DEVELOPMENT AND LAND USE IMPACTS ON MARINE ECOSYSTEMS IN THE UNITED STATES VIRGIN ISLANDS (USVI)

by

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Executive Summary

Anthropogenic and natural stressors have long been a source of concern as related to water quality and coral reef health. On St. John in the United States Virgin Islands (USVI), where approximately 60% of the land belongs to the Virgin Islands National Park and the waters are protected by the Virgin Islands Coral Reef National Monument, maintaining coral reef health should be a high priority.

Many studies have been conducted in the USVI, however, most have concentrated on one or two stressors and their associated impact. A meta-analysis of this data was conducted in order to determine what correlations exist between land use, development, water quality and coral health. The analysis was conducted to link factors together that may not have been previously considered, and to validate whether or not further monitoring should encompass more parameters.

The basic analysis included combining watershed boundary data and associated assessment units, land cover change, and live coral cover information using ArcGIS, a geographic information system (GIS). This data was then used to identify areas that had the highest potential for impact due to anthropogenic sources, either directly through sedimentation, or indirectly from contaminants that are carried with sediment or other discharges.

A significant correlation ($p < 0.01$) was found between increased development and increased turbidity over a seven year period from 2005-2012. Turbidity is a measurement of the clarity of water. Increased turbidity detrimentally affects coral cover by limiting light penetration needed by photosynthetic algae called zooxanthellae which have a mutualistic relationship with coral. Coral health depends on the health of zooxanthellae.

The percentage of each watershed that was developed was determined by combining the areas of impervious surface and open spaced developed land use. This information was compared to the average turbidity readings for each watershed and a linear regression analysis was performed. The result is consistent with expected patterns, as the most developed watersheds are primarily outside of National Park boundaries and do not have as many constraints on development and usage. As land use changed in each of these watersheds, the

number of exceedances for turbidity also increased. Although turbidity is just one water quality parameter, it is an indicator of issues with runoff carrying sediment and sea floor disturbance.

Additional studies should be conducted to look at multiple parameters in each of the watersheds on St. John to better understand the way that pollutants travel through waterways and into the bays around the island. This would include a more thorough analysis of sources of impairment, historical information for sediment deposits, and a comprehensive review of change over time as it relates to both water quality and coral health. Currently the information available for coral cover is limited, which minimizes its use as an indicator. A more detailed analysis of coral and fish assemblages should be conducted and included in further studies to determine shifts and how they relate to each other.

Traditional ecosystem health assessments are complex. Research shows a growing need to expand study inputs and relate them to each other to determine how to appropriately manage these areas. Management plans have not been adequately designed to address the complexity of ecosystems. Management decisions must be made after gaining a better understanding of how elements within ecosystems interact with one another. Most environmental managers have limited resources to pursue projects needed to improve ecosystem health. Better data and improved modeling systems provide managers with the tools needed to decide what projects will be the best use of their resources.

Lastly, consistent enforcement of existing regulations would also improve ecosystem health in the surrounding area. Issuing appropriate permits, increasing on-site compliance inspections and more stringent enforcement of existing regulations would hold those with the highest potential for impacting fragile ecosystems accountable for their actions. A lack of regulatory oversight can adversely impact coral reefs surrounding the island. The need for protection is evident, as tourism associated with coral reefs in the USVI accounts for almost 30% of the gross domestic product.

Setting aside marine protected areas, National Parks, and National Monuments are a great first step in protecting valuable natural resources. However, designations alone cannot keep these areas safe from anthropogenic and natural stressors and their impacts. A delicate balance between use, protection, and preservation must be made to keep them in good condition for future generations.

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Introduction

Development in coastal regions poses a significant problem worldwide. With estimates that 40% of the world's population occupies coastal zones (United Nations, 2007), management programs must be robust to ensure degradation of associated ecosystems does not occur.

Development in the United States Virgin Islands (USVI) comes at a cost to marine ecosystems surrounding the islands. Improper management of anthropogenic sources of pollution over time can cause a decline in marine ecosystem health, especially in near-shore coral reef habitat.

Previous research, particularly on coral populations around the USVI, shows a decline in ecosystem health many reasons including both anthropogenic and natural stressors (Rogers & Beets, 2001) (Rogers & Miller, 2006) (Smith, et al., 2008). Current literature primarily focuses on individual causes to include climate change, runoff from development and other human use, removal of wetlands and mangroves, hurricanes, coral disease and changing water quality due to pollutant loading from a variety of sources. Taking an integrated approach to link the causes of degradation together and relating their overall effect on the marine ecosystems of this area will assist managers in developing management practices uniquely related to the USVI.

Tourism and other services attributed to near-shore marine ecosystems are directly impacted by development and land use, particularly in the USVI (Ramos-Scharron & MacDonald, 2007). Looking at just one variable such as sediment delivery from unpaved roads shows a significant impact. Models have predicted that erosion from unpaved roads in the USVI can have an increase in sediment yields up to four times above background (Anderson & MacDonald, 1998) (Ramos-Scharron & MacDonald, 2005).

This sediment has the potential to reduce productivity of reef systems for the purposes of tourism. In general, it is estimated tourism associated with coral reefs provides up to 80% of income in small tropical and subtropical island nations (Carbery, Owen, Frickers, Otero, & Readman, 2006) (Ennis, Brandt, Wilson-Grimes, & Smith, 2016). Surveys conducted by van Beukering et al (2011) found that almost half of visitors cited their trip to the USVI was related to coral reefs. If reef health declined, survey results indicate that return visitors from this subset would drop again by almost half. This suggests that the economy would be significantly impacted if coral cover and health were to decline, as tourism accounts for approximately 30% of the gross domestic product (GDP) in the USVI (The World Travel and Tourism Council, 2015).

Coral reefs have long been recognized in this region as an important resource in need of protection. The Buck Island Reef National Monument on St. Croix was established in 1961, and the Virgin Islands National Park (VINP) on St. John was established in 1956. Marine areas were added to the VINP in 1962. These are two of the first marine protected areas (MPAs) established in the United States (Rogers & Beets, 2001). Additionally, the Virgin Islands Coral Reef National Monument (2001) was established to further protect the shoreline and a 3 mile belt in the waters surrounding St. John.

Sediment has impacts on other near-shore ecosystems as well. Seagrass beds, which are a primary food source for endangered green sea turtles, can be affected by sediment from both runoff and disturbance from construction activities or storms. Recent information published by Rogers et al (2014) shows that an invasive species of seagrass called *Halophila stipulacea* is spreading quickly through the Caribbean Sea. The invasive species takes advantage of sediment disturbances as it is faster-growing and outcompetes native species. It is unknown at this time if the invasive seagrass will affect coral communities, turtles, and fish assemblages in the region in a positive or negative manner. Understanding the adjacency effects on the many near-shore habitats from sedimentation and associated changes in ecosystem composition is critical to preservation of the overall environmental health in the USVI.

Research conducted in other National Parks indicates that multiple criterion must be evaluated and that long-term monitoring data are needed to determine trends that can be used to prioritize management activities in fiscally constrained times (Brown, et al., 2016). Brown et al (2016) demonstrated through a series of case studies that combining parameters such as benthic marine community assemblages, fish abundance, and water quality data for both surface and groundwater can provide ecosystem “vital signs”. Evaluations of these signs are needed to ensure focused management decisions are made.

A watershed and ecosystem based approach provides managers with comprehensive data needed to determine specific sources that must be mitigated to minimize impacts in the associated near-shore environment. Similar factors as those studied by Brown et al (2016) must be evaluated for the USVI. By doing so, a clearer picture of strategies needed to maintain or improve ecosystem health should emerge.

Objective

The focus of this project was to evaluate pollutant loading implications from development and other associated changes in land use on marine ecosystems surrounding St. John, USVI. Existing Geographic Information System (GIS) data was used to estimate the percentage and type of development in each watershed on St. John. This included an analysis of land cover change with a focus on impervious and developed open space. Erosion potential associated with the slope and soils for each watershed were also evaluated.

In order to determine correlations by watershed, development patterns, available water quality data, and information on near-shore marine habitats were analyzed. Additionally, existing regulations and permits were reviewed to look for gaps that may indirectly impact ecosystem health.

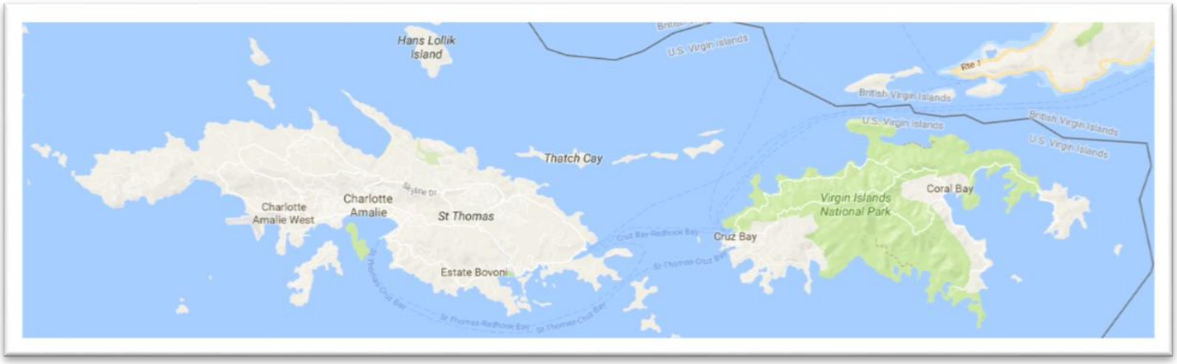
After an initial analysis of available data and a literature review, it was determined that the focus of this project should be on St. John exclusively. Similar studies of both St. Croix and St. Thomas (Oliver, Lehrter, & Fisher, 2011) (Ennis, Brandt, Wilson-Grimes, & Smith, 2016) (Sabine, Smith, Williams, & Brandt, 2015) have already been conducted. Information will be included in this report for St. Croix and St. Thomas to provide comparisons and context for data from St. John.

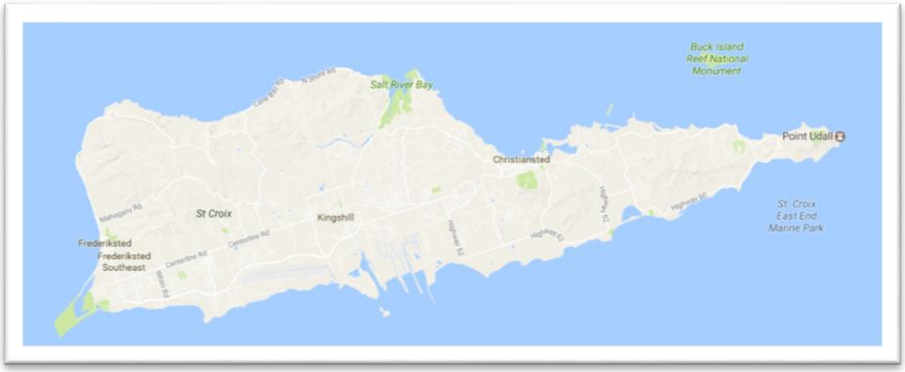
Background

The territory of the USVI consists of St. Thomas, St. John, and St. Croix, plus 57 additional smaller islands and cays for a total of approximately 136 square miles or 110,000 acres (DPNR, 2014). The USVI are located in the northeastern Caribbean (Figure 1) (Brooks, Larson, Devine, & Schwing, 2015).

Figure 1 - Location of USVI

Source: NOAA





Source: Google

The USVI are characterized by their subtropical dry climate (Ramos-Scharron & MacDonald, 2007) with mean annual rainfall ranging from 28.81-47.89 inches per year (NOAA, n.d.). A summary of each island by size and population is provided in Table 1 below.

Table 1 - Characteristics of Virgin Islands Watersheds and Islands

	St. Croix	**St. Thomas**	**St. John**	**Total**
Population	51,389	54,259	4,014	109,661
Land Area (mi²)	84	32	20	136
Land Area (acres)	53,499	17,489	12,323	83,311
Tidal/sub-tidal Wetlands (mi²)	2.5	2.4	1.1	5.9
Coastal Shoreline	70.3	52.8	49.7	172.8
Embayments (mi²)	1.5	0.9	0.1	3.5

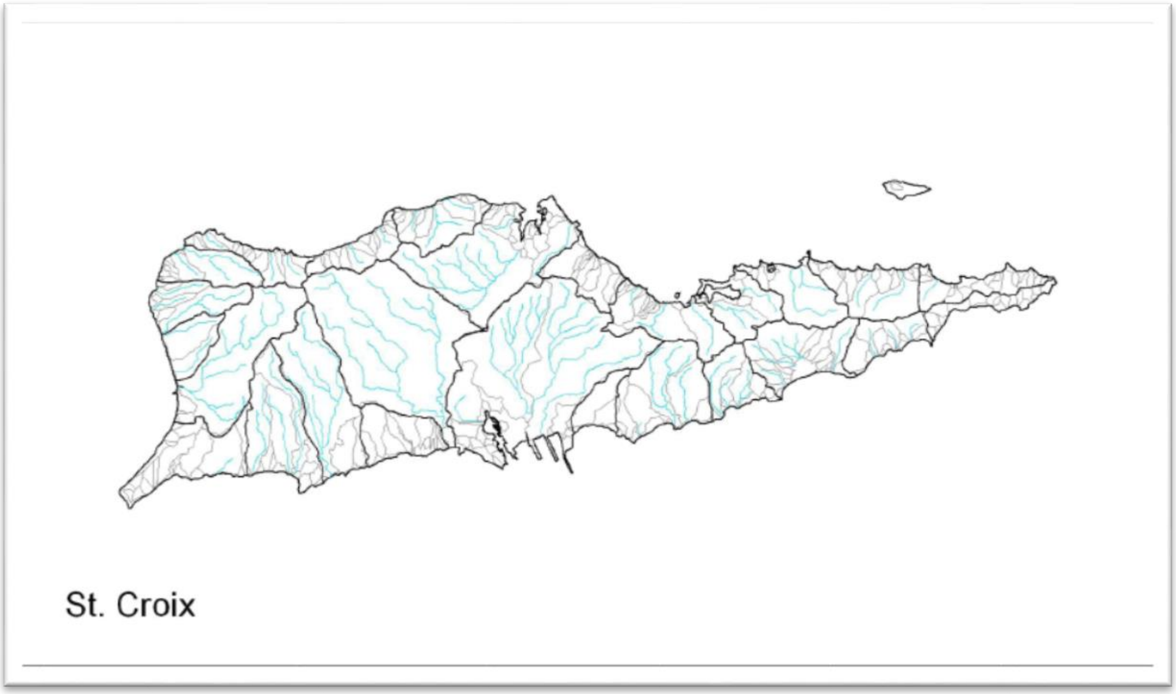
Source: USVI Integrated Water Quality Monitoring & Assessment Report (2014)

St. Thomas and St. John are of volcanic origin, exhibiting steep, rugged terrain and irregular coastlines. St. Croix, which is located approximately 50 km to the south of St. Thomas and St. John, is of sedimentary origin and is therefore less rugged, consisting primarily of rolling hills with a straighter coastline (Brooks, Larson, Devine, & Schwing, 2015).

Intermittent watercourses, locally called “guts”, provide drainage as there are no permanent rivers or streams in the USVI. The topography of the islands, drainage networks and rainfall patterns lead to flashy flows of water through the guts that make studying the relationship between sediment deposits, rain events, and their associated impacts easier. Guts either exit directly into a bay, or into a salt pond that can trap runoff, limiting the amount of sediment that can make it to fragile ecosystems and producing a chronological record of deposition (Brooks, Larson, Devine, & Schwing, 2015).

Figure 2 depicts watershed boundaries for each of the islands, showing how water will move through each (WRI & NOAA, 2005). The figures were developed as a collaboration between the World Resources Institutes (WRI) “Reefs at Risk” project and the National Oceanic and Atmospheric Administration’s (NOAA) “Summit to Sea” project. The dark lines represent the 53 watersheds tracked by the USVI Department of Planning and Natural Resources (DPNR), where each watershed reflects a large area that discharges to a single bay. Light gray lines represent over 400 basins with a minimum area of 6 hectares. The basins each have a single point where they discharge to the Caribbean Sea. Blue lines represent guts.

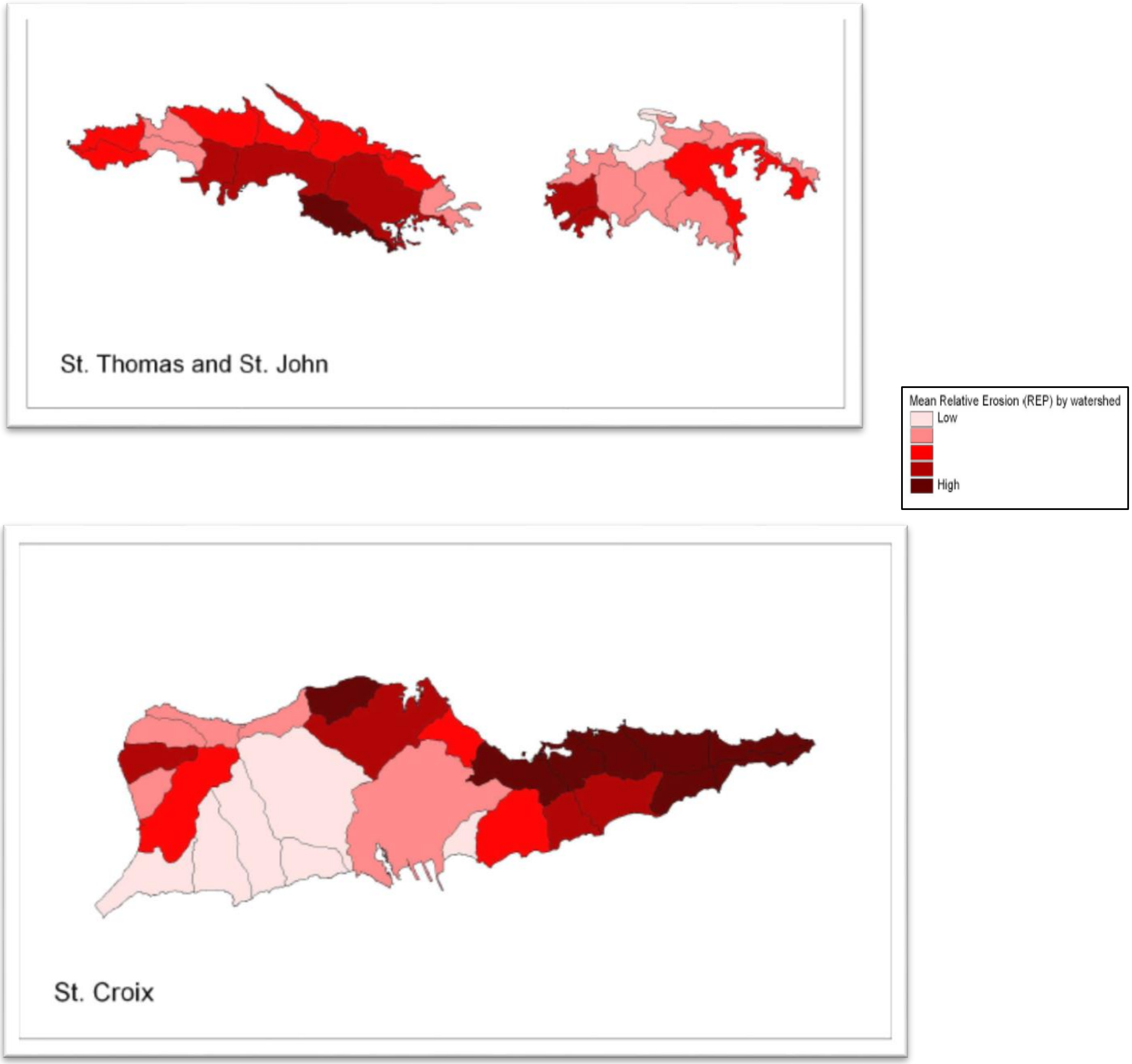
Figure 2 - Hydrology in the USVI



Source: World Resources Institute and NOAA (2005)

The same collaboration devleoped maps for each island for relative erosion potential based on a multitude of factors. The project utilized a simplified Revised Universal Soil Loss Equation (RUSLE) from the US Department of Agriculture (USDA) and looked at land cover type, slope, soil erodibility (k-factor), and precipitation to determine relative erosion potential (Figure 3) (WRI & NOAA, 2005). This data is useful when planning development, as areas with a high potential for erosion can be avoided.

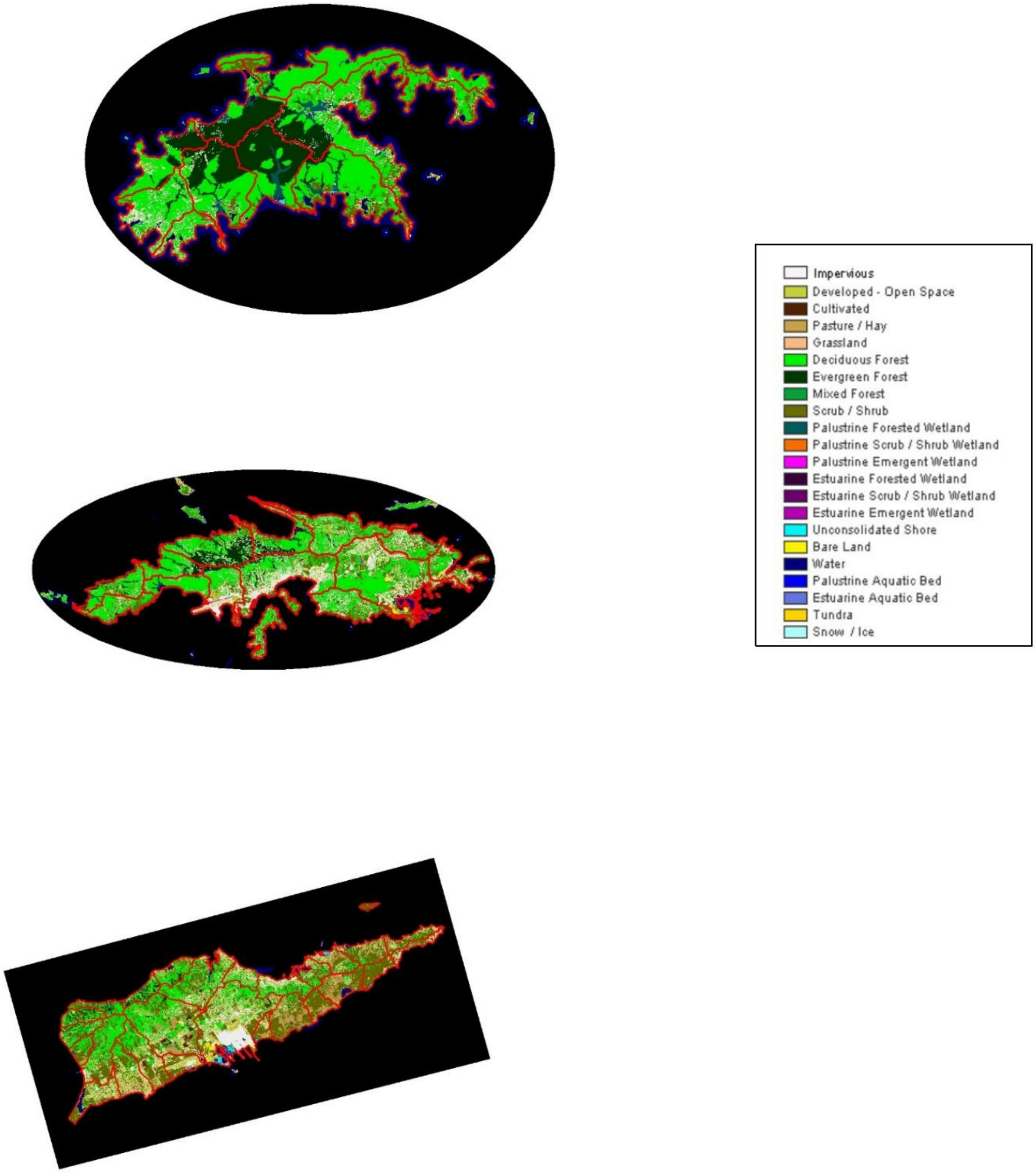
Figure 3 - Relative Erosion Potential by Watershed



Source: World Resources Institute and NOAA (2005)

NOAA’s Coastal Change Analysis Program (C-CAP) shows land cover for each island, which is provided in Figure 4 for reference. Land cover data is available for the USVI beginning in 2002 and ending in 2012. The most recent data (2012) is shown in Figure 4. Land cover has been classified into 18 categories as presented in the associated legend (N. Herold & R. Mataosky, personal communication, November 2016).

Figure 4 - Land Use by Category



Source: NOAA C-CAP Data

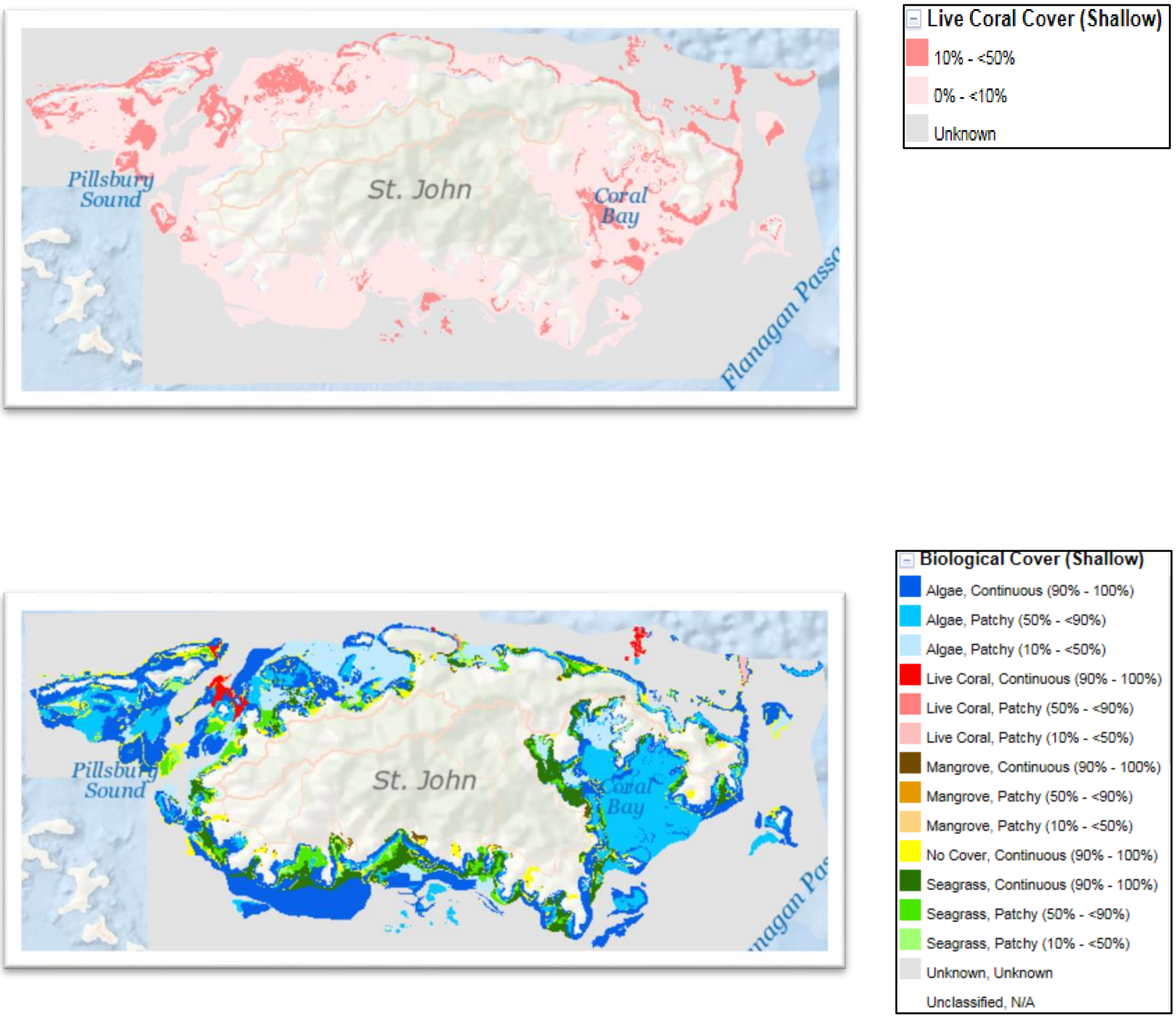
Land cover has been classified into 18 categories as presented in the associated legend (N. Herold & R. Mataosky, personal communication, November 2016). Categories range from bare land, developed, impervious, cultivated, wetland and forested or other vegetatively covered areas. The type of land use is an important factor in determining what type of pollutant load to expect in the associated watershed and how to mitigate those sources. For example, impervious and developed areas typically have higher loads of sediment, pathogens, and residual compounds from petroleum based products than one would see from forested or vegetated areas. A watershed with this type of land use would need to use a mitigation strategy such as a constructed wetland that would help remove those pollutants from water prior to discharging into the Caribbean Sea.

Coral cover information has been mapped through NOAA’s National Centers for Coastal Ocean Science (NCCOS, 2016). All three islands were mapped in 2002 to summarize benthic habitat. Buck Island was mapped in 2012 for coral cover and benthic habitat. In 2013, another mapping event covered the St. Thomas East End Reserve (STEER), and Fish and Coral Bays on St. John. The most comprehensive data as related to this project is from the St. John BIOMapper project from 2009 and is presented in Figure 5.

Shallow-water (<30 m) and moderate-depth (30-60 m) coral reefs have been mapped, to include the biological cover for both habitats. For this analysis, only shallow-water data is included. The live coral cover layers are divided into three categories for shallow-water systems: 10 - <50%, 0 - <10%, and unknown. For biological cover, 14 categories are presented to include three different degrees of algae, live coral, mangrove, and seagrass cover, and then either no cover or unknown.

Coral cover was used as a general indicator of near-shore ecosystem health, with low live coral cover used as a measure of a potentially impaired habitat or watershed. Coral cover is difficult to analyze beyond 10% intervals (T. Battista, personal communication, March 2017). As shown in Figure 5, most near-shore areas fall in to the lower level of coral cover (0% - <10%), with the exception of bands of higher cover (10% - <50%) around some of the north shore bays that are associated with the National Park.

Figure 5 - Shallow Water Coral Cover and Biological Cover St. John



Source: NOAA NCCOS St. John BIOMapper (2009)

Knowledge of land use, erosion potential, and how water moves across the landscape is important for understanding where the areas of highest risk are for potential impacts to near-shore marine ecosystems. Further analysis can be made by looking at historical water quality data trends in these high risk areas to determine if a correlation exists linking land use, erosion potential, water quality, and ecosystem health together.

Materials and Methods

For this project, I conducted a meta-analysis of existing data related to land use and development, erosion potential, water quality, and ecosystem health to determine if there is a correlation between all of these factors.

Land use information was obtained from NOAA's available data sets from C-CAP and the Land Cover Atlas tools. This dynamic data has been analyzed to show the land cover change from 2005- 2007, and then from 2007-2012 to show the percent change by land cover by type for each watershed. The relative erosion potential information was obtained from WRI and NOAA (2005).

Watershed delineation maps, assessment unit (AU) information, water sampling points and Beaches Environmental Assessment and Coastal Health (BEACH) Act sites were obtained from USVI DPNR (B. Keularts, personal communication, October 2016). Water quality data was pulled from available information on the Environmental Protection Agency's (EPA) Storage and Retrieval (STORET) database.

Coral health indices were derived from NOAA's NCCOS St. John BIOMapper information. It is assumed that low live coral cover equates to a potentially impaired habitat for the purposes of this analysis as described in the previous section.

Available data layers from these organizations were combined in ArcGIS for trends analysis. This basic analysis gives a starting point for where to look for anomalies in water quality data. For instance, if development in a specific watershed is high and coral health for the watershed is low, water quality data would be analyzed to look for exceedances and potential sources of impact.

After reviewing ArcGIS data, available water quality data from STORET listed by sample point was pulled for St. John. For this analysis, each sample point was coded to relate to its corresponding Assessment Unit Identification code (AU ID) and watershed. Data prior to 2005 or after 2012 was included in the analysis for reference, though land use change from NOAA was only available from 2005 to 2012. A similar summary was completed as part of the National Park Service Inventory and Monitoring (I&M) Program in 1995 utilizing data from the STORET database from 1969-1995 (US Department of the Interior, 1995). This data was not analyzed for this report as land cover change data was not available for this time frame.

Data was then summarized per AU per year from 2000-2016. The mean of available water quality data for each of the parameters listed in Table 2 were used for each year to give a single data point, and were compared to existing standards for the USVI. It should be noted that the availability of data for both Phosphorus and Kjeldahl Nitrogen was limited due to lab availability and quality assurance issues (DPNR, 2014). Additional analysis of turbidity data was conducted to provide more information on frequency of exceedances from 2005 to 2012 to determine trends between this parameter and percent development in each watershed.

Table 2 - Evaluated Water Quality Parameters by Class of Coastal Water

	Class A	Class B	Class C	Summary of Measurement
Dissolved Oxygen (DO)	Existing natural conditions shall not be changed. The biological condition shall be similar or equivalent to reference condition for biological integrity. In no case shall Class B water quality standards be exceeded.	Not less than 5.5 mg/l	Not less than 5.0 mg/l	DO is needed to support aquatic life. When concentrations are too low, aquatic life can die
Enterococcus		Not to exceed a geometric mean of 35 enterococci per 100 ml, not to exceed a single sample maximum of 104 per 100 ml at any time.	Not to exceed a geometric mean of 35 enterococci per 100 ml, not to exceed a single sample maximum of 104 per 100 ml at any time.	Indicator of pathogenic bacteria, viruses and parasites from human or other warm blooded mammals. Can be used as a substitute measurement for coliform.
Fecal Coliform		A geometric (log) mean of 70 fecal coliforms per 100 ml by MF or MPN count	A geometric (log) mean of 200 fecal coliforms per 100 ml by MF or MPN count	Indicator of pathogenic bacteria, viruses and parasites from human or other warm blooded mammals
Kjeldahl Nitrogen		No numerical criteria listed	No numerical criteria listed	High levels cause excessive growth of aquatic plants and algae leading to low oxygen levels and reduced light attenuation
pH		<8.3 Tolerable Limit >7.0	<8.5 Tolerable Limit >6.7	Influences solubility and biological availability of nutrients and heavy metals
Phosphorous		Shall not exceed 50 ug/L in any coastal waters	Shall not exceed 50 ug/L in any coastal waters	Can cause excessive growth of aquatic plants and algae leading to eutrophication
Salinity		No numerical criteria listed	No numerical criteria listed	Amount of salt present in a water body
Temperature		Not to exceed 32° C at any time, nor as a result of waste discharge to be greater than 1° C above normal.	Not to exceed 32° C at any time, nor as a result of waste discharge to be greater than 1° C above normal.	Governs biological activity and growth and influences water chemistry
Total Suspended Solids (TSS)		None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters	Solids not in true solution that can be removed via filtration. Contributes directly to turbidity measurements.
Turbidity		A secchi disc shall be visible at a minimum depth of one meter or a maximum nephelometric turbidity unit reading of three (3) shall be permissible	A secchi disc shall be visible at a minimum depth of one meter	Affects light penetration, altering photosynthesis. Particles also allow for attachment of other pollutants such as bacteria or metals.

Source: USVI Integrated Water Quality Monitoring & Assessment Report (2014) and United States Geological Survey (USGS).

Table 2 provides the existing water quality standard for each parameter based off of class of water. The USVI classifies its waters as Class A, B, and C based on designated uses. Definitions of each class from the USVI Integrated Water Quality Monitoring & Assessment Report (2014) are listed below:

Class A: waters for the preservation of natural phenomena requiring special conditions with existing natural conditions that shall not be changed. Conditions for Class A waters cannot be altered except toward natural conditions. Class A water standards are the most stringent of the three classes because of its pristine or near-pristine state.

Class B and C waters are designated for maintenance and propagation of desirable species of aquatic life (including threatened, endangered and indigenous species) and primary contact recreation.

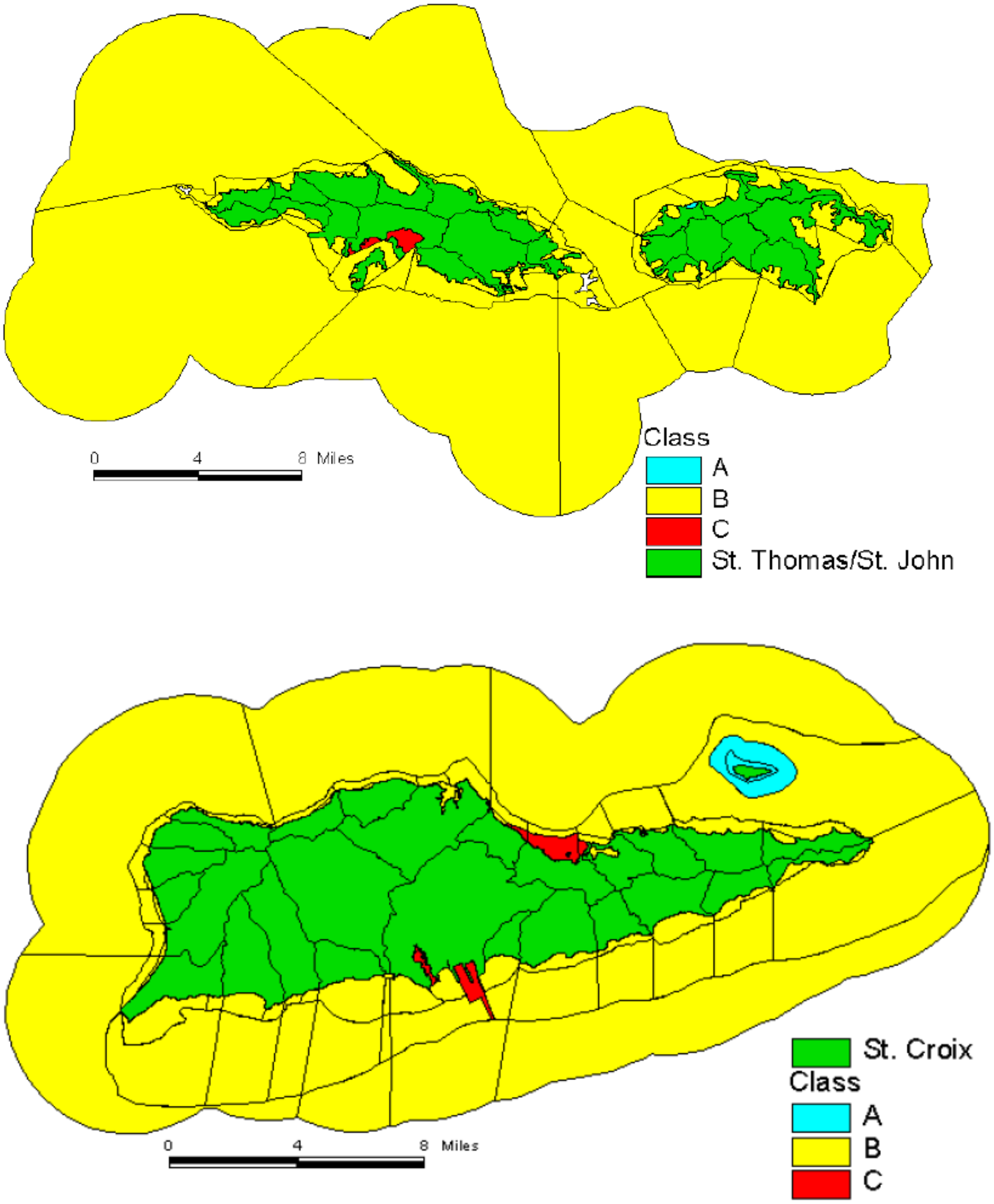
Class C waters have less stringent water quality standards than Class B.

Source: USVI Integrated Water Quality Monitoring & Assessment Report (2014)

There are very few Class A waters in the USVI. They are limited to the area surrounding Buck Island's Natural Barrier Reef on St. Croix, and Trunk Bay on St. John. Class C waters are typically associated with heavy industrial use such as the Hess Oil Virgin Islands Harbor (oil refinery) on St. Croix, Enighed Pond Bay on St. John (shipping and barge traffic), and St. Thomas Harbor, St. Thomas (shipping, barge and cruise ship traffic).

For the purposes of this paper, an exceedance of the Class B standard was considered an exceedance for overall water quality. Figure 6 depicts each watershed, associated AU's, and the class of water for each. AU's will be described in more detail in the Results section.

Figure 6 - Watersheds and Associated Assessment Units by Water Class



Source: USVI Integrated Water Quality Monitoring & Assessment Report (2014)

Each watershed was then evaluated by looking at available land use change data from NOAA. In this dataset, development in each watershed was listed by type for 2005, 2007, and 2012 for St. John, with change data summarized for 2005-2007, and then from 2007-2012. Land use change information for both of these time periods is presented in Figures 8a and 8b, and a summary is provided in Table 3.

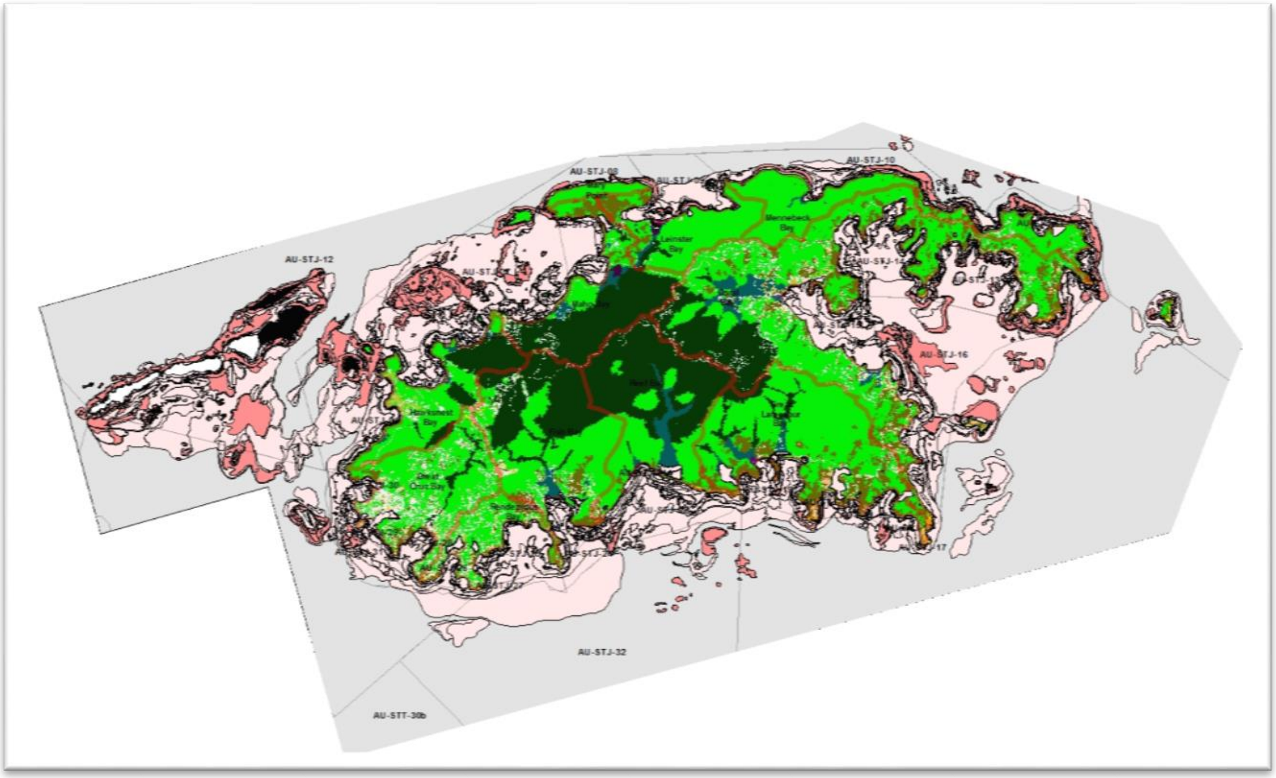
Coral cover data obtained from NOAA's NCCOS St. John BIOMapper (2009) is also included in Figures 8a and 8b. By evaluating the live coral cover as it relates to watershed development, low live coral density and high percentage change in development should correlate with each other. These locations should in turn show more exceedances in the water quality data.

Finally, a review of both the EPA and USVI DPNR's regulations, policies and permitting procedures was conducted. This review will be used to help develop recommendations for strategies or policy changes to implement to improve ecosystem health.

Results/Observations

After combining land cover data from 2012, watershed boundaries, AU boundaries, and coral cover data into one map, a more thorough analysis was conducted. This visual representation in Figure 7 quickly directs attention to areas with low coral cover and high development. A review of water quality data for exceedances in the associated AU's allows one to determine if this data corresponds to areas with lower coral cover. Once at risk watersheds are identified, a thorough review of potential inputs and corresponding mitigation factors can be conducted.

Figure 7 - Summary Map St. John



A review of land cover change data from NOAA aids in focusing where to look for poor water quality trends over a specific time period. By determining where the most significant amount of change has occurred from 2005-2012, water quality can be correlated to the development data. Land cover change information from 2005-2007 and 2007-2012 for St. John is shown in Figures 8a and 8b.

Evaluating data from NOAA's NCCOS St. John BIOMapper (NCCOS, 2017) shows that live coral cover is predominantly low around the most developed watersheds unless further off shore or otherwise affected by water movement within a bay. Coral cover increases in relation to areas associated with the National Park, with higher live coral cover bands along some of the north shore bays. Low live coral density and a high percentage change in development are related, as shown in Figures 8a and 8b.

Figure 8a - Land Use Change 2005-2007

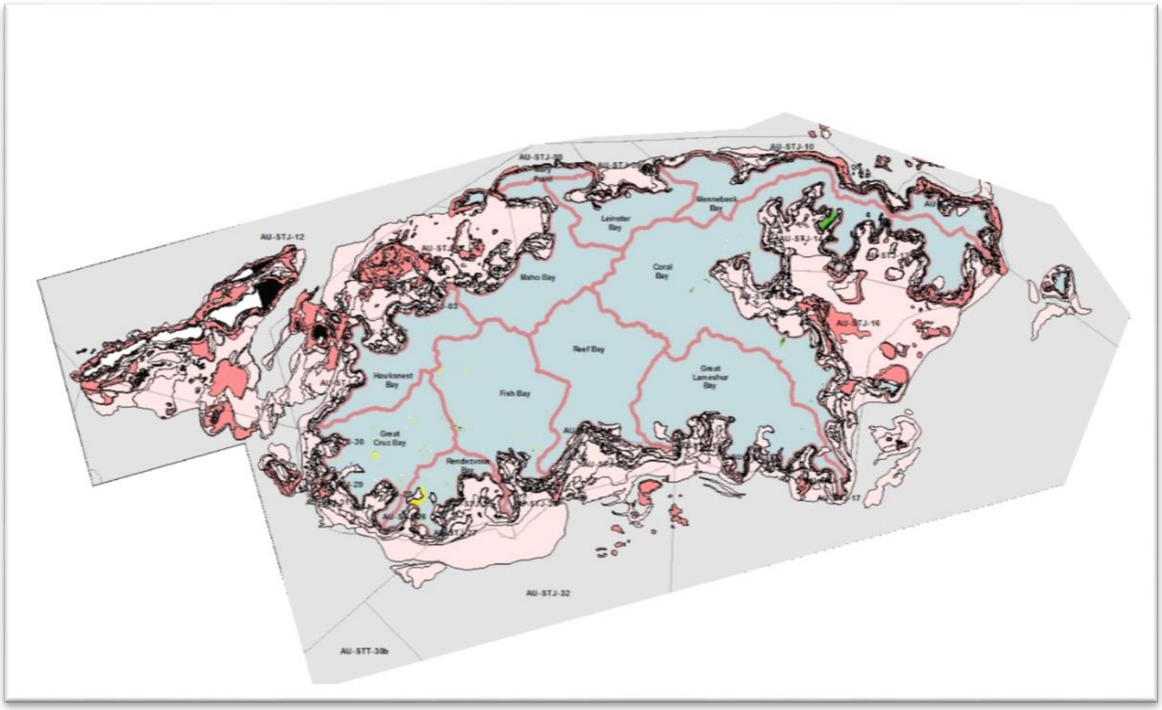
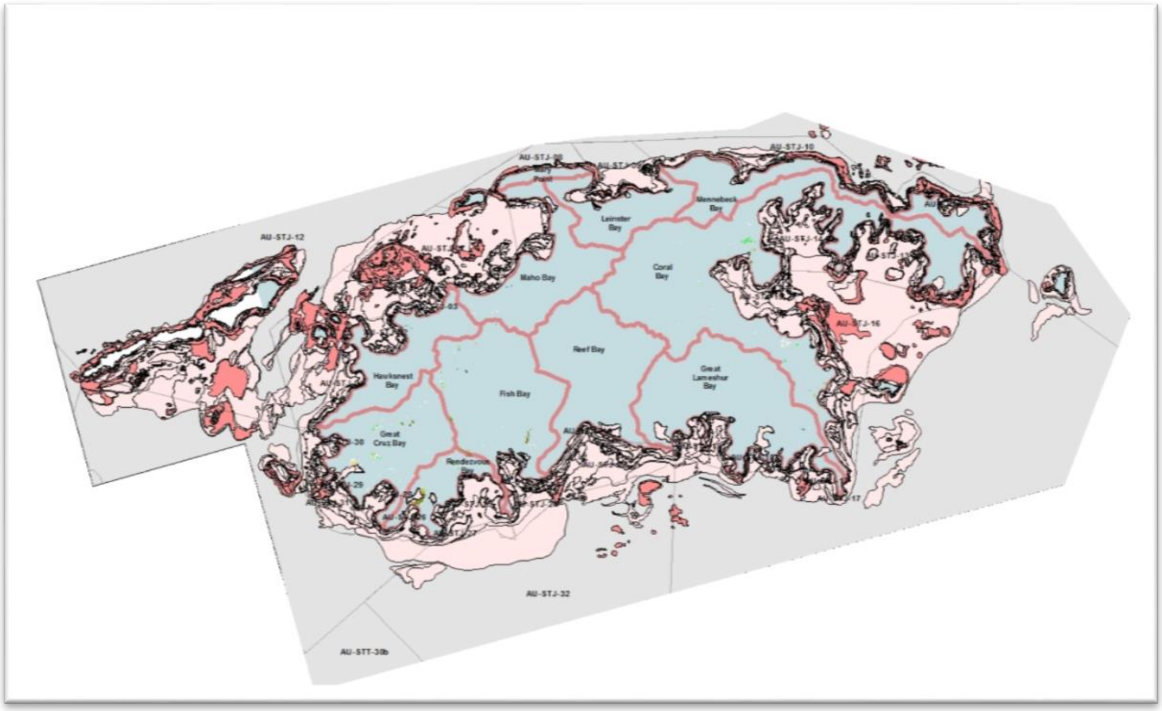
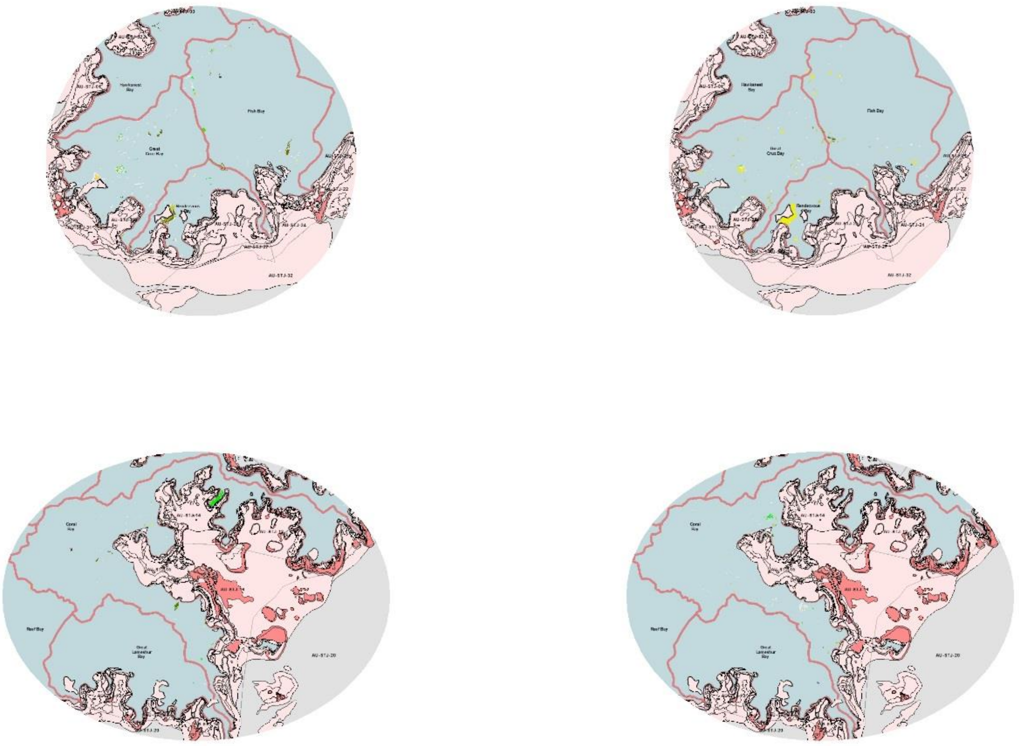


Figure 8b - Land Use Change 2007-2012



Through an evaluation of the ArcGIS data, one can see that the most land cover change occurred in Fish, Great Cruz, Rendezvous, and Coral Bays (see Figure 9). These bays are also categorized as having low live coral cover (0-10%) (NCCOS, 2017), and their watersheds were rated as having medium to high mean relative erosion potential (WRI and NOAA, 2005). These four bays are primarily outside of both the National Park and National Monument boundaries, and therefore are subject to additional development such as housing, businesses, or industrial areas.

Figure 9 – Development and Coral Cover for Fish, Great Cruz, Rendezvous and Coral Bays



2005-2007 **2007-2012**

A summary of watershed characteristics based on the land use change data from the NOAA C-CAP Land Cover Atlas information (N. Herold, personal communication, March 2017) is presented in Table 3. The percent developed column is the sum of the impervious surface and developed open space layers. The total change column represents change from all layers from 2005-2012 to show overall shifts in land use. Watershed slope is included from a separate survey (The Cadmus Group, Inc., 2011) to show general erosion potential from run off, with a higher slope indicating higher potential for impacts.

Table 3 - Summary of Watershed Development, Change and Slope

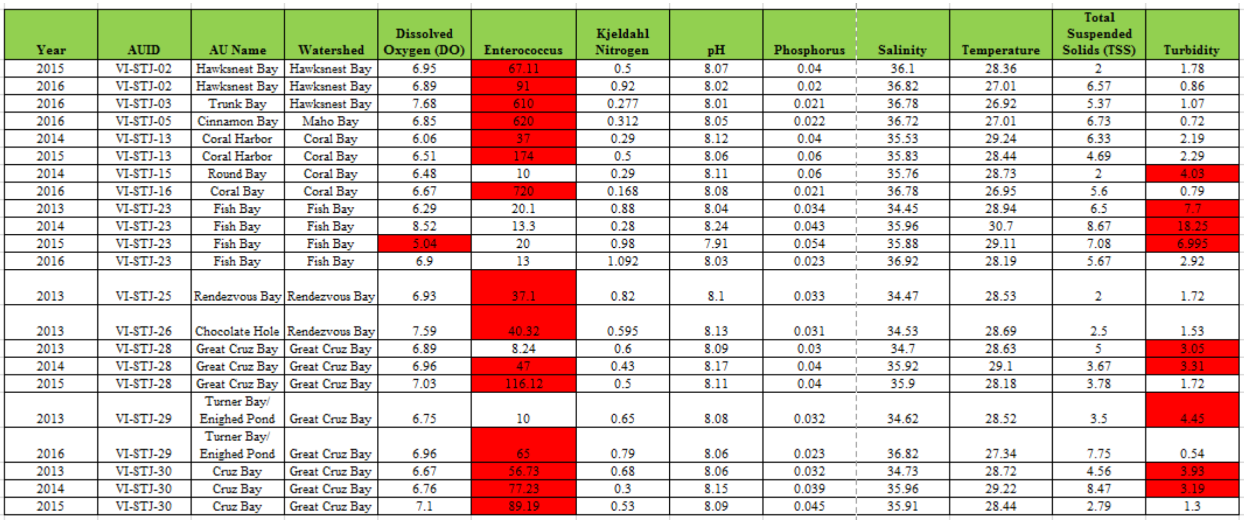
Watershed	Area (Acres)	Percent Developed (2012)	Percent Total Change (2005-2012)	Watershed Slope
Mary Point	109.91	0%	0%	56%
Leinster Bay	612.12	1.58%	13.17%	38%
Mennebeck Bay	812.58	1.36%	31.50%	36%
Hawksnest Bay	776.73	8.73%	-2.46%	35%
Maho Bay	984.1	4.32%	3.14%	40%
Coral Bay	3,005.5	9.44%	51.02%	37%
Great Lameshur Bay	1,679.5	1.78%	27.78%	37%
Reef Bay	1,395.36	1.18%	-95.33%	42%
Fish Bay	1,487.58	6.75%	207.26%	32%
Great Cruz Bay	1,037.58	24.82%	117.18%	28%
Rendezvous Bay	419.58	23.12%	46.11%	31%

Source: NOAA (2017) and the Cadmus Group, Inc. (2011)

A review of information provided in Table 3 indicates that the same four bays predicted from a review of ArcGIS layers are those with the most total change in development in the seven year period evaluated. Water quality data for these bays was then evaluated for exceedances.

Many gaps exist in the STORET database for water quality data. The most comprehensive and complete set of information encompassed 16 AU's and 9 water quality parameters from the years 2009-2016. For simplification, a summary of just those sample points that exceeded a water quality standard for Class B waters, which are more stringent than Class C water standards, are provided in Table 4. Almost all of the exceedances occurred within AU's associated with Fish, Great Cruz, Rendezvous and Coral Bays and are associated with only three parameters: dissolved oxygen, enterococcus, and turbidity. Enterococcus exceedances that fall within Maho and Hawksnest Bays are likely attributed to high human recreation use.

Table 4 - Summary of Sampling Results



Year	AUID	AU Name	Watershed	Dissolved Oxygen (DO)	Enterococcus	Kjeldahl Nitrogen	pH	Phosphorus	Salinity	Temperature	Total Suspended Solids (TSS)	Turbidity
2015	VI-STJ-02	Hawksnest Bay	Hawksnest Bay	6.95	67.11	0.5	8.07	0.04	36.1	28.36	2	1.78
2016	VI-STJ-02	Hawksnest Bay	Hawksnest Bay	6.89	91	0.92	8.02	0.02	36.82	27.01	6.57	0.86
2016	VI-STJ-03	Trunk Bay	Hawksnest Bay	7.68	610	0.277	8.01	0.021	36.78	26.92	5.37	1.07
2016	VI-STJ-05	Cinnamon Bay	Maho Bay	6.85	620	0.312	8.05	0.022	36.72	27.01	6.73	0.72
2014	VI-STJ-13	Coral Harbor	Coral Bay	6.06	37	0.29	8.12	0.04	35.53	29.24	6.33	2.19
2015	VI-STJ-13	Coral Harbor	Coral Bay	6.51	174	0.5	8.06	0.06	35.83	28.44	4.69	2.29
2014	VI-STJ-15	Round Bay	Coral Bay	6.48	10	0.29	8.11	0.06	35.76	28.73	2	4.03
2016	VI-STJ-16	Coral Bay	Coral Bay	6.67	720	0.168	8.08	0.021	36.78	26.95	5.6	0.79
2013	VI-STJ-23	Fish Bay	Fish Bay	6.29	20.1	0.88	8.04	0.034	34.45	28.94	6.5	7.7
2014	VI-STJ-23	Fish Bay	Fish Bay	8.52	13.3	0.28	8.24	0.043	35.96	30.7	8.67	18.25
2015	VI-STJ-23	Fish Bay	Fish Bay	5.04	20	0.98	7.91	0.054	35.88	29.11	7.08	6.995
2016	VI-STJ-23	Fish Bay	Fish Bay	6.9	13	1.092	8.03	0.023	36.92	28.19	5.67	2.92
2013	VI-STJ-25	Rendezvous Bay	Rendezvous Bay	6.93	37.1	0.82	8.1	0.033	34.47	28.53	2	1.72
2013	VI-STJ-26	Chocolate Hole	Rendezvous Bay	7.59	40.32	0.595	8.13	0.031	34.53	28.69	2.5	1.53
2013	VI-STJ-28	Great Cruz Bay	Great Cruz Bay	6.89	8.24	0.6	8.09	0.03	34.7	28.63	5	3.05
2014	VI-STJ-28	Great Cruz Bay	Great Cruz Bay	6.96	47	0.43	8.17	0.04	35.92	29.1	3.67	3.31
2015	VI-STJ-28	Great Cruz Bay	Great Cruz Bay	7.03	116.12	0.5	8.11	0.04	35.9	28.18	3.78	1.72
2013	VI-STJ-29	Turner Bay/ Enighed Pond	Great Cruz Bay	6.75	10	0.65	8.08	0.032	34.62	28.52	3.5	4.45
2016	VI-STJ-29	Turner Bay/ Enighed Pond	Great Cruz Bay	6.96	65	0.79	8.06	0.023	36.82	27.34	7.75	0.54
2013	VI-STJ-30	Cruz Bay	Great Cruz Bay	6.67	56.73	0.68	8.06	0.032	34.73	28.72	4.56	3.93
2014	VI-STJ-30	Cruz Bay	Great Cruz Bay	6.76	77.23	0.3	8.15	0.039	35.96	29.22	8.47	3.19
2015	VI-STJ-30	Cruz Bay	Great Cruz Bay	7.1	89.19	0.53	8.09	0.045	35.91	28.44	2.79	1.3

Exceedances in Table 4 all occurred after 2012, and are presented as a mean of available data for that particular year. A general correlation was observed between development, water quality exceedances and coral health when reviewing combined imagery and the data in Table 4. In watersheds with more change in development, there were more exceedances of water quality parameters in the associated bay, as well as lower levels of live coral.

One parameter, turbidity, was selected as the focus of a more in depth analysis for the seven year period of land use change data. The United States Geological Survey (USGS) defines turbidity as “the measure of relative clarity of a liquid” (USGS, 2016), indicating either an input of sediment or a disturbance of the bottom of a waterbody. Higher turbidity levels are indicative of a greater amount of disturbance of upland areas within the watershed. High turbidity also impacts the health of coral reefs by interfering with photosynthetic processes.

Corals have a microscopic algae called zooxanthellae living in their polyp tissue. (Figure 10). The zooxanthellae have a mutualistic relationship with the coral. Zooxanthellae are affected by light penetration as they are photosynthetic organisms, and therefore cannot tolerate water with high turbidity levels. The algae receive a safe habitat and compounds necessary to perform photosynthesis from the coral. Products from photosynthesis are then used by the coral to produce their stony calcium carbonate structure. Corals are dependent on zooxanthellae to be productive and to grow. When coral is stressed or conditions are not right, the algae are expelled leading to a higher susceptibility to disease or ultimately the death of the coral tissue (NOAA, 2008).

Figure 10 – Zooxanthellae and Coral Health

Zooxanthellae in coral polyp tissue (left); healthy coral and after expulsion of zooxanthellae (right)

Source: Smithsonian Ocean Portal and NOAA

For the analysis, the percentage of each watershed that is developed was determined by combining the land use areas of impervious surface and open spaced developed. This information was compared to the average turbidity readings for each watershed. A linear regression analysis (Figure 11a) was performed to relate these data points to each other. A significant correlation ($p < 0.01$) exists between increased watershed development and increased average turbidity readings. Additionally, when turbidity sample data was summarized in relation to the change in land use from 2005-2012, watersheds with a higher percent change had more exceedances as shown in Figure 11b. Increased development therefore leads to higher turbidity, which adversely affects coral cover in the associated bay.

Figure 11a – Average Turbidity Readings vs. Percent Development (2012)

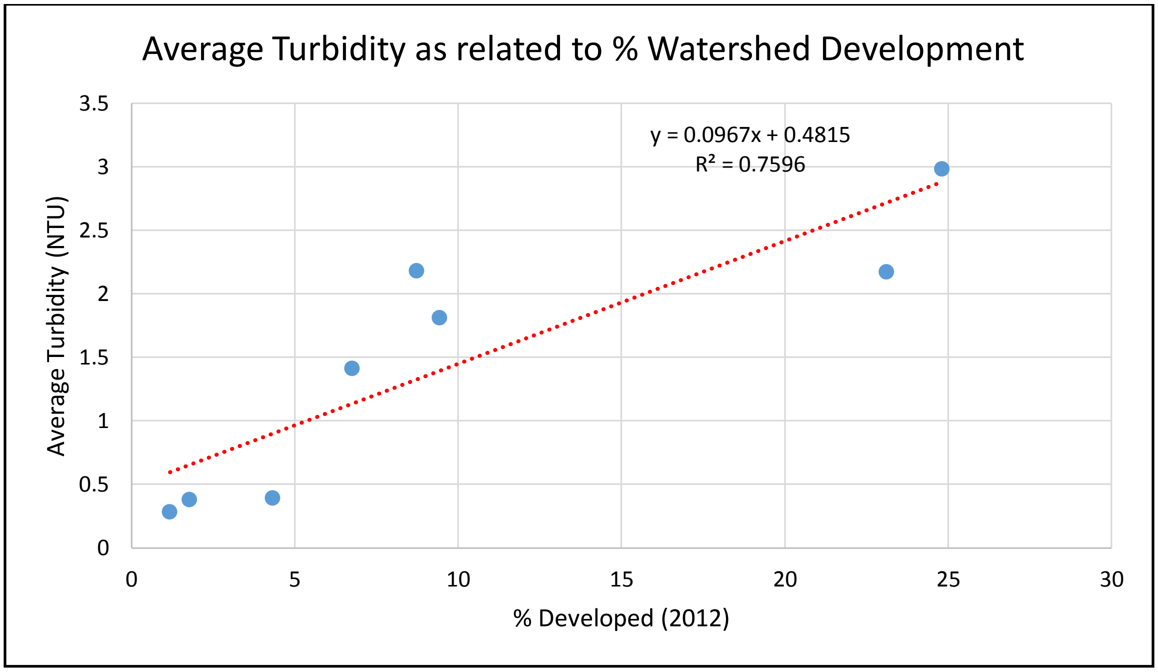
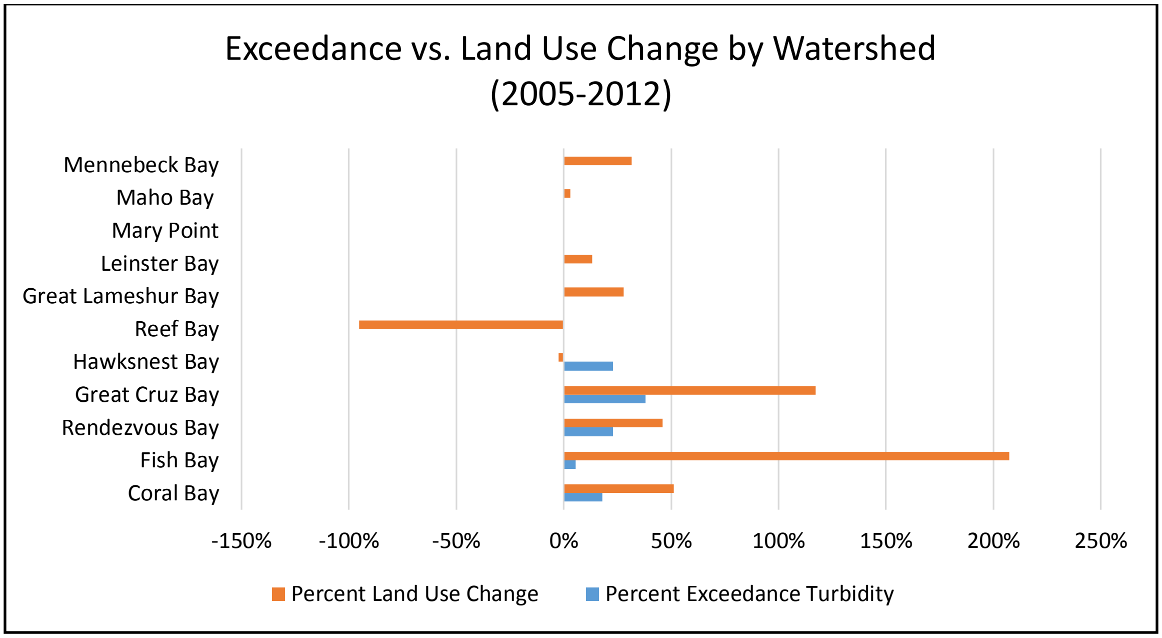


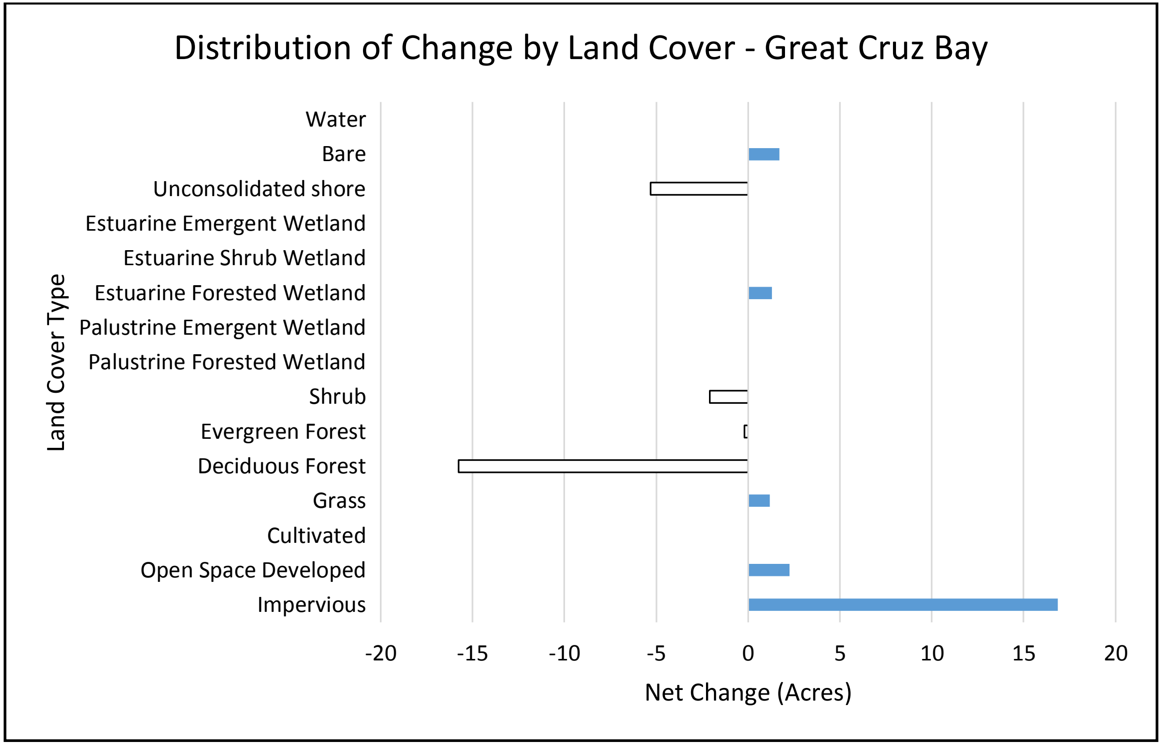
Figure 11b – Turbidity Exceedances vs. Land Use Change by Watershed

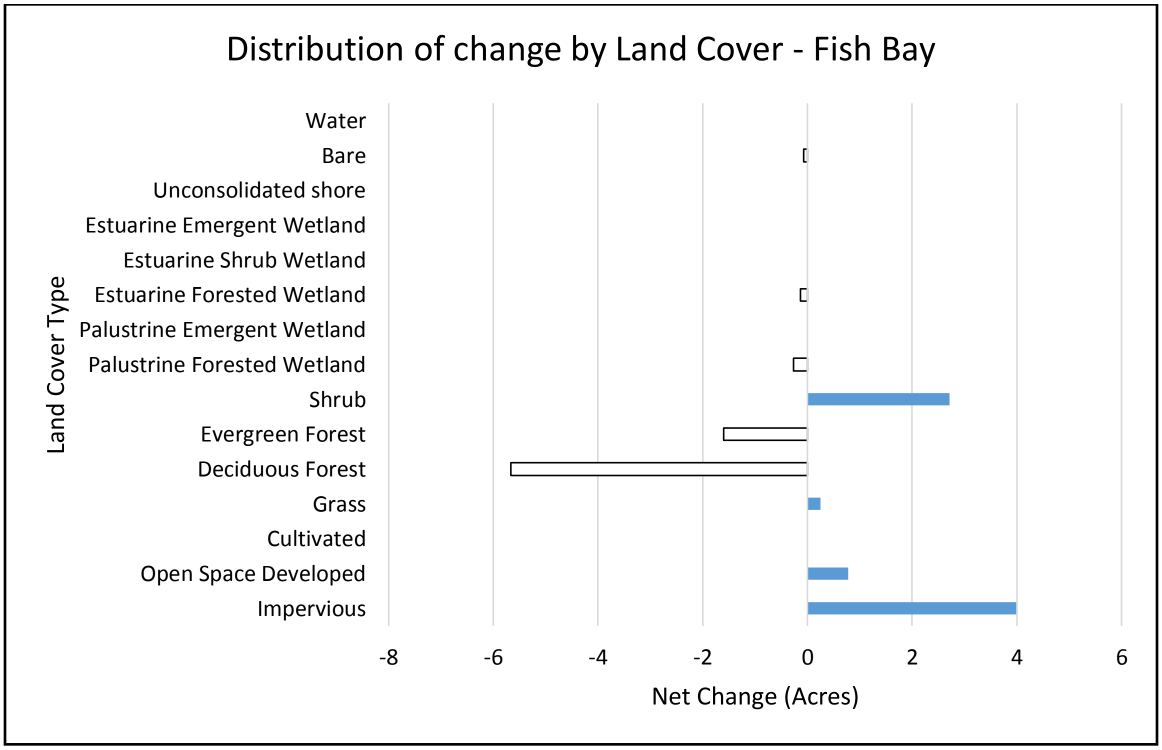


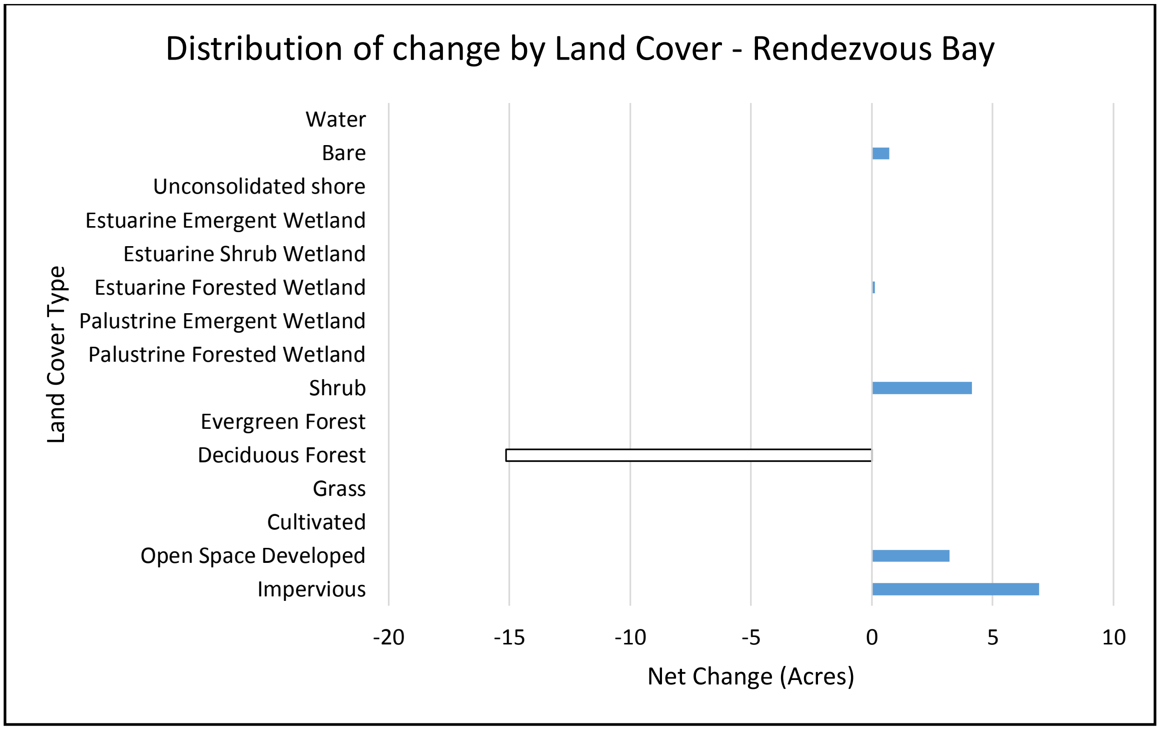
It should be noted some watersheds were not sampled as frequently for turbidity as others, or sometimes not at all in the time frame evaluated. For example, Reef Bay shows a high percentage of change, but only 23 samples were taken from 2005-2012. Mennebeck Bay also shows a high percentage of change, but no water quality samples were taken. Great Cruz Bay had the highest number of exceedances for turbidity, but also had the highest number of samples taken (1412). This is due primarily to funding availability for VIDPNR and the National Park Service having responsibility for some of the AU's (B. Keularts, personal communication, April 2017).

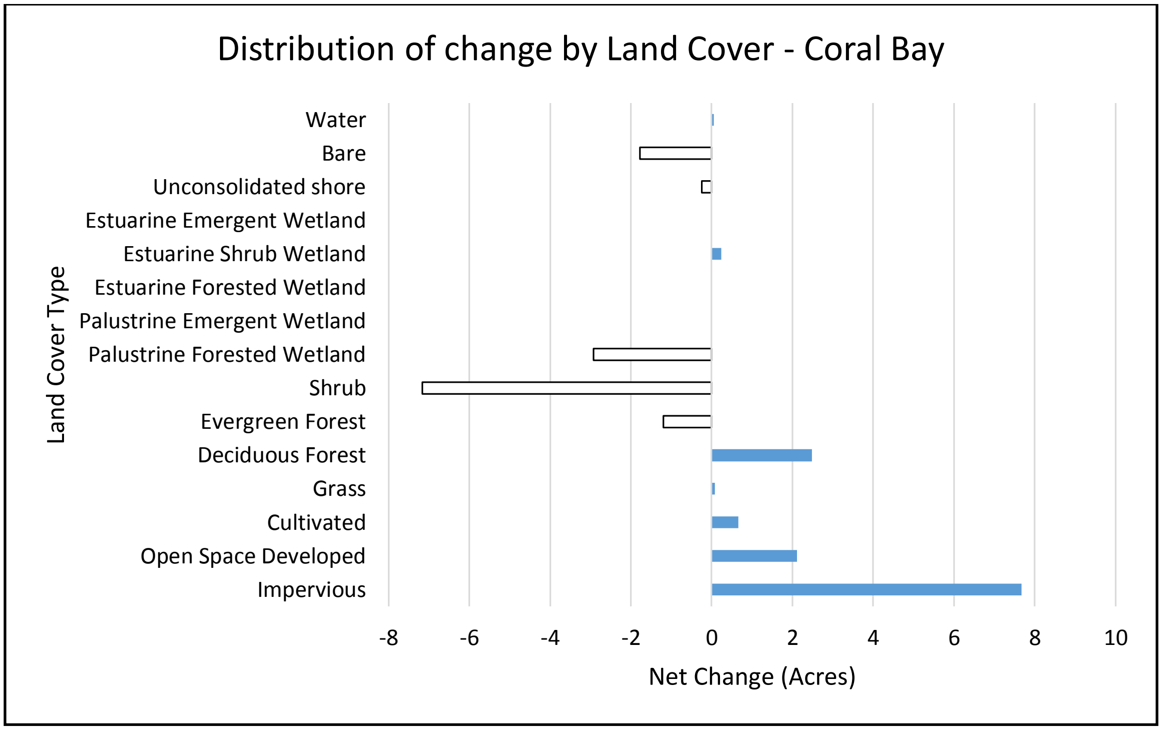
Figure 12 shows the actual change in land cover type for the four watersheds that had the highest percentage of change and exceedances for turbidity.

Figure 12 – Distribution of Change by Land Cover Type









In all four bays, the general trend was a loss of vegetated cover, and an overall gain in impervious, developed or cultivated land cover. Turbidity exceedances can come from run off from these types of areas, especially during the transition from one land cover type to another. For example, construction necessary to clear forested areas for development or paving would leave the land more susceptible to erosion during those phases of the project. This is especially true of projects that occur in the rainy season no matter how far they are from shore based on the severity of slopes in this region.

Discussion

Research Challenges/Limitations

A challenge to previous research, particularly for sediment transport and erosion, is that existing modeling systems are primarily based on agricultural landscapes that do not translate well to the primarily steep slopes of tropical island watersheds (Messina & Biggs, 2016) (Ramos-Scharron & MacDonald, 2005). If the type of watershed is not accounted for in the modeling system, it cannot be used to make predictions, and obtaining data becomes more costly.

Another challenge is incorporating large and small magnitude storms into research data. Most tropical islands have rainy seasons and can be further impacted by events such as hurricanes. Water flow and movement within bays also complicates the overall measurement and determination of sources of impact on ecosystem health (Sabine, Smith, Williams, & Brandt, 2015). Natural patterns of movement within a bay can quickly move suspended sediment and other pollutants to other areas making it difficult to measure direct impacts (Messina & Biggs, 2016). This project did not evaluate rainfall or water movement patterns. Future studies should use these elements as another variable in the overall analysis.

Furthermore, there is an overall lack of data to adequately show long-term trends for any one parameter. This information is necessary to determine the baseline measurement of each factor that contributes to overall ecosystem health. Without a baseline, a thorough and ongoing evaluation cannot be made to determine where to focus conservation efforts. The following section summarizes additional information required to provide a more comprehensive analysis of ecosystem health.

Factors influencing Ecosystem Health

Sediment Deposition

Various modeling tools have been developed to try to correlate development and associated sediment yields. As previously described, many of these modeling systems are based on agricultural land use and do not account for steep slopes associated with tropical island ecosystems. Ramos-Scharron and MacDonald (2007) developed a GIS-based model called STJ-EROS to “more accurately model watershed-scale erosion and sediment yields on St. John." They compared the modeled results to actual sediment yield data available for the island, finding similarities between the predicted and measured values which validates their product. The model can be utilized as a tool in regions such as the eastern Caribbean through adapting associated equations to differing conditions.

STJ-EROS estimated that within three modeled basins, sediment yields are “3-9 times higher than under natural conditions”, owing most of the increase to unpaved roads (Ramos-Scharron & MacDonald, 2007). This data can aid managers in determining mitigation strategies for sediment delivery from this type of source. By changing inputs within the system to model suggested improvements to the drainage network, the tool can be used to significantly increase confidence in expected results during the planning phase of the project.

It is also important to discuss changes over longer time frames in order to determine how much impact human activities actually have on these ecosystems. Some shifts in sediment deposits happen naturally over time from runoff and natural events such as hurricanes or periods of dust (volcanic and African dust storms) (Brooks, Larson, Devine, & Schwing, 2015).

Sampling sediment cores from coastal marine areas and salt ponds in the USVI show deposition trends over both short and long-term time scales. Within this data there are correlations to development showing up as a ten-fold increase in sediment accumulation (heavy development – Coral Bay), a 2.5 fold increase (moderate – Fish Bay), and no increase (undeveloped - Newfound Bay) (Brooks, Larson, Devine, & Schwing, 2015).

The long-term data is critical to understanding the implications of development as it factors in both natural occurrences and human influence. Without this data, the true extent of anthropogenic influence cannot readily be extrapolated. A case can be made for addressing erosion and sedimentation when it shows up as a ten-fold increase in the deposition record. In this specific case, the increase is directly attributed to activities such as the construction of Centerline Road on St. John in the 1960s and the increase in construction of large homes from 2000 to the present (Devine et al, 2004).

The use of long-term monitoring strategies, or obtaining data through sediment cores which relate long term information with a singular sampling event supports Brown et al's (2016) research. This data must be combined with water quality samples representing a snapshot in time for specific parameters. For example, sampling for turbidity after significant rain events should be combined with pulling associated sediment cores or measuring from catches installed on a reef. This allows a manager to understand what a specific reading of turbidity means as related to potential impact to the coral through associated deposition.

Knowledge of rainfall amounts, turbidity results, and actual sediment deposition measurements can further our understanding of total inputs and what a pollutant load correlates to in terms of water quality measurements. Relating this information to existing coral reef health data allows managers to make decisions based on a more comprehensive set of criteria.

Other Anthropogenic Inputs

Anthropogenic inputs can come from a variety of sources. Many of these pollutants are carried with sediment when runoff and erosion occurs, and the impact that each compound has is not always known. A recent study by Whitall et al (2015) focused on the chemical contaminants present in Coral Bay and Fish Bay, two of the four areas that have had substantial change in their development since 2005. The results indicated that only copper and total chlordane, which is associated with older pesticides, exceeded a sediment quality guideline. Although this research provided valuable data, there are too many chemical compounds in existence to fully research each one, which indicates how complex studies must be to gain an understanding of near-shore ecosystem health.

Another study by Carbery et al (2006) looked at just one chemical input, Irgarol 1051, an herbicide used in antifouling paint for boats. Irgarol 1051 has been shown to have an impact on photosynthesis in corals at levels of 50 ng 1^{-1} and was found in some locations to be in excess of 1300 ng 1^{-1}. This is one of many chemicals that could potentially have an impact on coral and other near-shore ecosystems that have not been fully evaluated.

The EPA contracted the Cadmus Group, Inc. to evaluate pathogen sources and determine how to reduce their input into the watersheds (The Cadmus Group, Inc., 2011). Fecal coliform is suspected to affect coral reefs by causing disease outbreaks (Kaczmarsky, Draud, & Williams, 2005). The primary sources of high fecal coliform levels in the USVI are from failing on-site septic systems, agriculture and associated land use changes over time. Management of these sources as well discharges associated with boat use should be a priority to reduce fecal contamination of near-shore waters (The Cadmus Group, Inc., 2011).

Turbidity and total suspended solids (TSS) are water quality parameters associated with sedimentation and must also be considered when looking at anthropogenic inputs to ecosystems. Sediment creating a TSS load can carry harmful pathogens and other substances such as those previously described that can adversely affect coral health (The Cadmus Group, Inc., 2011). Pollutants like fecal coliform, chemicals, metals, and pesticides/herbicides persist in the soil and are easily transported during rain events to the nearest bay.

Cruise ship activity and anchoring can also contribute to TSS and turbidity in specific bays. Although this is not a major concern for St. John as no cruise ships are currently allowed to anchor there, it directly impacts St. Thomas and St. Croix. Re-suspended sediment plumes follow cruise ships in and out of the bays on these islands, increasing turbidity and limiting light available for photosynthetic organisms such as zooxanthellae. Zooxanthellae have a mutualistic relationship with coral. Once expelled from the coral tissue, the coral are more susceptible to disease and death (NOAA, 2008). Studies have shown significant increases in TSS, turbidity, and sediment deposition after ship passages (Kisabeth, Smith, Primack, & Wilson, 2016). This could also cause an issue on a smaller scale for St. John with the amount of ferry, barge and other boat traffic.

Fishing intensity also has a negative impact on coral reef ecosystems. When fish populations decline or overall assemblages change, their associated herbivory on macroalgae living on coral also declines. This is also true when long-spined black sea urchins (*Diadema* *antillarum*) decline (Rogers & Beets, 2001). An increase in macroalgae can disrupt coral recruits, which in turn can stunt the growth of existing coral colonies. Overfishing in the USVI highlights another issue – lack of enforcement within marine protected areas (MPA) such as Virgin Islands National Park (1962 – St. John) and the Buck Island Reef National Monument (1961 – St. Croix).

The last major source of stress to the near-shore environment is industrial and construction activity. The 2014 Integrated Water Quality and Assessment Report highlights existing permits for both of these functions.

On the industrial side, leaking underground storage tanks (UST) can cause pollutants to enter waterways. Most of the USTs in the USVI are associated with either active or abandoned gas stations. Pollutants of concern are benzene, ethylbenzene, toluene, xylenes and total petroleum hydrocarbons. There are three USTs registered on St. John, of which only one is still in use. The other two are on the leaking UST (LUST) list, with one that has been delisted in Coral Bay, and another in Cruz Bay that has been removed and is awaiting a designation of no further action.

Used oil collection facilities also have the potential to add harmful constituents to the environment. In order to collect used oil, these facilities must be permitted. As of 2013, there are 15 permitted facilities on St. John, with 1 in Coral Bay and the remainder in Great Cruz Bay (DPNR, 2014). Again, these are two of the four most highly developed bays, adding to the potential for pollutants to be carried into compromised bays during rain events.

On the construction side, only 3 Earth Change Permits were issued between 2012 and 2013, one in Cruz Bay and 2 in Coral Bay. An Earth Change Permit is required when a project will disturb the land. There are specific permits for projects less than one acre, over an acre, and for clearing of guts or brush. Each permit requires the permittee to outline best management practices that will be utilized to minimize the potential for discharge of sediment from the project site. Additionally, any projects that may have an impact on water quality that are regulated under Coastal Zone Management (CZM) authority are reviewed by USVI DPNR. Only one project fell into this category in the 2012-2013 timeframe, which was a project in Coral Bay associated with the Water and Power Authority (WAPA).

Climate change can also have an impact on coral reefs. Higher levels of atmospheric carbon dioxide have increased sea surface temperatures and ocean acidification. Bleaching events occur in coral populations in response to increased temperatures (Norstrom, et al., 2016). Trying to control emissions from industrial sources and vehicles may also improve coral health, as bleaching can lead to compromised corals (Miller, et al., 2009). Corals that have been bleached are more likely to be affected by disease.

Coral Disease and Mortality

A multitude of stressors are known to impact coral. The stressors can act acutely or over decadal time scales, and also at local and global levels. Corals are also susceptible to the physical stressors of tropical storms related to factors such as wave action from hurricanes. Secondary mortality due to already compromised corals from any one or combination of these factors is also a concern (Smith, et al., 2008).

Locally in the USVI, a high rate of development and associated high rate of sediment deposition (Nemeth & Sladek Nowlis, 2001), population growth, and industrial activity have added pressure to already compromised corals (Smith, et al., 2008). A mass bleaching event in

2005 led to severe mortality and disease in corals around the USVI (Miller, et al., 2009), which can decrease the resilience of the coral against other stressors.

Oliver et al's (2011) research concluded that the health of reef communities increases as distance from human activity and disturbance increases. Additionally, Smith et al. (2008) showed sedimentation rates and bleaching are higher in near-shore environments. Both findings suggest that anthropogenic influences on coral health are more prevalent in near-shore scenarios. This conclusion is further supported by the identified correlations between increased development, increased turbidity, and lower live coral cover in Fish, Great Cruz, Rendezvous, and Coral Bays.

Regulations and Management Strategies

A variety of management strategies exist in the USVI. Protection of approximately 60% of the land area of St. John is through the Virgin Islands National Park (VINP). The Virgin Islands Coral Reef National Monument was established (2001) to further protect shorelines and a 3 mile belt surrounding St. John. As part of a marine protected area (MPA), certain restrictions apply to these coastal waters. Unfortunately, policies associated with MPAs are not adequately enforced, to include limitations on fishing and anchoring. Both of these factors adversely affect near-shore coral reef and seagrass beds (Rogers & Beets, 2001).

USVI DPNR is the permitting authority for areas that fall under Coastal Zone Management regulations, as well as for Territory Pollutant Discharge Elimination System (TPDES) associated with wastewater treatment plants and other discharges to water. DPNR also issues permits encompassing construction activity (Earth Change permits), underground storage tanks, air quality, pesticide use, solid waste, hazardous waste, and special wastes like used oil.

Although the permitting programs are robust, issues still exist with environmental quality in the territory.

Recent reports recommend that the EPA take over permit authority or improve oversight and enforcement in the USVI (EPA, 2015). The recommendations were based on a review of existing permits issued by DPNR in many program areas, all of which can affect the fragile ecosystems of the islands. The EPA found that overall, the USVI has not met requirements associated with implementation of programs, to include "monitoring environmental conditions, conducting compliance inspections and enforcing program requirements" (EPA, 2015). After conducting a review of permits specifically related to water quality, the EPA concluded that they were inadequate. The permits reviewed did not consistently follow the guidelines of the Clean Water Act, did not have technology based limitations for effluent, and failed to factor in existing receiving water impairments with regard to permit limitations and monitoring (EPA, 2014). All of these factors can influence overall watershed health.

Water Quality Results and Implications

Previous studies have been conducted in St. Thomas (Ennis, Brandt, Wilson-Grimes, & Smith, 2016) (Smith, et al., 2008) and St. Croix (Oliver, Lehrter, & Fisher, 2011) (Sabine, Smith, Williams, & Brandt, 2015) to measure how changes in water quality affect coral reef health. While St. John has had a similar study to look at overall reef health (Smith, et al., 2008), the focus was on sedimentation overall and not specific water quality parameters. Additional research projects relating sedimentation from run off have been conducted on St. John (MacDonald, Anderson, & Dietrich, 1997) (Ramos-Scharron & MacDonald, 2005), but none that specifically evaluate water quality parameters such as turbidity compared to reef health could be found during the literature review.

Sabine et al (2015) found that tissue regeneration rates for scleractinian (stony) corals at highly impacted or developed sites around St. Thomas were three times slower than those with less impact. This correlation specifically related high turbidity and low-water flow at the study sites. With massive bleaching and disease events that have occurred in the USVI (Miller, et al., 2009) , anthropogenic factors from development can greatly influence the rate of recovery for already affected coral reefs.

Ennis et al (2016) correlated declining water quality from development in the form of high turbidity and chlorophyll concentrations with near-shore reef decline and an increase in bleaching prevalence in St. Thomas. This further supports the idea that numerous factors are linked when discussing coral reef health and impacts of terrigenous sediment on this ecosystem.

Downs et al’s (2011) research on St. John showed stress markers in mustard hill coral (*Porites asteroids*) related to anthropogenic sources. The stress markers are related to contamination from polyaromatic hydrocarbons at two sites within the National Park boundaries, and contamination in Cruz Bay from semi-volatile organochlorines and nitrogen-based biocides. The scope of their research was a total of six sites, but shows that additional information may be needed to fully understand the impacts on corals from local pollutant stressors to gain a full understanding of how to aid impacted reefs.

Meta-analysis of available data, even in the absence of conducting additional research, can be a valuable tool to determine trends. By combining existing map layers, areas with higher rates of development and lower live coral cover provide a starting point for managers to begin evaluating water quality and pollutant sources.

In this analysis, Fish, Great Cruz, Rendezvous, and Coral Bays were shown to have higher rates of development and lower live coral cover, and subsequently had higher turbidity levels. High turbidity impacts light penetration and causes a disruption in photosynthetic processes needed to maintain coral health. Using this information, managers can focus limited resources on projects in these bays that will have a higher return on investment in protecting near-shore ecosystems such as coral reefs.

Conclusion

Development and land use has detrimental impacts on water quality and associated near-shore ecosystems, particularly coral reef health, in the USVI. A significant correlation ($p < 0.01$) was found between increased development and increased turbidity in Fish, Great Cruz, Rendezvous, and Coral Bays over a seven year period from 2005-2012. Turbidity is a major driver for coral cover, which is lower in bays with increased development as compared to those associated with the National Park.

Although meta-analysis of existing data provide a starting point for determining where to implement mitigation strategies, it may not be enough. Through improved modeling, obtaining more data, and conducting all-encompassing studies, more precise projects can be developed, evaluated and prioritized for how well they will benefit an ecosystem. Projects that will either help restore impaired watersheds, or that will minimize impacts to watersheds in relatively good health must be a priority. Managers should spend their limited resources on projects with the best return on investment.

Increased enforcement of existing regulations and permits will reduce the impact of anthropogenic sources of pollution on near-shore marine ecosystems. More frequent inspections and enforcement actions need to occur across all levels of management. Enforcement will hold those that can have a significant impact on the environment accountable for their actions.

New and innovative approaches should be taken to limit pollution occurring from existing sources. Implementation of green infrastructure would limit the reliance on natural features such as salt ponds and mangroves to filter the majority of the runoff from the island. Since minimal drainage structures currently exist, implementation of green infrastructure in areas prone to erosion and sediment loss would be a good investment to minimize downstream impacts.

St. John is a small island with limited sources of pollutant loading due to restrictions for development within National Park boundaries. The island also has one watershed, Mary Point, with no development that could be used as a baseline for further studies. Using the island as a case study for long-term monitoring and evaluation of management practices could improve strategies for other similar ecosystems.

The best strategy to improve water quality and subsequent ecosystem health is one that can be implemented either as a whole or in part based on need and availability of funds. It should build upon existing strategies by relating effectiveness to current data from marine health and resiliency. Meta-analysis should be utilized as a tool to better understand all of the impacts from both natural and anthropogenic sources on near-shore ecosystems that are vital to the economy of St. John and other small tropical islands.

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