously impacted than the west. The eastern half is also where considerable long-term investments were made to protect coral reef ecosystems through establishment of marine protected areas by federal and territorial governments supported by nongovernmental organizations and community groups.

At the time of the park's establishment, there were substantial data gaps in knowledge about the living marine resources, watersheds, and environmental interactions that influence the park's marine resources. To address these data gaps, the Government of the US Virgin Islands requested the support of the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) to characterize

- the landscape and adjacent seascape condition relevant to threats to coral reef ecosystem condition; and

- the marine communities within the Saint Croix East End Marine Park boundaries to increase local knowledge of resources exposed to various stressors.

This chapter provides a synopsis of the land-sea characterization of the Saint Croix East End Marine Park. It describes the calculation and mapping of the landscape development intensity index (LDII) as a spatial proxy for evaluating the threat from runoff and analyses of biotic communities within watershed impact zones (WIZs) associated with each watershed. The focus was on examining and identifying locations where vulnerable species were exposed to threats from land-based sources of pollution and providing a baseline for tracking potential changes in habitat composition. Pittman et al. (2013) is a comprehensive report on the land-sea characterization of the Saint Croix East End Marine Park.

Background

Alteration of the natural landscape for development, road construction, or agriculture can have adverse impacts on coral reefs through increased delivery of sediment and pollution to coastal waters. The threat associated with land clearing is higher in areas of steep relief, intense precipitation, and where soils are erosive in nature (World Resources Institute and NOAA 2006). Our land-sea characterization seeks to highlight potential linkages between land-based sources of pollution (LBSP) and the condition of coral reef ecosystems for the East End Marine Park by building on previous efforts to help managers prioritize actions and guide local action strategies. Specifically, we quantified and mapped watershed condition in the landscapes in closest proximity to the Saint Croix East End Marine Park, and then examined spatial distribution patterns of marine communities and potentially vulnerable species to determine relative coral reef condition.

Previous studies have characterized spatial patterns in stressors and threats to coral reef ecosystems, but only a few studies have examined landscape condition as a proxy for threats to coral reefs and linked assessment of ecological condition of coral reef ecosystems to adjacent watersheds. Burke et al. (2011) analyzed coastal development, watershed-based pollution, marine pollution and damage, and overfishing to characterize factors affecting coral reef ecosystems and categorized the US Virgin Islands as experiencing “high” levels of exposure to threats from local human activities. Exposure to threats increased even further when projected climate change stressors (sea temperature and acidification) were included in the risk assessment. Another study analyzed the relative erosion potential of watersheds as well as estimated erosion from roads, and found that the majority of the eastern end of Saint Croix had high vulnerability to land erosion (World Resources Institute and NOAA 2006).

To address increasing concerns about watershed condition, the NOAA Coral Reef Conservation Program commissioned two projects by Horsley Witten Group to assess threats from land-based sources of pollution to watersheds adjacent to the Saint Croix East End Marine Park. The first document, *St. Croix East End Watersheds Existing Conditions Report* (Horsley Witten Group 2011a), identified basic watershed characteristics such as soils, rainfall, land use, and infrastructure. It also examined individual sites, the potential for reduction in land-based sources of pollution, and feasibility of implementing restoration projects. Several restoration projects were highlighted as priorities for implementation. Building on watershed restoration activities associated with the American Recovery and Reinvestment Act of 2009, the NOAA Coral Reef Conservation Program, US Virgin Islands Department of Planning and Natural Resources, US Department of Agriculture, and The Nature Conservancy are coordinating comprehensive watershed restoration plans for six watersheds surrounding the park, some of which are 303(d)-listed impaired water bodies. In the second report, the *St. Croix East End Watersheds Management Plan* (Horsley Witten Group 2011b), one objective was to protect marine resources by reducing the negative impacts of land-based sources of pollution through reducing sediment and nutrient loads. The Watersheds Management Plan focuses on actions that can be taken on land to reduce negative impacts to marine ecosystems and natural resources.

In 2011, a team of scientists with the US Environmental Protection Agency applied an index of human disturbance to correlate landscape development with nearshore marine ecosystem conditions in Saint Croix (Oliver et al. 2011). Their analysis focused on the relationship between impervious surfaces and coral reef assemblage metrics such as stony coral colony density, taxa richness, coral colony size, and total coral cover. The LDII, an index of human disturbance, quantified impervious surfaces, agriculture, and other land-cover types to create a composite value for each watershed and represented a spatial proxy of the potential threat to water bodies from runoff. Oliver et al. (2011) found that the LDII was more robust than other indicators of human activity and correlated negatively with stony coral colony density, taxa richness, colony size, and total coral cover. The LDII was also an effective indicator of human impacts to corals, and highlighted the link between land-based human activity and marine ecosystems.

For this study, we adapted and applied the LDII techniques developed by Oliver et al. (2011). However, we expanded the LDII to include the additional variable of "dirt roads." Furthermore, we correlated the LDII to coral-cover metrics to highlight areas where human-impacted terrestrial conditions are proximal to high-priority marine species, habitats, and biodiversity hot spots.

Methods

The US Virgin Islands recognizes six watersheds, encompassing a total area of 3,145 ha, that make up the land adjacent to the park. These watersheds range in size from 807 ha for Great Pond Bay to 281 ha for Turner Hole, and were too coarse for the scale of this analysis. To examine potential linkages between land-based sources of pollution and ecological condition of coral reef ecosystems, we used the island's stream network and aerial photographs to aggregate 121 catchment basins identified from the US Geological Survey (USGS) National Hydrography Dataset (NHD) into 42 watershed units.

One of the primary contributors to land-based sources of pollution is erosion from land-cover conversion. To analyze the potential contribution to sedimentation for each analytical unit, we analyzed the land-cover data developed in 2007 by the NOAA Office for Coastal Management (formerly Coastal Services Center) Coastal Change Analysis Program (C-CAP) (figure 10.1). Our analysis applied the LDII developed by the Center for Environmental Policy of the University of Florida (Brown and Vivas 2005) (table 10.1). The index is intended to serve as a measure of human disturbance. It is calculated based on the level or density of human activity in a given area based on land-cover properties. The LDII quantifies impervious surfaces, agriculture, and other land-cover types to create a composite value for each watershed, forming a spatial proxy of potential threat to nearshore waters from runoff. Oliver et al. (2011) first linked the landscape development intensity index to coral reef condition along the coast of Saint Croix. The researchers found that the LDII was more robust than other indicators of human activity, exhibiting negative correlations with stony coral colony density, taxa richness, colony size, and total coral cover. The LDII provided an effective indicator of human impacts to corals, highlighting the link between land-based human activity and marine ecosystems. Using a more recent land-cover product and finer scale watershed units focused only on Saint Croix East End Marine Park, we modified the approach of Oliver et al. (2011) by incorporating dirt road density into the LDII. Our approach quantified and ranked landscape development intensity for each watershed unit, and then identified areas where high landscape development intensity is likely to threaten sensitive marine species and habitats.

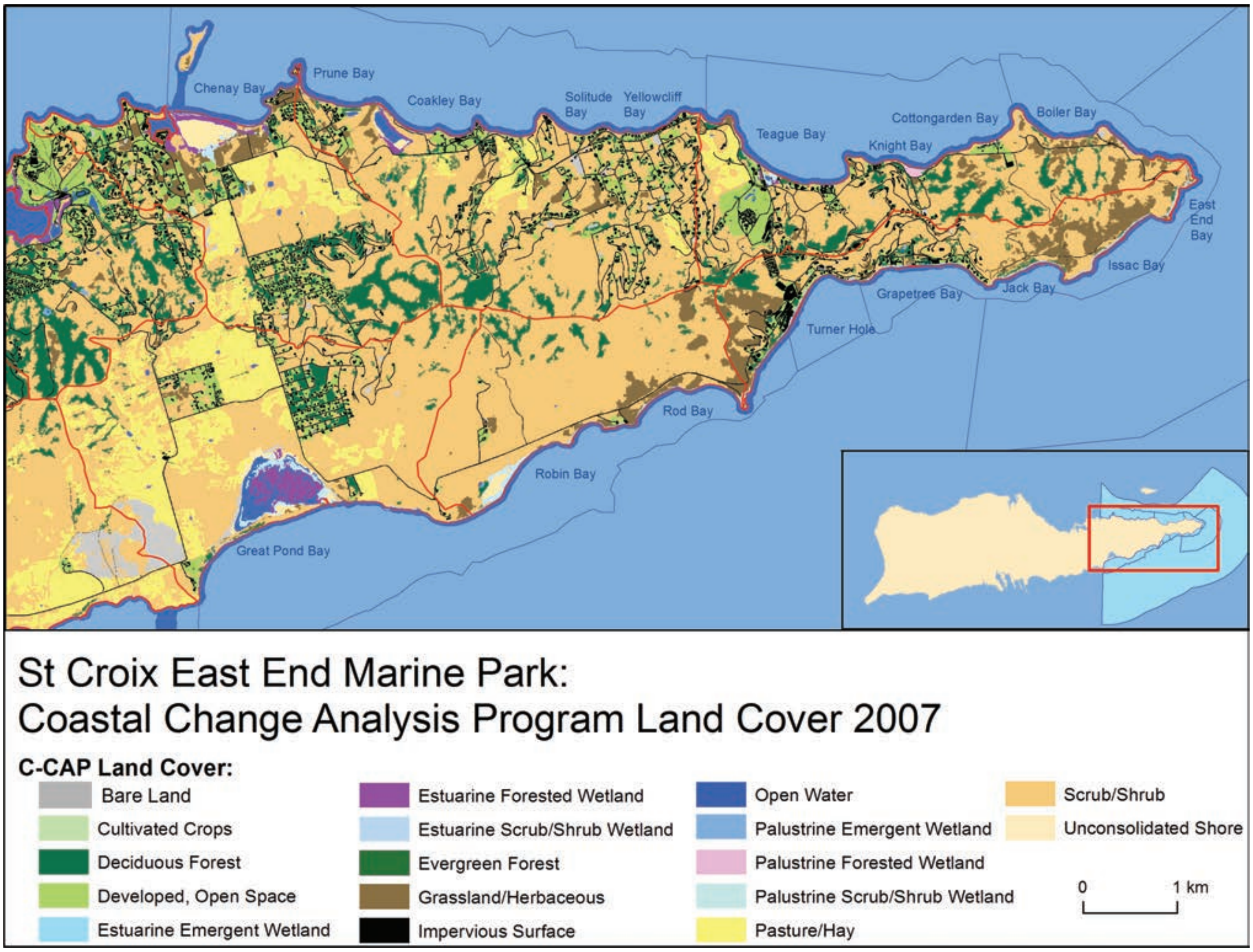

Figure 10.1. Land-cover map developed by the Coastal Change Analysis Program of the National Oceanic and Atmospheric Administration Office for Coastal Management, formerly the Coastal Services Center. Map by authors; data source: NOAA NOS Office for Coastal Management (formerly Coastal Services Center) Coastal Change Analysis Program.

Table 10.1. **Landscape Development Intensity Index Coefficients**

Land Cover Class	Landscape Development Intensity Index Coefficient
Impervious Surface	8.28
Pasture/Hay	3.03
Grassland/Herbaceous	2.06
Scrub/Shrub	2.06
Bare Land	1.85
Developed, Open Space	1.85
Deciduous Forest	1.00
Palustrine Forested Wetland	1.00
Palustrine Scrub/Shrub Wetland	1.00
Palustrine Emergent Wetland	1.00
Estuarine Forested Wetland	1.00
Estuarine Scrub/Shrub Wetland	1.00
Estuarine Emergent Wetland	1.00
Unconsolidated Shore	1.00
Open Water	1.00

Table by authors; data source: EPA.

We created WIZs adjacent to the watersheds of the Saint Croix East End Marine Park (figure 10.2). The WIZs were constructed using a 300 m buffer along the coast of the park that was then subdivided into smaller areas immediately adjacent to the watershed units. The zones were used as replicate sample units to determine potential effects of land-based sources of pollution on marine biota. A buffer of 300 m was selected based on the likelihood that impacts from land-based sources of pollution to marine biota are detectable within 300 m of the land-sea interface. We acknowledge that land-based sources of pollution can influence a broader geographical extent because local water movements could disperse terrigenous materials offshore and alongshore beyond 300 m. However, impacts from land-based sources of pollution on marine biota are likely to decrease with increasing distance from shore because of dilution. Therefore, our WIZs represent conservative regions of impact, within which marine biota most likely will be exposed to land-based sources of pollution. In addition, the intensity of a threat from land-based sources of pollution was included by weighting the WIZs with LDII values to account for spatial variability in land development within the study area.

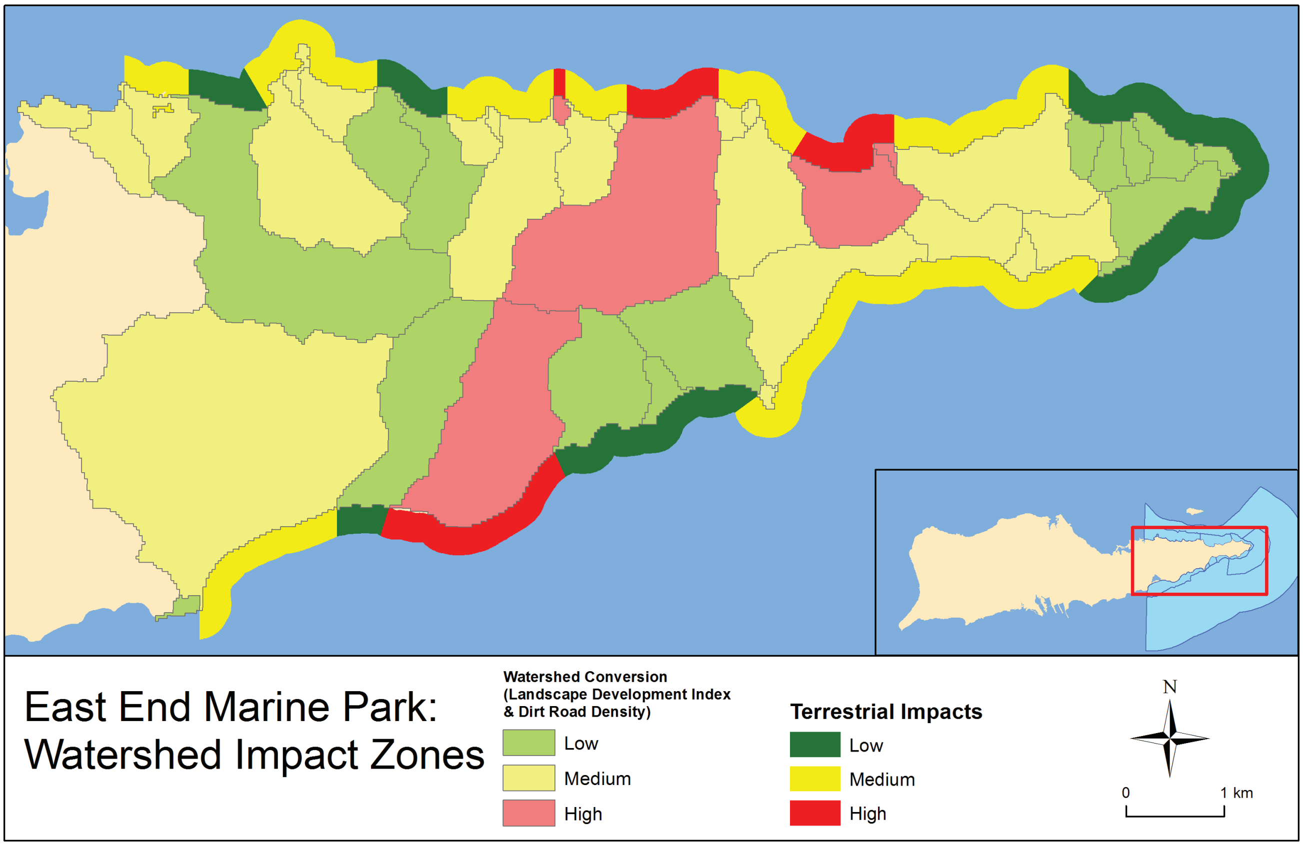

Figure 10.2. Terrestrial impacts and watershed impact zones. Map by authors; data source: NOAA National Centers for Coastal Ocean Science.

LDII provides one measure of the expected threat to coastal ecosystems from watershed-based pollution. Another expected threat is soil erosion from dirt roads. This threat was not captured by the LDII, so it was characterized independently. The area of dirt roads mapped by Horsley Witten Group was quantified for each analytical unit and used as a proxy for soil erosion from dirt roads. Horsley Witten Group interpolated 2009 aerial orthophotos and parcel boundaries as part of the Saint Croix East End Watershed Planning effort funded by the NOAA Coral Reef Conservation Program (Horsley Witten Group 2011a and 2011b). Road type was verified during January 2011 field assessment work (Horsley Witten Group 2011a). The LDII and dirt road variable were combined to create a single metric that represented potential negative impacts to nearshore habitats (see figure 10.2). Figure 10.3 summarizes the process used to map and link land-based stressors to adjacent WIZs.

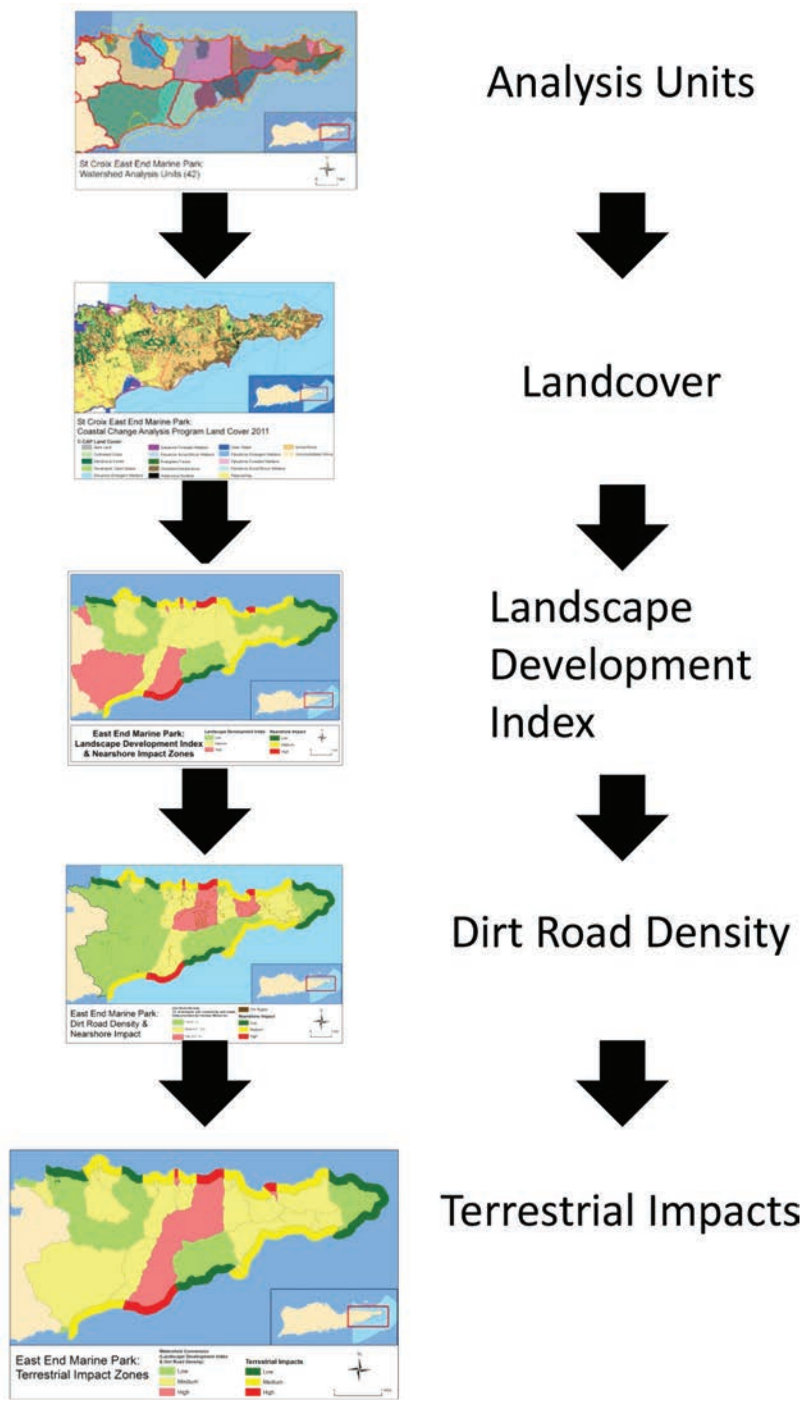

Figure 10.3. Analytical process for deriving terrestrial impacts to watershed impact zones. Map by authors; data source: NOAA NOS Office for Coastal Management (formerly the Coastal Services Center) Coastal Change Analysis Program and Horsley Witten Group.

Characterization of Marine Benthic Communities in Watershed Impact Zones

Benthic habitats were evaluated using two distinct datasets: (1) benthic habitat maps developed by the NOAA Coral Reef Conservation Program (Kendall et al. 2002), and (2) direct observation conducted by underwater surveys. Information from NOAA benthic habitat maps was analyzed to quantify the composition and area of habitat types (e.g., sea grasses, coral reef, sand) in each zone. This data provides managers with information on the proportions of each habitat type within each management unit. Benthic habitats were digitized from high-resolution aerial photographs, and their accuracy was assessed using underwater validation surveys (Kendall et al. 2002).

In addition to the information collected from benthic maps, we used a 10-year (2002–2010) dataset of in situ, field-based observations of benthic composition from direct observation, using 251 point locations to describe benthic communities within each WIZ, as well as management zones within the park. In situ variables analyzed from this study were the percentage cover of scleractinian corals, hydrocorals, algae gorgonians, sponges, and sea grasses. Datasets were collected with a stratified random sampling design to comprehensively assess faunal populations and benthic communities around Buck Island Coral Reef National Monument and the Saint Croix East End Marine Park (Menza et al. 2006; Pittman et al. 2008). Point locations were selected randomly from two strata based on benthic habitat maps of the area (Kendall et al. 2002). The "hard" stratum comprised bedrock, pavement, rubble, and coral reefs. The "soft" stratum comprised sand, sea grasses, and macroalgal beds. A subsample of the data was analyzed by selecting only sites that were located within the WIZs of the park (n = 190; figure 10.4).

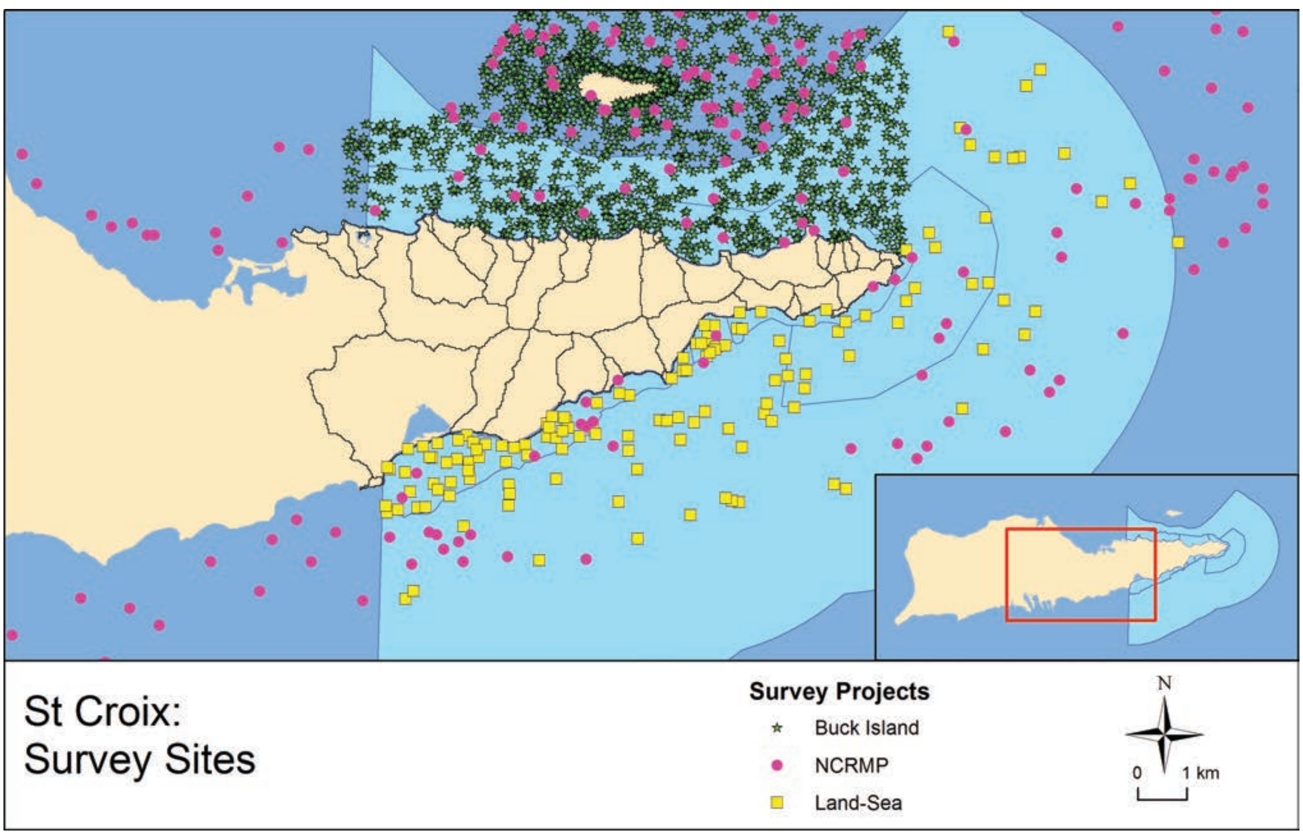

Figure 10.4. Survey locations. Map by authors; data sources: NOAA National Centers for Coastal Ocean Science.

Coral species that are considered sensitive to land-based sources of pollution were selected based on published literature (Bak and Elgershuizen 1976; Rogers 1983; Pastorok and Bilyard 1985; Gleason 1998; Nemeth and Nowlis 2001; Pait et al. 2007). Although observed seagrass species were not considered sensitive to contamination or sedimentation for this study, when exposed to nutrient enrichment or eutrophication, sea grasses experience changes in growth rates and relative dominance among species (Fourqurean et al. 1995; Ferdie and Fourqurean 2004; Burkholder et al. 2007).

Results

Marine Communities in the Watershed Impact Zones

Benthic Communities

Analysis of the benthic habitat maps indicates that coral areas are concentrated along the eastern end of the park, while sea grasses and macroalgae dominate the western side (figure 10.5). We analyzed benthic habitat composition as reported from the benthic habitat maps for differences among the impact classes (Kendall et al. 2002) (figure 10.6). We found significant differences between high-, medium-, and low-impact classes for the distribution of coral reef and colonized hard bottom and submerged aquatic vegetation (SAV) habitats. For coral reef and colonized hard bottom, there was a clear trend of greater coral cover in areas with lower anticipated impacts. For SAV, high-impact areas had greater amounts of SAV and low-impact areas had lower levels.

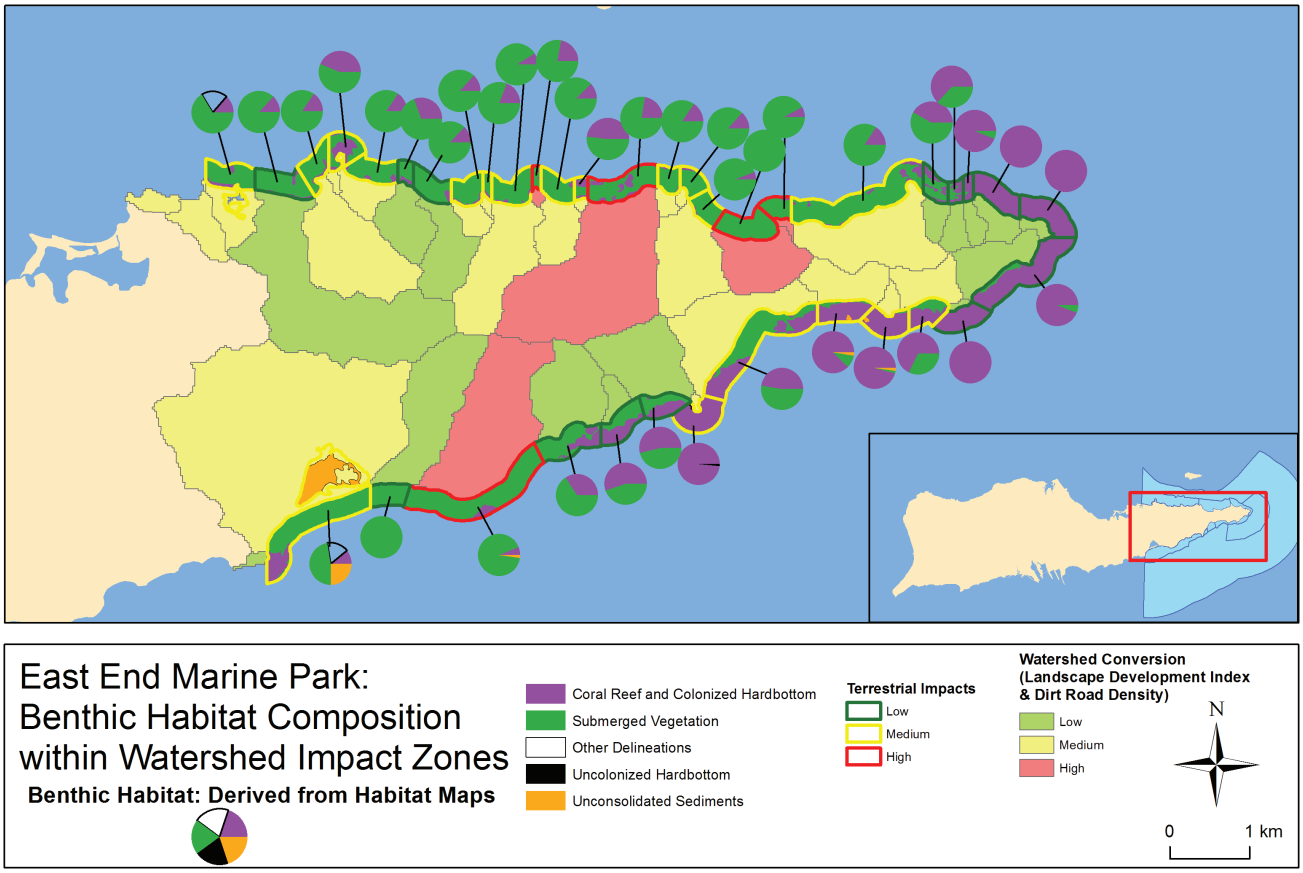

Figure 10.5. Benthic habitats mapped within watershed impact zones. Map by authors; data source: NOAA National Centers for Coastal Ocean Science.

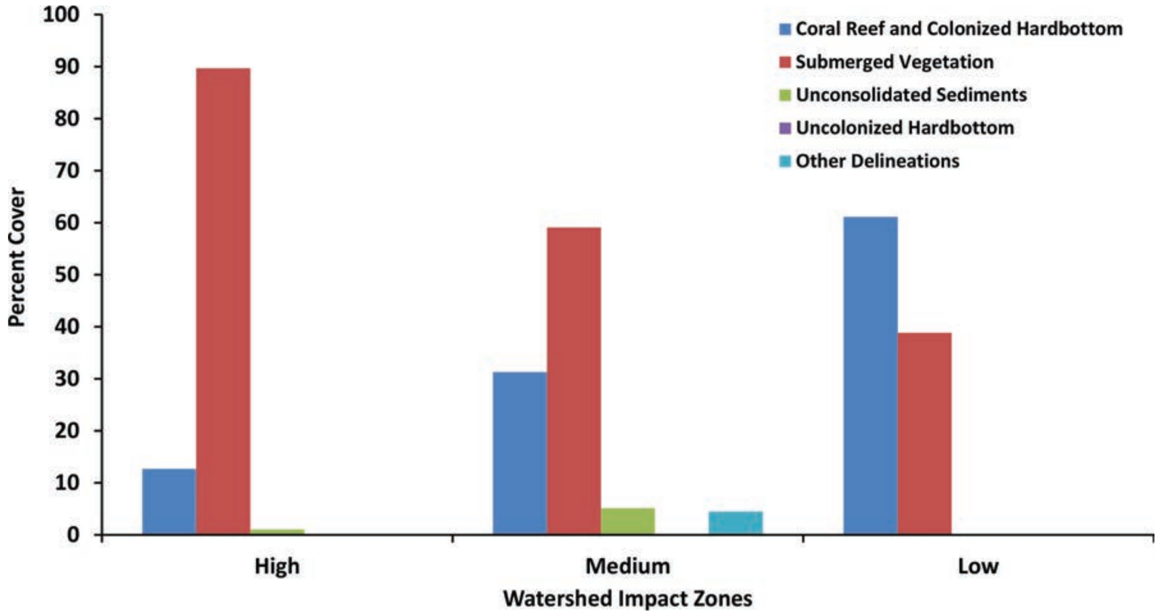

Figure 10.6. Graph of the distribution of habitat types within impact classes. Chart by authors; data source: NOAA National Centers for Coastal Ocean Science.

Based on the underwater surveys, the 300 m buffer contained primarily algae and sea grasses. Very little coral reef was found within the WIZs. The highest coral cover is found in Teague and Boiler Bays on the northeast end of the park. Figure 10.7 shows the composition of benthic habitat types for each of the WIZs, based on information collected through underwater surveys. Figure 10.8 shows benthic habitat composition within each impact class.

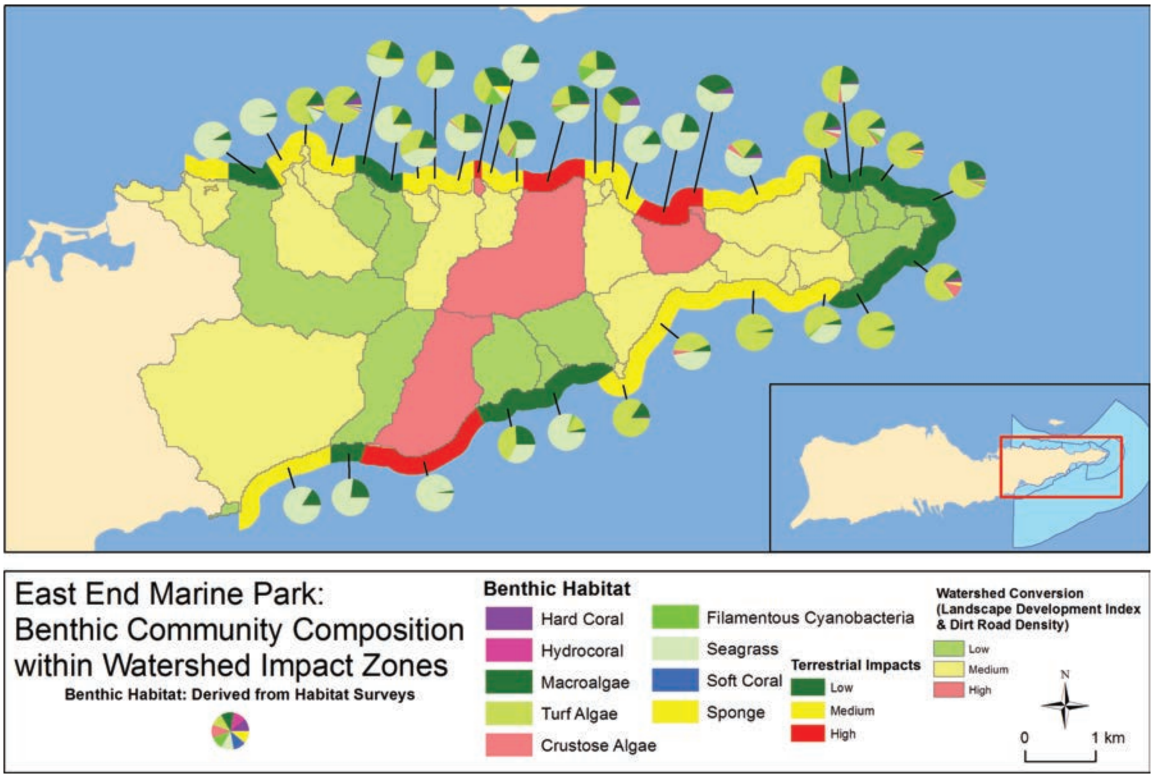

Figure 10.7. Benthic habitat composition as recorded from in situ surveys shown within watershed impact zones. Map by authors; data source: NOAA National Centers for Coastal Ocean Science.

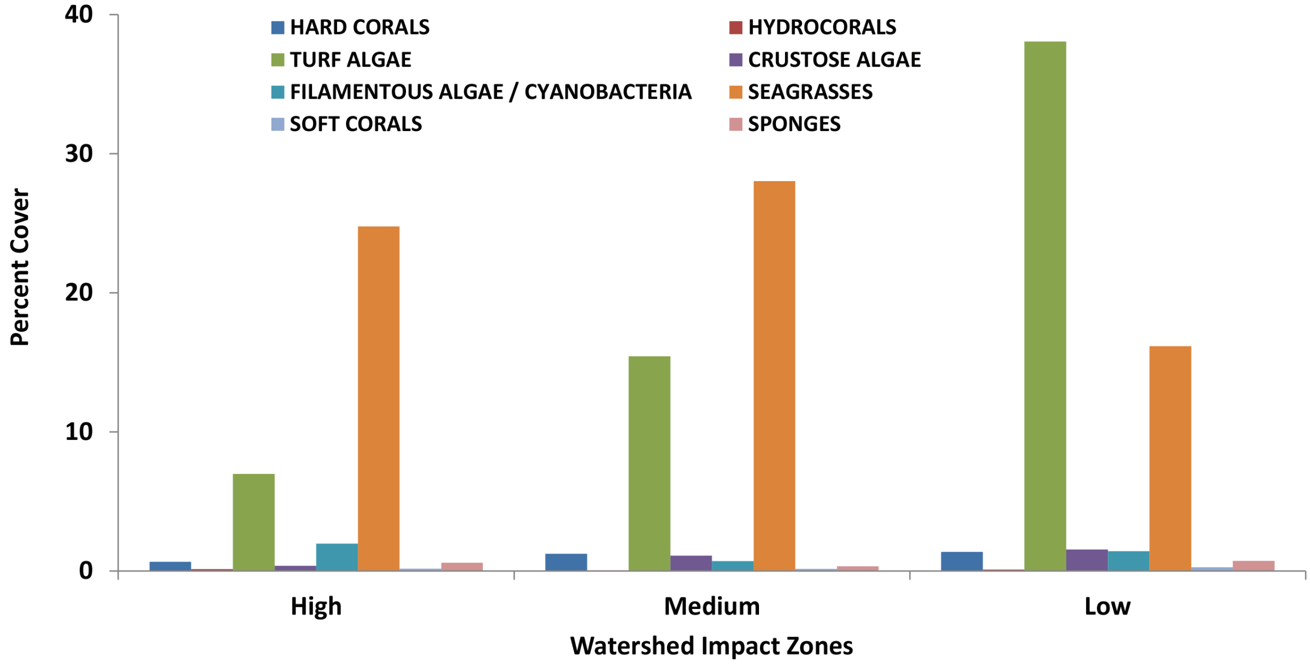

Figure 10.8. Graph of the distribution of habitat types within exposure classes of watershed impact zones based on National Oceanic and Atmospheric Administration underwater surveys. Chart by authors; data source: NOAA National Centers for Coastal Ocean Science.

Significant differences were detected among impact classes for three habitat types: hard corals occurring on hard substrate, turf algae on hard substrate, and hard corals in areas dominated by soft substrate. For hard corals occurring on hard substrate, the difference between medium impact and low impact was most significant, with hard coral habitats more abundant in areas classified as having medium terrestrial impact. There was also a difference in abundance between medium- and high-impact classes, with lower abundance in high-impact areas. A single site drove both of these results with nearly 33% coral cover occurring in an area classified as medium impact. This site is found in Boiler Bay. For turf algae on hard substrate, differences were significant between high and low classes and between high and medium classes. Turf algae distribution was greater in low and medium classes than in high. In areas dominated by soft-bottom substrate, significant differences were found between hard coral classes. Specifically, the difference was significant between high and low classes and between medium and low classes. For high-impact zones, the difference was driven largely by a single site with nearly 2% coral reef and colonized hardbottom cover.

Coral Reef Community

To assess the potential threat to coral species known to be sensitive to impacts from land-based sources of pollution, coral locations were mapped within the WIZs (300 m coastal buffer; figure 10.9). Elkhorn coral (*Acropora palmata*), a listed species in the Endangered Species Act (ESA), exists within the WIZs, primarily concentrated on the eastern tip of the island where watersheds are least developed. Staghorn corals (*Acropora cervicornis*) were not sighted within any of the WIZs.

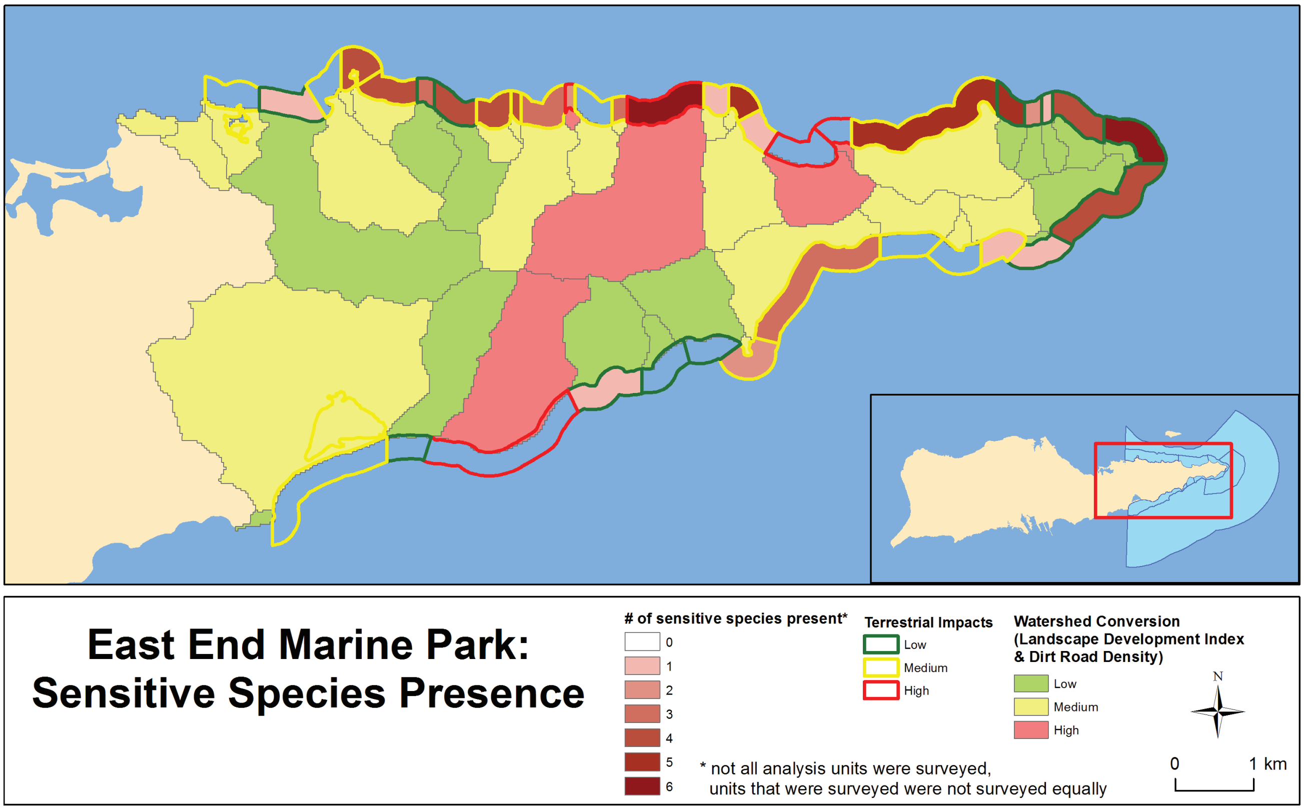

Figure 10.9. Sensitive species distributions within watershed impact zones. Map by authors; data source: NOAA National Centers for Coastal Ocean Science.

Brain coral (*Pseudodiploria strigosa*) was observed in 20 of 38 WIZs. Golfball coral (*Favia fragum*) was observed in 12 impact zone units along the north shore, and boulder star coral (*Orbicella annularis complex*) was observed in six units along the north shore. Yellow pencil coral (*Madracis auretenra*) was not observed within the impact zone. Finger coral (*Porites porites*) and mustard hill coral (*Porites astreoides*) were observed within 20 m and 17 m of the surveyed impact zone units, respectively. No significant differences were detected between threat classes when data on the distribution of sensitive coral species was combined (*Acropora palmat, Pseudodiploria strigosa, Favia fragum, Orbicella annularis* complex, *Madracis auretenra, Porites porites, and Porites astreoides*).

Many of the WIZs contained species that are known to be sensitive to sedimentation and land-based sources of pollution. Highest species richness for coral sensitive to sedimentation and pollution is found on the north shore of the park with varied exposure to threat (see figure 10.9). The Yellowcliff Bay watershed, containing six sensitive species, is estimated to be high threat, and several medium-threat impact zones along the northeast shore contain at least five species.

Sea grasses

Shoalgrass (*Halodule wrightii*) was observed in three WIZs. Paddle grass (*Halophila decipiens)* is known to be sensitive to land-based sources of pollution and was not observed in any of the analysis units. Manatee grass (*Syringodium filiforme*) was observed in 27 analysis units. Turtle grass (*Thalassia testudinum*) was widely distributed within the WIZs.

Discussion and Conclusion

On Caribbean islands, land-use patterns are an important concern to the conservation of coral reef ecosystems. Modifications to watersheds such as urbanization and agriculture have the potential to greatly increase erosion and sediment delivery to coastal waters. Many coral species are highly sensitive to declines in water quality caused by runoff of material from land. In response, best management practices in land development are being introduced to reduce erosion and runoff of land-based sources of pollution into coastal waters. The land-sea characterization presented here provides a technique to prioritize areas for management attention where potential threat to sensitive coral species is greatest.

We recognize that activities on land can influence the health of nearshore marine ecosystems. In particular, we understand that sedimentation and pollution delivered from land to coral reef ecosystems can kill corals and, by extension, negatively affect entire ecosystems. There are particular species of corals that are particularly susceptible to pollution and sedimentation. In this study, we highlight areas within the Saint Croix East End Marine Park where some of these species are present. The recognition of areas where sensitive species are present can assist coral reef managers in reaching their conservation objectives by highlighting the need for terrestrial management upstream of sensitive coral species. By reducing land-cover conversion and/or road development upstream of sensitive species, we can improve survival conditions for coral species of concern.

This study does not address the issue of how pollution or sediments are transferred from land to sea. It also does not address the complicated issue of exactly where benthic communities will be influenced by upstream watershed conditions. This study identifies areas that are expected to produce high levels of pollution and sediment and evaluates the composition of benthic communities associated with the areas expected to be impacted. When the Saint Croix East End Marine Park was established, it was recognized that the health of the ecosystems that the park was designed to protect would depend on both marine ecosystem management and management of the land adjacent to the park. Here, we hope to have identified one mechanism by which we can associate land-based management with its effects on nearshore marine ecosystems.

In this study, we found inconsistent results between our analysis of habitats from benthic maps and in-water surveys. From the mapped benthic habitats, we found coral cover decreasing where terrestrial impacts are greater and sea grasses increasing with greater terrestrial impacts. However, we did not find the same trend when we evaluated the information collected through underwater surveys. Here, we found greater coral cover in areas with medium terrestrial impacts. We expect that this discrepancy is a result of the limited number and uneven geographic distribution of surveys. The results of the survey information analysis appear to be driven by a single record where coral cover was recorded as 33%. This value is significantly different from the average value of 1.18% coral cover across the 190 surveys. We expect that greater survey effort and a more even geographic distribution of surveys might enable us to better track the impacts of terrestrial influence to direct observations of the benthic community.

Acknowledgments

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Supplemental Resources

For the digital content for this chapter, listed below in this section, go to the Esri Press "Book Resources" webpage at esripress.esri.com/bookresources.

Then, in the list of Esri Press books, click *Ocean Solutions, Earth Solutions*. On the *Ocean Solutions, Earth Solutions* resource page, click the chapter 10 link to access that webpage and view photos of sea life in the East End Marine Park, Saint Croix, US Virgin Islands. The photos were taken between 2007 and 2012 and are courtesy of the NOAA NCCOS Biogeography Branch. The photos include:

- Blackbar soldierfish (*Myripristis Jacobus*)
- Blue tang (*Acanthurus coeruleus*) in dense gorgonian habitat
- Coral within the park
- Elkhorn coral (*Acropora palmata*), an endangered species
- Finger coral (*Porites porites*)
- Large school of adult and juvenile grunts (family *Haemulidae*)
- Red hind (*Epinephelus guttatus*)
- Scuba divers collecting fish and benthic composition data