U.S. VIRGIN ISLANDS COASTAL RESILIENCE ASSESSMENT

2020

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IMPORTANT INFORMATION/DISCLAIMER: This report represents a Regional Coastal Resilience Assessment that can be used to identify places on the landscape for resilience-building efforts and conservation actions through understanding coastal flood threats, the exposure of populations and infrastructure have to those threats, and the presence of suitable fish and wildlife habitat. As with all remotely sensed or publicly available data, all features should be verified with a site visit, as the locations of suitable landscapes or areas containing flood threats and community assets are approximate. The data, maps, and analysis provided should be used only as a screening-level resource to support management decisions. This report should be used strictly as a planning reference tool and not for permitting or other legal purposes.

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Report cover images: Aerial view of Frydendal, St. Thomas (top); red mangrove (bottom)

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GLOSSARY OF RELEVANT TERMS

The analysis was developed in adherence to the following terms and their definitions adapted from the U.S. Climate Resilience Toolkit and NFWF.

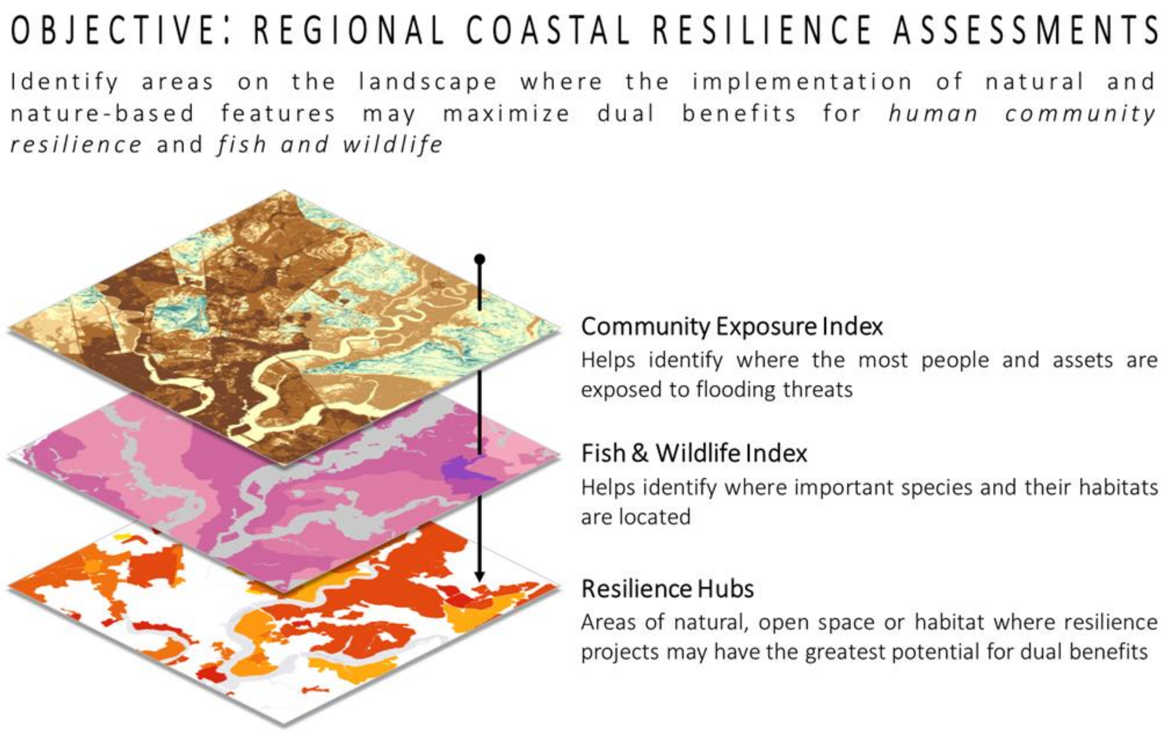
Term	Definition
Adaptive capacity	The ability of a person or system to adjust to a stressor, take advantage of new opportunities, or cope with change.
Ecosystem services	Benefits that humans receive from natural systems.
Exposure	The presence of people, assets, and ecosystems in places where they could be adversely affected by hazards.
Impacts	Effects on natural and human systems that result from hazards. Evaluating potential impacts is a critical step in assessing vulnerability.
Natural features	Landscape features that are created and evolve over time through the actions of physical, biological, geologic, and chemical processes operating in nature (Bridges et al. 2014).
Nature-based features	Features that may mimic characteristics of natural features, but are created by human design, engineering, and construction to provide specific services such as coastal risk reduction (Bridges et al. 2014).
Nature-based solutions	Actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN).
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.
Risk	The potential total cost if something of value is damaged or lost, considered together with the likelihood of that loss occurring. Risk is often evaluated as the probability of a hazard occurring multiplied by the consequence that would result if it did happen.
Sensitivity	The degree to which a system, population, or resource is or might be affected by hazards.
Threat	An event or condition that may cause injury, illness, or death to people or damage to assets.
Vulnerability	The propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive capacity.

EXECUTIVE SUMMARY

Coastal communities throughout the United States face serious current and future threats from natural events, and these events are predicted to intensify over the short and long term. Dynamic processes such as coastal erosion, storm surge flooding, and river runoff exacerbate the threat from sea level rise. Intense hurricanes and extreme flooding have the potential to devastate both human communities and fish and wildlife habitats, as has been seen in recent years throughout the Caribbean. Recently, the U.S. Virgin Islands have experienced numerous consecutive hurricanes and other major storm events that have left communities exposed to severe and devastating effects of coastal flooding. As communities rebuild, decision-makers need tools and resources that allow for data-driven decision support in an effort to maximize available funding opportunities and other planning needs.

The U.S. Virgin Islands Coastal Resilience Assessment aims to support effective decision-making in order to help build resilience for communities facing flood-related threats. The National Fish and Wildlife Foundation (NFWF), in partnership with the National Oceanic and Atmospheric Administration (NOAA), is committed to supporting programs and projects that improve resilience by reducing communities' vulnerability to coastal storms, sea level rise, and flooding events through strengthening natural ecosystems and the fish and wildlife habitat they provide.

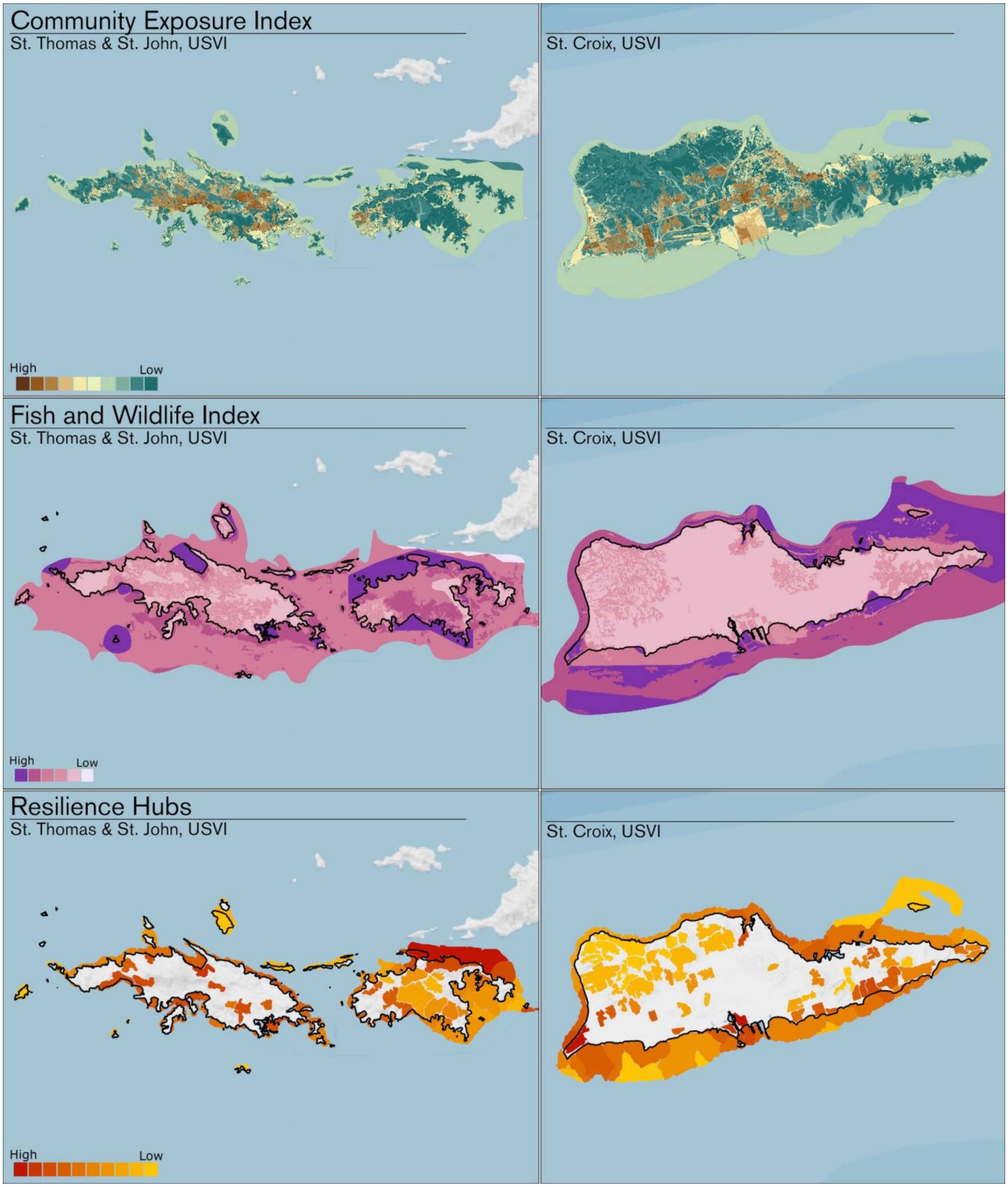
This Geographic Information System (GIS)-based Coastal Resilience Assessment combines spatial data related to land use, protected areas, human community assets, flooding threats, and fish and wildlife resources in order to identify and prioritize Resilience Hubs (see figure below). Resilience Hubs are large areas of natural, open space or habitat where, if investments are made in conservation or restoration, there is potential for improved human community resilience and benefits to fish and wildlife habitats and species.



The Assessment identified areas throughout the U.S. Virgin Islands that are not only exposed to a range of coastal-flood related threats, but also contain higher concentrations of community assets. In addition, through the development of habitat extent and suitability models, the analysis identified terrestrial and nearshore marine areas with significant fish and wildlife resources. Together, the Assessments revealed natural areas of open space and habitat ideal for the implementation of resilience projects that may be capable of supporting both the people and wildlife of the U.S. Virgin Islands. The primary mapping products from the U.S. Virgin Islands Assessment are shown below.

Local community planners, conservation specialists, and others can use the outputs of the U.S. Virgin Islands Assessment to help make informed decisions about the potential of restoration, conservation, or resilience projects to achieve dual benefits for both human and fish and wildlife communities.

This U.S. Virgin Islands Coastal Resilience Assessment report provides a detailed discussion of the data and methods used for the three analyses (Community Exposure, Fish and Wildlife, and Resilience Hubs), regional results, and a case study. In addition to the results presented in this report, NFWF has developed the Coastal Resilience Evaluation and Siting Tool (CREST), an accompanying GIS-based web tool that allows users to view, download, and interact with the inputs and results of the U.S. Virgin Islands Assessment (available at resilientcoasts.org).



Final Community Exposure Index (top), Fish and Wildlife Index (middle), and Resilience Hubs (bottom) for the U.S. Virgin Islands Coastal Resilience Assessment. Higher values represent areas where a higher concentration of assets are exposed to flooding threats (Community Exposure Index), areas where numerous important species and their habitats are located (Fish and Wildlife Index), or areas where resilience projects may have the greatest potential to benefit both human communities and wildlife (Resilience Hubs).

INTRODUCTION

1.1 U.S. Virgin Islands

The U.S. Virgin Islands are rich in biodiversity, natural resources, and cultural heritage. With nearly 200 kilometers of coastline, communities throughout the U.S. Virgin Islands are highly exposed to a variety of coastal-flood related threats. In this subtropical climate, flooding threats can have devastating effects, particularly in densely populated areas like Charlotte Amalie and the east end of St. Thomas, Cruz Bay on St. John, and Christiansted on St. Croix.

Local flooding threats range from coastal storms and hurricanes to the long-term threat of rising sea levels. Compound flooding associated with multiple, simultaneous or sequential heavy rain events and coastal storms can significantly impact both coastal and inland communities. For instance, in 2017, Hurricanes Irma and Maria caused widespread damage to the U.S. Virgin Islands. While Maria resulted in extensive impacts on St. Croix, Irma mainly affected the northern islands.

The record-breaking disasters of 2017 increased concern and attention to storm readiness, response, and resilience in the islands. In response to the 2017 hurricanes and previous storms, numerous national and territory-level efforts were initiated in order to better understand the threats, needs, gaps, and nature-based approaches that could be applied to help build resilience in the U.S. Virgin Islands. Such efforts include, but are not limited to, the results of the USVI Hurricane Recovery and Resilience Task Force (USVI Task Force 2018), U.S. Virgin Islands Climate Change Ecosystem-Based Adaptation guidance document (Schill et al. 2014), the USVI Territorial Hazard Mitigation Plan (FEMA 2019), and the U.S. National Climate Assessment (USGCRP 2018). Such studies are critical to help communities understand, respond to, and prepare for future storm events. In addition to these studies, several recent meetings and workshops have made progress towards planning and implementation of both gray and green infrastructure designed to respond to the threat of flooding and storms. In August 2019, NOAA hosted stakeholder workshops on St. Croix focused on using green infrastructure and adaptation planning[1]. In an extensive and ongoing planning effort, the U.S. Army Corps of Engineers also hosted a workshop in St. Thomas in October 2019 to gain stakeholder feedback and advance the South Atlantic Coastal Study[2]. To enable broad and coordinated stakeholder engagement, the workshop included a special session focused on this U.S. Virgin Islands Coastal Resilience Assessment.

As the U.S. Virgin Islands take steps to lower their exposure and plan for a more resilient future, resources such as this Coastal Resilience Assessment can equip decision-makers and stakeholders with valuable tools and information to help them better plan for future flood and storm events. The U.S. Virgin Islands Assessment provides a framework for a holistic approach that considers both human community resilience and fish and wildlife habitat.

[1] Information associated with the NOAA in the Caribbean Stakeholder Workshop available here.

[2] For information about the South Atlantic Coastal Study, visit https://www.sad.usace.army.mil/SACS/.

1.2 Overview of the Regional Coastal Resilience Assessments

The National Fish and Wildlife Foundation (NFWF) and the National Oceanic and Atmospheric Administration (NOAA) are committed to supporting programs and projects that improve community resilience by reducing communities' vulnerability to coastal storms, sea level rise, and flooding by strengthening natural ecosystems and the fish and wildlife habitat they provide. In response to growing coastal flooding threats, NFWF commissioned the University of North Carolina (UNC) Asheville's National Environmental Modeling and Analysis Center (NEMAC) to develop an assessment to identify coastal areas that are ideal for the implementation of nature-based solutions that build both human community resilience and fish and wildlife habitat. The resulting Regional Coastal Resilience Assessments (referred to from here forward as the Regional Assessments or Assessments) aim to identify and rank open space areas and habitat cores where targeted investments can implement resilience-building projects before devastating events occur and impact surrounding communities.

The U.S. Virgin Islands Coastal Resilience Assessment is part of a broader effort that seeks to evaluate regional resilience for all U.S. coastlines. Regional Assessments are already complete for the U.S. Atlantic, Gulf of Mexico, and Pacific coastlines, Puerto Rico, and the Commonwealth of the Northern Mariana Islands. Additional Assessments are expected for American Samoa, Guam, Hawaii, Alaska, and the Great Lakes (Figure 1).

Figure 1. The geographic extent of the Regional Coastal Resilience Assessments in dark gray and the U.S. Virgin Islands Assessment in orange. All Regional Assessments will be completed by 2021. Map not shown to scale.

Strategically implementing resilience projects can increase the ability of surrounding communities and habitats to withstand and recover from the impacts of coastal storms and flooding events (Narayan et al. 2017). Efforts to build resilience begin by determining the exposure of a community's assets to a hazard or threat. The Regional Assessments use a Geographic Information System (GIS)-based approach to model landscape characteristics and their potential impacts in order to identify places throughout the

United States where assets are potentially exposed to flood threats. They combine human community assets, flooding threats, and fish and wildlife resource spatial data in order to identify and rank Resilience Hubs. Resilience Hubs are large areas of natural, open space or habitat where, if investments are made in conservation or restoration, there is potential for improved human community resilience and benefits to fish and wildlife habitats and species.

From a modeling standpoint, the Regional Assessments consist of three separate but interrelated analyses: (1) the Community Exposure Index, (2) the Fish and Wildlife Index, and (3) the Resilience Hubs (Figure 2). These three components make these Assessments unique as they look at resilience potential through the lens of both human and fish and wildlife communities. Specifically, the Community Exposure Index can guide land use and hazard mitigation planners in identifying potential development constraints and improve the understanding of potential risks to critical infrastructure and human populations. The Fish and Wildlife Index can inform where on the landscape important species and habitats occur. The Resilience Hubs then identify open spaces and habitat suitable for the implementation of projects expected to build communities' resilience to flood events while also benefiting fish and wildlife.

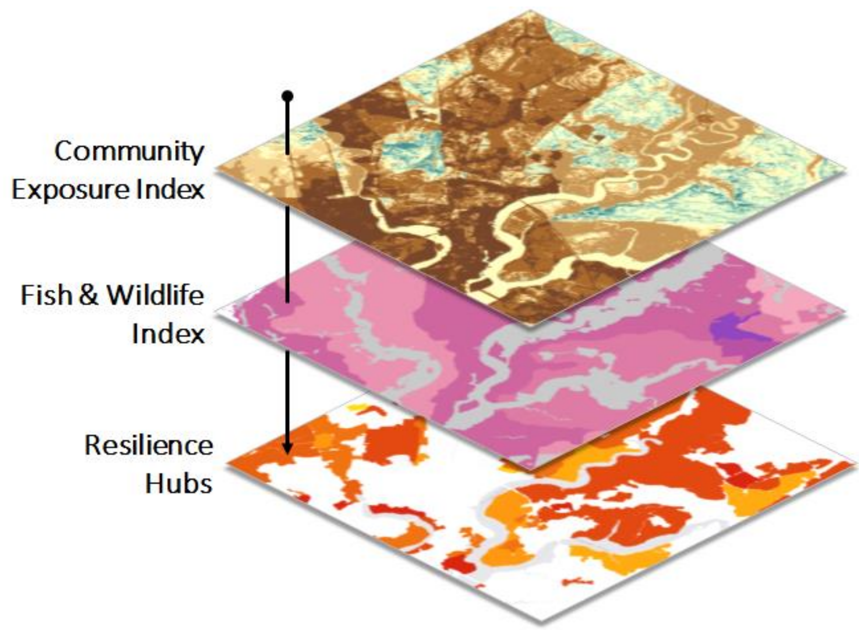


Figure 2. A conceptual model showing the separate, but interrelated components of the Regional Coastal Resilience Assessments.

While the Resilience Hubs are the primary output of the Regional Assessments, each component can be used individually or in combination to help community planners, conservation specialists, funding applicants, and others make informed decisions about the ability of potential restoration, conservation, or resilience projects to achieve dual benefits for both human community resilience and fish and wildlife species and habitats.

METHODS

2.1 Introduction

The foundation of the Regional Coastal Resilience Assessments is based on the coastal vulnerability research outlined in Gornitz et al. (1994). In 2011, the New Jersey Office of Coastal Management and Department of Environmental Protection adapted that research to assess existing and future hazard vulnerabilities on a local scale (NJ-DEP 2011). This research was integral to structuring the inputs and methodology of this analysis.

The following sections provide a brief overview of the methods used in the U.S. Virgin Islands Coastal Resilience Assessment (or U.S. Virgin Islands Assessment). For more details about overarching methodology and data sources common across all Regional Coastal Resilience Assessments, please refer to Dobson et al. (2020). To the extent possible, the Regional Assessments aim to use the same methodology and data across all regions. However, given the unique geographic characteristics of each region and the fact that data availability varies, some regionally-specific modifications were required. Additionally, given the small geographic scale of the U.S. Virgin Islands, the Advisory Committee recommended that all GIS modeling be completed at a 10-meter resolution to best match the resolution common to the input data. The following sections briefly discuss pertinent methodological changes to the Community Exposure Index, Fish and Wildlife Index, and Resilience Hubs for the U.S. Virgin Islands.

2.2 Study Area

The U.S. Virgin Islands Assessment focuses on the three main islands of St. Thomas, St. John, and St. Croix, extending offshore as far as the 30-meter depth contour or boundary (Figure 3). As described below, the 30-meter depth boundary was used for the Fish and Wildlife Index to allow for the inclusion of the marine habitats with potential to host significant biodiversity. Based on the recommendation of technical experts, however, the Resilience Hub analysis only considered habitats less than 10 meters in depth since shallow water habitats are expected to provide greater coastal protection benefits through the implementation of nature-based solutions.

The U.S. Virgin Islands is an archipelago located in the Caribbean. The islands vary geographically, consisting of mountain forests, coastal wetlands, and coral reef ecosystems. St. Croix is the largest of the three islands, with a total area of about 220 square kilometers, followed by St. Thomas with 83 square kilometers, and St. John with 51 square kilometers. The highest peak in the U.S. Virgin Islands is Crown Mountain on St. Thomas at a height of 474 meters (Platenberg & Valiulis 2018). Combined across all islands there is a total of nearly 200 kilometers of coastline, much of which is developed with a total population of over 104,000 and a population density of 310 people per square kilometer. St. John, the smallest of the three islands, contains the Virgin Islands National Park, which covers over 60 percent of the island.

This Assessment is unique in that it not only takes into account the immediate coastline, as many other studies have done, but it also focuses on inland areas that can often directly contribute to coastal flood-related issues. For instance, intense rain and riverine flooding that then drains directly to the coast can exacerbate coastal flooding. In all regions, the boundary of the Assessments follow the U.S. Environmental Protection Agency's (EPA) designated coastal watersheds, which are watersheds that drain directly to the ocean and are represented at a hydrologic unit code eight scale (HUC-8)[3]. For the U.S. Virgin Islands, the HUC-8 watersheds cover all of the islands and thus the study area also covers the entirety of each island (Figure 3).

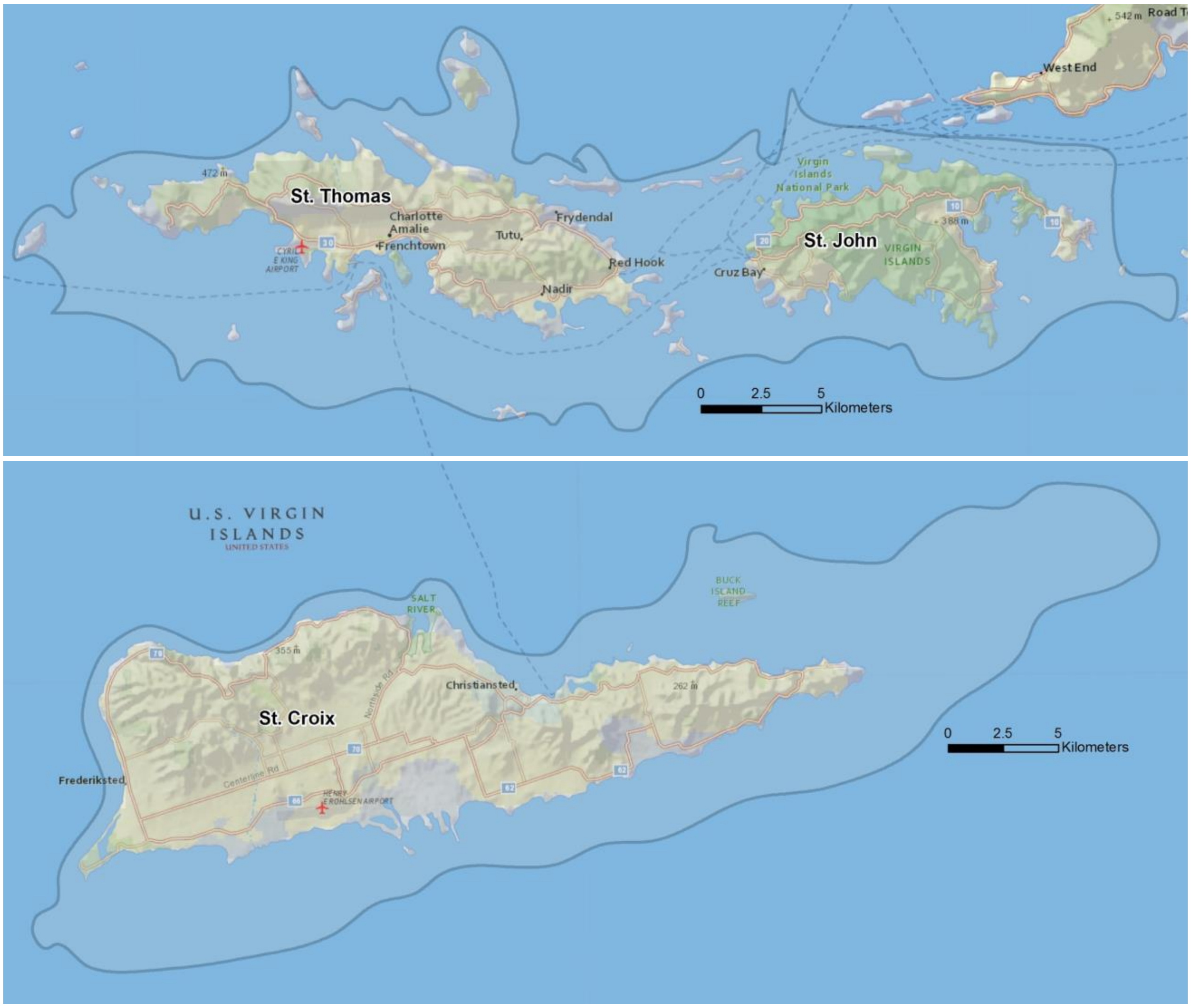


Figure 3. The U.S. Virgin Islands Coastal Resilience Assessment study area. The 30m depth boundary is shown in black. Dashed lines represent ferry routes. Top: St. Thomas and St. John. Bottom: St. Croix.

2.3 Data Collection and Stakeholder Engagement

The Project Team compiled an initial set of data from multiple national and regional data sources, including NOAA's sea level rise data and floodplain data from the Federal Emergency Management Agency (FEMA). In addition to reviewing publicly available data sources, the U.S. Virgin Islands Assessment relied on significant input from local and regional stakeholders to identify and inform the use of additional data sets.

[3] According to the Environmental Protection Agency's Coastal Wetlands Initiative: https://www.epa.gov/wetlands/coastal-wetlands.

To help guide the Assessment process, the Project Team established an Advisory Committee consisting of six members representing NOAA, the U.S. Fish and Wildlife Service, the U.S. Virgin Islands Department of Planning and Natural Resources, and the Lieutenant Governor's Office. The Advisory Committee met regularly with the Project Team to:

1. Provide guidance to the Project Team at key decision points in the analyses, including recommendations on data to be included;
2. Help identify additional local stakeholders within federal agencies, local and territorial governments, universities, non-governmental organizations, and others to provide input into the development of the U.S. Virgin Islands Assessment; and
3. Advise on final products and tools, including the effective dissemination of results.

With input from the Advisory Committee and building on initial data collection, the Project Team hosted a workshop to allow local stakeholders to review and provide input on preliminary Assessment products. The Stakeholder Workshop was held on October 9, 2019 at the University of the U.S. Virgin Islands in conjunction with the U.S. Army Corps of Engineers' South Atlantic Coastal Study Workshop. Over 20 people attended the workshop, helping the Project Team:

1. Identify geographic features, flooding threats, cultural and socio-economic factors, and additional considerations that are unique to the region;
2. Identify, collect, and appropriately use GIS datasets related to flooding threats, community assets, and species and habitat;
3. Provide references and contact information for additional experts that may be able to contribute data or knowledge to the effort; and
4. Obtain overall buy-in to the Assessment process and solicit ways in which it can be used by local stakeholders in U.S. Virgin Islands.

Participants reviewed draft maps and data sources, and provided important feedback and recommendations to improve the analyses.

Following the stakeholder workshop, the Project Team reconvened with the Advisory Committee to assess the feedback, comments, and suggestions provided during the workshop and to determine which content and data to incorporate into revised products. NEMAC then followed up individually with Committee members and other key stakeholders to further discuss data and methodology as needed. Final results of the U.S. Virgin Islands Assessment were reviewed by the Advisory Committee and shared with local stakeholders via a public webinar.

2.4 Creating the Community Exposure Index

The Community Exposure Index was created by combining the Threat Index and Community Asset Index, depicting the spatial distribution of the potential exposure of assets to flood threats (Figure 4). The following equation calculates exposure:

$$\textit{Threat Index} \times \textit{Community Asset Index} = \textit{Community Exposure Index}$$

To accommodate local datasets and needs, the following text describes the specific methods used for the U.S. Virgin Islands Assessment. A complete list of datasets included can be found in Appendix A. See Appendix D for a description of the methodology used to calculate the Community Exposure Index.

Figure 4. Elements of the Threat and Community Asset Indices used to create the Community Exposure Index.

2.4.1 Threat Index

Flood-related datasets are used to help communities understand what kind of threats are potentially present in their area. While other threats may exist, for the purposes of this analysis only those threats relevant to coastal flooding in the U.S. Virgin Islands were included. Threats are defined as datasets that show coastal flood and severe storm hazards on the landscape. The Threat Index is a raster-based model with a cumulative scoring of inputs (Dobson et al. 2020). As in other Regional Assessments, the U.S. Virgin Islands analysis included data related to storm surge, sea level rise, flood-prone areas, soil erodibility, impermeable soils, and areas of low slope, each of which are described in detail in the Methodology and Data Report (Dobson et al. 2020). Additional details on those data used to create the Threat Index for the U.S. Virgin Islands can be found in Appendix A.1 and Appendix B.

2.4.2 Community Asset Index

The Community Asset Index included infrastructure and human population. The Index used datasets that quantify the number of assets present—not their magnitude of vulnerability or susceptibility to flood threats. The infrastructure and facilities that were incorporated into the Regional Assessments were chosen for their ability to help people respond to flood events.

In the U.S. Virgin Islands, the Community Asset Index included population density, social vulnerability, and the full complement of critical facilities and infrastructure detailed in the Methodology and Data Report (Dobson et al. 2020). It was of utmost importance to include locally available data whenever possible. Therefore, based on feedback from the stakeholder workshop and Advisory Committee, additional infrastructure types such as communication infrastructure were included due to their importance in responding to storm and flood events on remote islands. Due to the size and landscape of the islands, many of the infrastructure types typically used in other regions were irrelevant (e.g., bridges and dams). The following types of critical infrastructure were included in the U.S. Virgin Islands Assessment:

- Primary roads
- Airports
- Ports
- Power Plants & Substations
- Petroleum Terminals
- Hazardous Sites
- Wastewater Treatment Facilities
- Communication Infrastructure

In addition, as with all other regions, the following list of critical facilities were included because of their relevance and widespread use following flood events or other disasters:

- Medical facilities (hospitals, nursing homes, etc.)
- Law enforcement (police, sheriff stations, etc.)
- Schools (public and private, universities)
- Fire stations

A detailed list of datasets used for all Community Asset Index inputs included in the U.S. Virgin Islands Assessment can be found in Appendix A.2. See Appendix C for a description of methods used to create the Community Asset Index.

2.5 Creating the Fish and Wildlife Index

The Fish and Wildlife Index, which consists of Marine and Terrestrial components, allows for a greater understanding of important habitats and fish and wildlife resources to aid in the identification of areas where implementing nature-based solutions may support coastal resilience and ecosystem benefits (Figure 5). The Index attempts to identify areas on the landscape where terrestrial, aquatic, and marine species and their habitats are located. For the purpose of the U.S. Virgin Islands Assessment, only those species of concern with federal- or state-level protection status and/or those included in resource management plans were considered. By nature, the Fish and Wildlife Index varies regionally; however, a detailed description of the general methods governing the Fish and Wildlife Index is available in the Methodology and Data Report (Dobson et al. 2020). Regional considerations for the U.S. Virgin Islands are discussed below; a complete list of data can be found in Appendix A and a description of the methods used to create the Fish and Wildlife Index can be found in Appendix E.

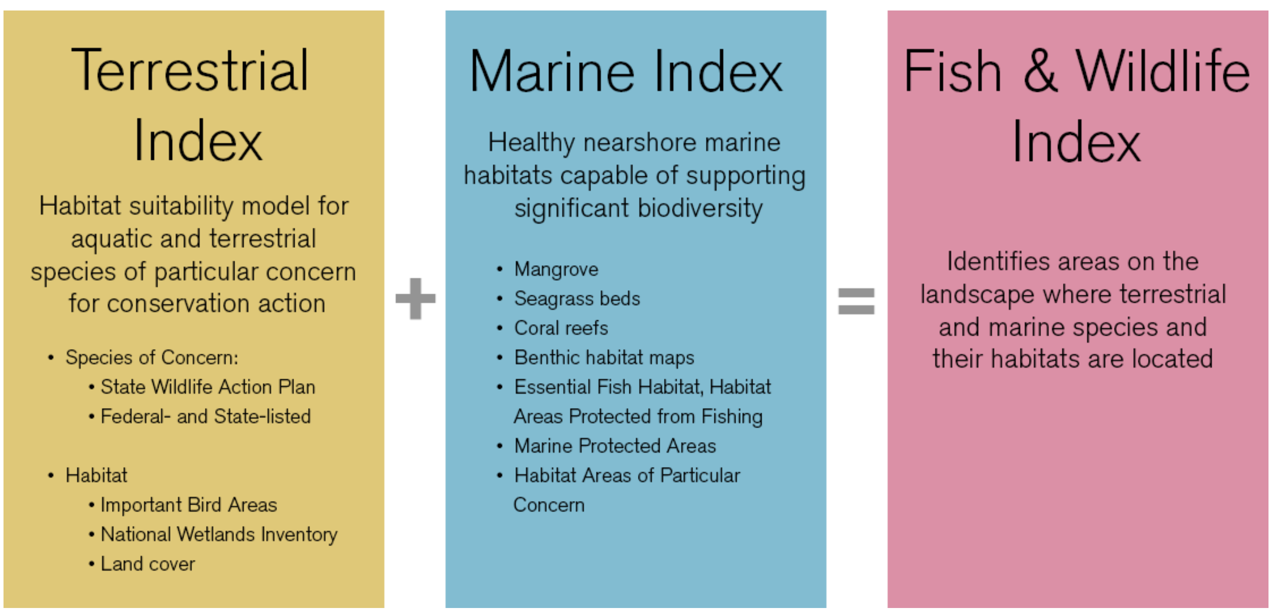


Figure 5. Elements of the Terrestrial and Marine Indices used to create the Fish and Wildlife Index.

2.5.1 Terrestrial Index

The Terrestrial Index aims to identify suitable habitats for major taxonomic groups using available land cover and habitat data. The Index is created relative to the habitat preferences and needs of the species of greatest conservation concern in the region, which were identified using the 2018 United States Virgin Islands Wildlife Action Plan (Platenberg & Valiulis 2018) and species listed as threatened or endangered under the Endangered Species Act. Broad taxonomic groupings were used to model species' habitat preferences throughout the region, including:

- Amphibians
- Reptiles
- Birds
- Freshwater Fauna
- Terrestrial Mammals

Based on habitat preferences associated with each taxonomic group, the analysis modeled primary, secondary, and tertiary habitat suitability (for details, see Dobson et al. 2020). A complete list of species (organized by taxonomic group) included in the U.S. Virgin Islands Assessment is available in Appendix E.1.

In addition to using NOAA Coastal Change Analysis Program land cover, U.S. Fish and Wildlife Service's National Wetlands Inventory, and USGS National Hydrography Dataset to identify habitat types, the analysis utilized the 2007 USGS GAP Landcover. BirdLife International Important Bird Areas (IBAs) were also included. A complete list of datasets and methods used to create the U.S. Virgin Islands Terrestrial Index can be found in Appendix A.3 and Appendix E.1, respectively.

2.5.2 Marine Index

The Marine Index aims to identify marine habitat types that are capable of supporting significant biodiversity. In the U.S. Virgin Islands, three important habitat types were considered: coral reefs, seagrass beds, and mangroves. While other marine habitat types may support significant biodiversity, the U.S. Virgin Islands Assessment focused on those habitat types where restoration and resilience projects may offer the multiple benefits of species richness, ecosystem enhancement, and coastal protection.

Benthic habitat maps, extending to a 30-meter depth bathymetry boundary around all islands, were used to define the spatial extent of coral reef and seagrass habitat. These data were also used to evaluate the percent cover of seagrass patches, where more species are assumed to occupy thicker patches (McCloskey & Unsworth 2015). To assess coral condition, estimates of live coral cover were obtained from NOAA's National Coral Reef Monitoring Program, which regularly implements stratified random sample surveys throughout the islands. Based on surveys from 2013-2017, areas with higher coral cover—and thus more likely to support higher numbers of reef associated species (Komyakova et al. 2013)—were ranked higher. Data on mangrove extent and health were also incorporated (Bunting et al. 2018), where mangrove habitat that is growing in spatial extent was considered more healthy and thus capable of supporting higher species richness.

In addition to the spatial extent and condition of these habitat types, the Marine Index calls upon a number of additional datasets including managed areas such as NOAA Habitat Areas of Particular Concern (HAPC), Essential Fish Habitat (EFH), and marine protected areas. Several Fisheries Management Plans designate EFH in the U.S. Virgin Islands, including corals, queen conch, reef fish, spiny lobster, and highly migratory species. A complete list of datasets and methods used to create the U.S. Virgin Islands Marine Index can be found in Appendix A.4 and Appendix E.2.

2.6 Creating the Resilience Hubs

Resilience Hubs are areas of natural, undeveloped space that attempt to identify places that may be suitable for resilience-building conservation or restoration efforts that can help prepare for potential, adverse impacts to infrastructure and communities, while also improving the habitats of fish and wildlife species. Therefore, Resilience Hubs represent open spaces and habitats that have a high potential to provide benefits to both human communities and fish and wildlife. Accounting for natural spaces on both inland areas and in the nearshore marine environment, Resilience Hubs are formed based upon undeveloped landscapes and habitat types to create two outputs: Green Habitat Cores (inland) and Blue Habitat Cores (marine)(Figure 6).

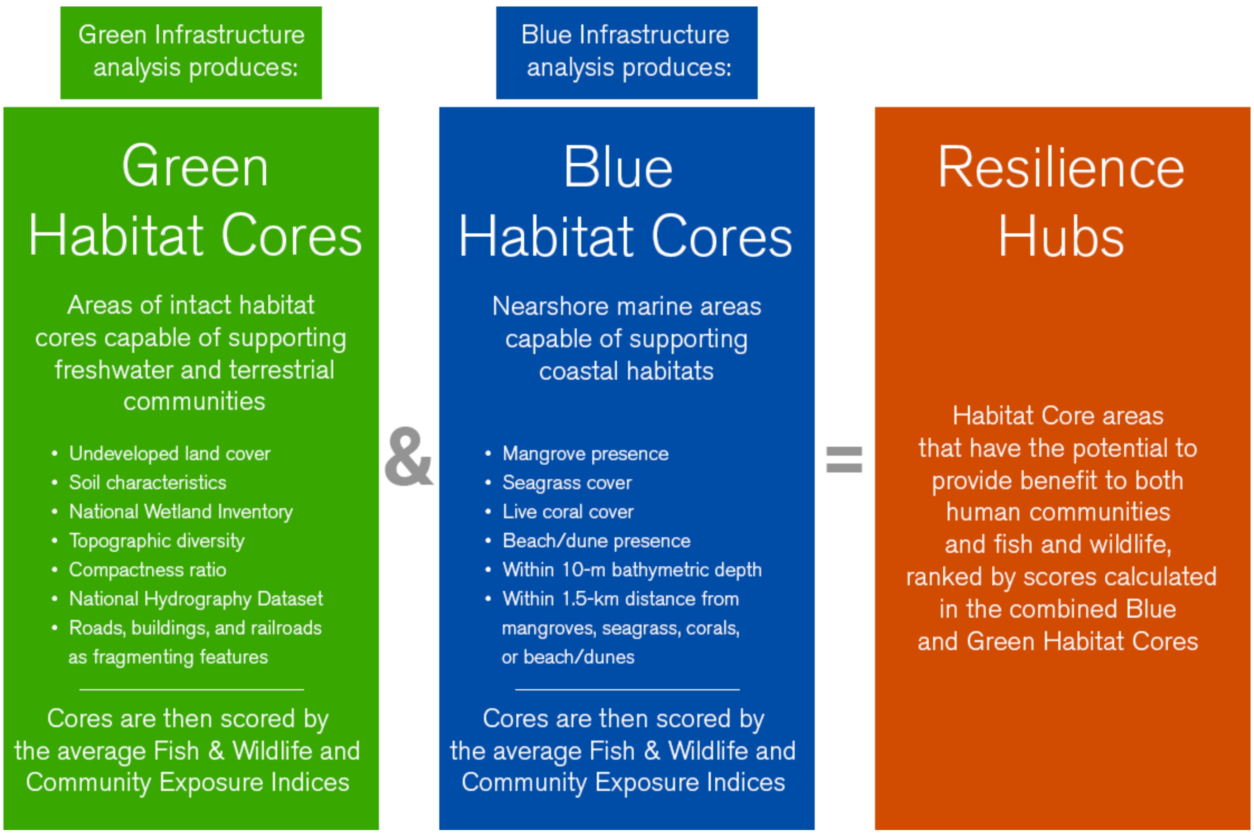


Figure 6. Elements of the Green and Blue Habitat Core outputs used to create the Resilience Hubs..

While the criteria differ between the Green and Blue Habitat Cores, both models rank Resilience Hubs according to the combined average values of the Community Exposure Index and the Fish and Wildlife Index (for a detailed description of methods see Dobson et al. 2020). To show variation within Resilience Hubs, the Habitat Cores are further subdivided and scored at a finer 4-hectare (10-acre) hexagon grid (Figures 7, 8, and 9). This scale was chosen for all Regional Assessments to facilitate local decision-making commensurate with the size of potential nature-based projects and solutions.

Figure 7. An initial step in creating the Green and Blue Habitat Cores. Note the Green Habitat Cores include both terrestrial and freshwater aquatic areas. The Blue Habitat data include estuarine, beach and dune, mangrove, and nearshore marine areas less than 10 meters in depth, but have not yet been grouped into Cores.

Figure 8. Green and Blue Habitat Cores converted to 4-hectare (10-acre) hexagons. As with each Habitat Core, each hexagon is later ranked to show variation within Resilience Hubs.

Figure 9. Final Green and Blue Habitat Cores. The Blue Habitat hexagons are grouped into Habitat Cores by bathymetric basin. The resulting Green and Blue Cores are then ranked to become Resilience Hubs.

2.6.1 Green Infrastructure

The Green Infrastructure[4] analysis used in the Regional Assessments builds upon methodology developed by the Green Infrastructure Center for the continental United States (Firehock & Walker 2019). Since these data were not available for the U.S. Virgin Islands, NEMAC replicated the analysis to create this important layer for the U.S. Virgin Islands Assessment. The analysis identifies "intact habitat cores," or every natural area 40.5 hectares (100 acres) or greater, regardless of ownership or preservation status. The dataset is intended to guide local, regional, and urban planners in identifying important places to conserve prior to planning development projects. The dataset also helps to prioritize which landscapes to protect and connect—such as natural systems that mitigate flooding, provide recreational opportunities, and benefit air and water quality (Firehock & Walker 2019). Habitat cores also represent relatively intact habitat that is of a sufficient size to support more than one individual of a species and takes into account fragmenting features that may disrupt the movement of wildlife species.

Applying these methods to U.S. Virgin Islands, the Green Infrastructure analysis resulted in the creation of Green Habitat Cores, or inland habitat cores encompassing both terrestrial and aquatic habitats. The resulting Green Habitat Core features are then converted into a 4-hectare (10-acre) hexagonal grid (Figure 8). The hexagonal grid helps to highlight variation in the Community Exposure Index and Fish and Wildlife Index scores associated with each habitat core to help facilitate fine-scale decision-making. For full documentation on how the Green Habitat Cores were created, please refer to Dobson et al. (2020).

[4] Note that Green Infrastructure analysis—as it is referred to in this Assessment—pertains to a specific methodology and is not intended to represent other local planning and management projects.

In summary, the Green Infrastructure approach—in determining both Green Habitat Cores and their subsequent hexagons—identifies contiguous natural landscapes composed of similar landscape characteristics. Lands identified have the potential to be of higher ecological integrity and thus may offer improved potential for both human and wildlife benefit. This allows for a more accurate determination of the boundaries of natural landscapes when forming and ranking the Resilience Hubs. See Appendix A.5 and Appendix F for more details.

2.6.2 Blue Infrastructure

Recognizing the prominence of valuable coastal marine habitats in the U.S. Virgin Islands, the Assessment developed a Blue Infrastructure[5] analysis. Marine and coastal habitats, such as coral reefs, seagrass beds, mangroves, and beach and dune systems not only support significant biodiversity, but are also important natural features that can protect human communities and infrastructure. Unlike the methodology used in the Green Infrastructure analysis, marine environments typically lack the fragmenting features that are necessary to delineate and form open spaces into inland habitat cores. As a result, the Project Team developed a different approach in order to identify Blue Habitat Cores, or marine and coastal areas represented by habitats that may be suitable for the implementation of conservation or nature-based resilience projects. The Blue Habitat Cores were delineated by creating a 4-hectare (10-acre) hexagonal grid of all coastal and marine habitats less than 10 meter in depth and then by grouping hexagons according to the U.S. Virgin Islands' bathymetric basins (according to extent of the HUC-8 watershed boundary) and the marine habitats they contain. Unlike the Fish and Wildlife Index, only habitats less than or equal to 10 meters in depth were considered in the Blue Infrastructure analysis since nature-based solutions are more likely to provide coastal protection when implemented in shallow water habitats. For full documentation on how the Blue Habitat Cores were created, please refer to Appendix F and Dobson et al. (2020).

2.6.3 Combining Habitat Cores and Ranking Resilience Hubs

To capture the potential impact the Green and Blue Habitat Cores may have on reducing the effects of coastal flooding on nearby community assets while also benefiting fish and wildlife, the Habitat Cores were scored using the average values of the Community Exposure and Fish and Wildlife Indices to determine the rankings of Resilience Hubs. For details about how Green and Blue Habitat Cores were scored, see Dobson et al. (2020). As noted above, every habitat core feature was converted into a finer-resolution 4-hectare (10-acre) hexagonal grid. As a result, each hexagon also received its own individual ranking, allowing for a finer-scale view of areas within any given Habitat Core. When considered in combination with the Resilience Hubs, the hexagons can help identify areas that may be ideal for resilience-building efforts that achieve dual human community and fish and wildlife benefits. See Appendix A.5 and Appendix F for more details.

[5] Note that Blue Infrastructure analysis—as it is referred to in this Assessment—pertains to a specific methodology and is not intended to represent other local planning and management projects.

RESULTS

The U.S. Virgin Islands Coastal Resilience Assessment reveals abundant opportunities to use nature-based solutions to help build human community resilience while supporting fish and wildlife habitat and species. Nature-based solutions include actions that sustainably manage and utilize natural systems to address societal challenges such stormwater management, urban flooding, and heat islands while benefiting biodiversity and human well-being. Implementing nature-based solutions, such as mangrove restoration, can provide tremendous co-benefits to people and wildlife as described in the case study presented below (see Section 4). The Community Exposure Index shows that areas of high exposure are concentrated around dense urban areas. The Fish and Wildlife Index shows a concentration along the coastline of all three islands of habitat types expected to support wildlife species, with sparsely distributed areas inland that support high concentrations of important habitat. Finally, the Resilience Hubs show that there are numerous Hubs across all islands, though they are largely concentrated along the coastline. For the purposes of this report, the results for St. Thomas, St. John, and St. Croix are described separately; however, a single model was used for all three islands, which allows results to be directly compared within and among islands.

3.1 Community Exposure Index

The Community Exposure Index for the U.S. Virgin Islands shows that exposure is fairly concentrated around densely populated urban areas, which contrast with large areas of undeveloped natural, open spaces. With an average population density of 309 people per square kilometer, populated areas are evident in the Community Exposure Index. Interestingly, when compared to other coastal regions of the United States, the U.S. Virgin Islands do not contain vast stretches of highly exposed coastline. In fact, coastal areas around each island exhibit relatively low exposure values. This is likely due to the steep topography of the coastline, which not only prevent high densities of community assets from being located directly on the water, but also result in relatively low values for several flood-related threats.

The highest exposure values, indicated by the darker browns, are concentrated in several discrete areas of high population (Figures 10 and 11). On St. Thomas high exposure values are found primarily in and around Charlotte Amalie, Nadir, and Smith Bay. On St. Croix, high exposure values are found around the communities of Frederiksted, the greater Kingshill areas, and Christiansted. On St. John, areas of high exposure were mostly limited to Cruz Bay. Most of the smaller islands, including Water Island off the southern coast of St. Thomas, primarily exhibit relatively low to medium levels of exposure.

The Threat Index reveals relatively few, isolated areas of high values along the coastline (Figures 10 and 11). This is likely driven by the topography of the islands, which resulted in relatively low values across many of the flood-related inputs. For example, the Threat Index incorporates low-lying areas as a key input; however, due to steep slopes that are characteristic of many areas throughout the islands, most areas received very low or non-ranking values, indicating there are few areas outside of bay and inlet areas where water is likely to pool. Similarly, the impermeable soils input only identified concentrated areas of imperviousness around densely populated areas, with the remainder of the landscape featuring well- to moderately well-drained soils. Cumulatively across all inputs, there are relatively few areas highly threatened by the coastal flood threats analyzed.

While the topography of the region may result in fewer areas of high flooding threat, portions of the U.S. Virgin Islands are densely populated, leaving important community assets exposed to the impacts of flooding. The Community Asset Index identifies concentrations of developed, populated areas (Figures 10 and 11); however, important community assets can be seen throughout the island, including roads, communication infrastructure, ports, and airports, all of which are critical for effective emergency response in the event of flooding.

On St. Thomas in and around Charlotte Amalie (Figure 12), the Threat Index is mostly driven by storm surge, sea level rise, and the prevalence of impermeable surfaces (impermeable soils input). As expected for a city of this size, the Community Asset Index is mostly driven by population density and the density of critical infrastructure and facilities. Areas further inland still exhibit higher amounts of exposure in some locations, also primarily due to inputs from the Community Asset Index. To explore the results of the analysis in more detail for any area of interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4 below.

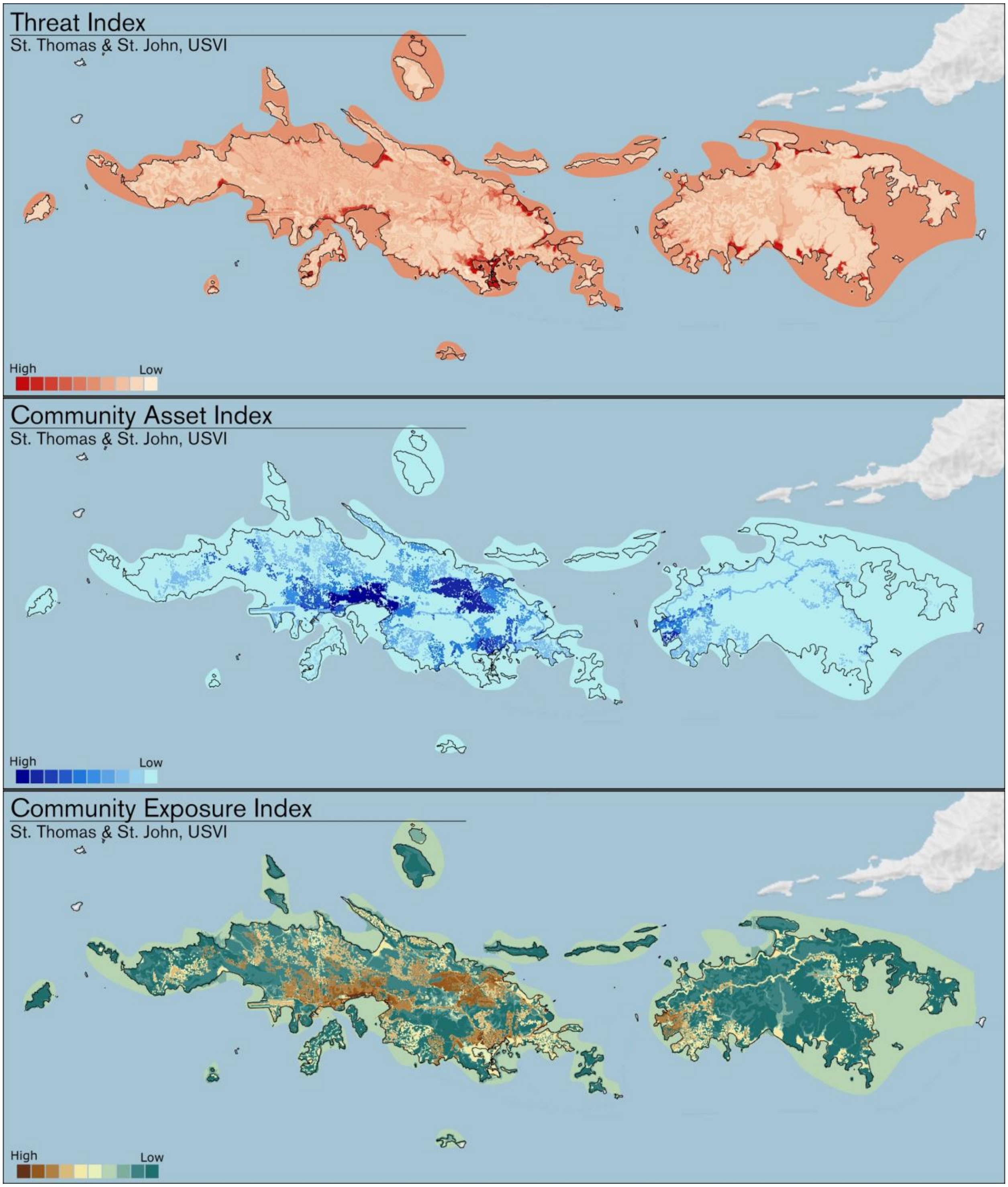


Figure 10. Threat, Community Asset, and Community Exposure Indices for St. Thomas and St. John. The Threat and Community Asset Indices are multiplied to produce the Community Exposure Index, which shows areas where assets overlap flood threats.

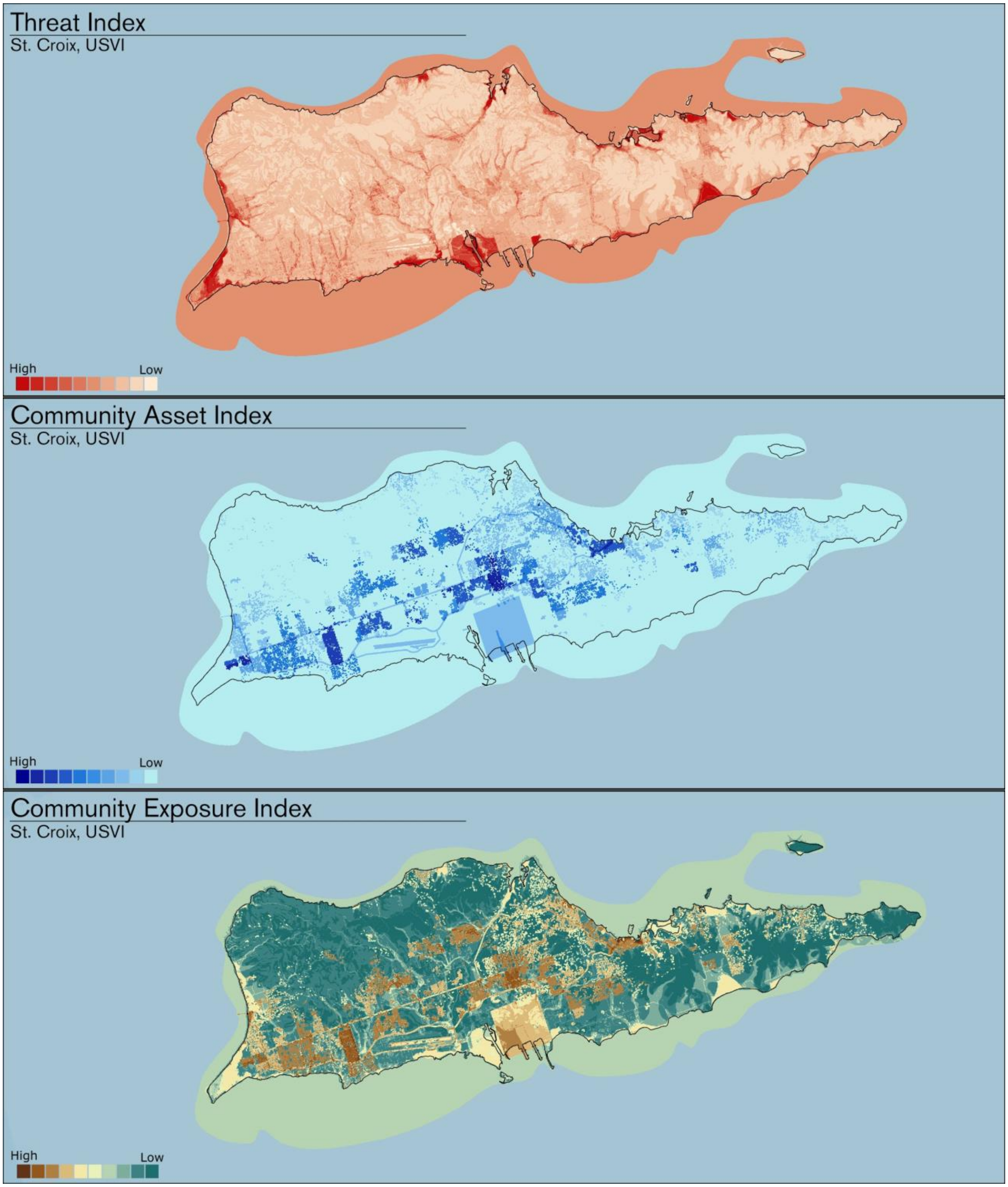


Figure 11. Threat, Community Asset, and Community Exposure Indices for St. Croix. The Threat and Community Asset Indices are multiplied to produce the Community Exposure Index, which shows areas where assets overlap flood threats.

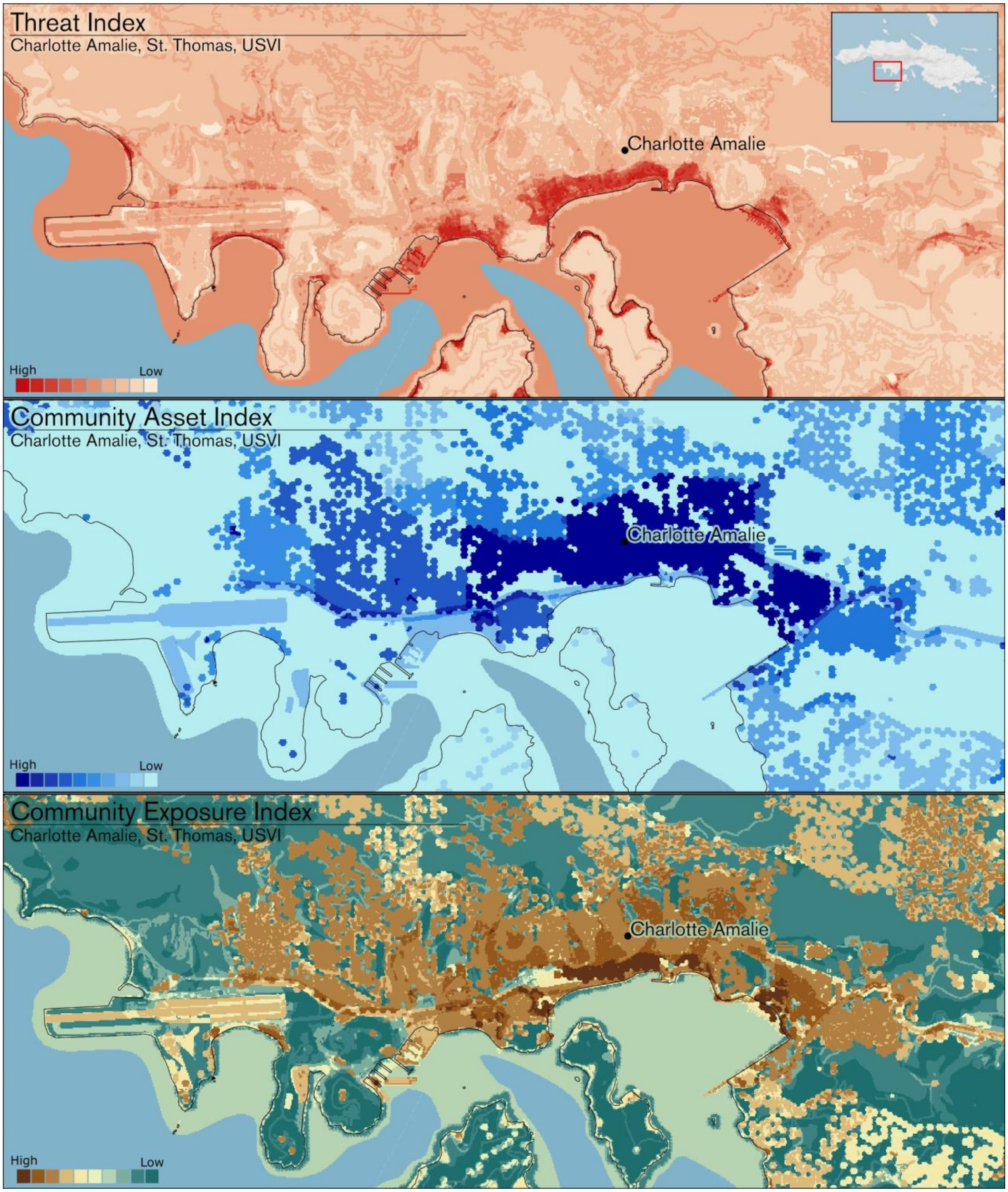


Figure 12. Charlotte Amalie shows higher values of exposure, resulting from the combination of flood threats and community assets.

3.2 Fish and Wildlife Index

The combined Fish and Wildlife Index shows that habitat types expected to support wildlife species are also concentrated along the coastlines of all three islands, although there are sparsely distributed areas inland that support high concentrations of important habitat (Figures 13 and 14). As may be expected, marine and terrestrial protected areas received high values in the Fish and Wildlife Index. For instance, the Virgin Islands National Park on St. John features large areas of intact habitat suitable for a wide range of terrestrial species, such as reptiles, terrestrial mammals, and birds. The National Park and nearshore area around the island also serve as an Important Bird Area (IBA), where a total of 120 bird species have been confirmed[6]. Similarly, the marine reserves in southeastern St. Thomas and the eastern end of St. Croix all scored highly due to the presence of biodiverse marine habitats (e.g., coral reefs, seagrass beds, and mangroves). While higher scoring areas are evident, there are significant fish and wildlife assets throughout all three islands, indicating there are ample opportunities for habitat conservation and restoration projects to sustain the U.S. Virgin Islands' biodiversity.

As noted in the Methods section, the Terrestrial Index evaluated habitat suitability across taxonomic groups. Due to the proportionally low number of native terrestrial mammals, freshwater fauna, and amphibians listed in the U.S. Virgin Islands State Wildlife Action Plan (Platenberg & Valiulis 2018), birds and reptiles dominated the Terrestrial Index. The Terrestrial Index clearly shows higher concentrations of wildlife assets along the coastlines due to the importance of coastal habitats for sea birds and reptiles, particularly the leatherback, green, and loggerhead sea turtles (Figures 13 and 14). The Index also shows higher values for taxonomic groups such as Terrestrial mammals and amphibians, which includes species such as the fisherman bat and yellow mottled coqui that are found across the Islands. For a complete list of species referenced for this analysis, see Appendix E.1.

The Marine Index reveals many very high values around each island, highlighting the importance of marine habitat and species throughout the region (Figures 13 and 14). This is largely driven by the prevalence of coral reefs, seagrass beds, and Essential Fish Habitat (EFH). High values are evident along the southeastern portion of St. Thomas near the Great Bay and Cas Cay-Mangrove Lagoon Marine Reserve and Wildlife Sanctuary. As one of the few areas in the U.S. Virgin Islands with relatively large stands of mangrove, this area scores highly when coupled with moderate to high amounts of seagrass and relatively high coral cover. In addition to the presence of mangrove, corals, and seagrasses, the Great Bay area also includes EFH and Habitat Areas of Particular Concern, all indicating this region features significant marine biodiversity. St. Croix also features numerous areas with high Marine Index values, including the southwestern and northeastern parts of the island. For instance, within the Buck Island Reef National Monument, the presence of relatively high coral cover, seagrass, EFH, and the marine protected area status, all contribute to high marine index values.

Throughout the U.S. Virgin Islands, inlets and bays featured some of the highest Fish and Wildlife Index values. This pattern is evident in Coral Bay, on the eastern coast of St. John (Figure 15). Here, high values result from a combination of marine and coastal habitat used by *both* marine and terrestrial species. Much like in other areas, the Marine Index in Coral Bay is driven by moderate to high amounts of seagrass and coral cover, and the presence of EFH and the Virgin Islands Coral Reef National Monument. Moreover, this area also features coastal and marine habitat important to reptiles and birds, including overlap with the Virgin Islands National Park IBA, contributing to an increased combined Fish and Wildlife Index score for this region. To explore the results of the analysis in more detail for any area of

[6] For additional details about the Virgin Islands National Park Important Bird Area, visit: http://datazone.birdlife.org/site/factsheet/virgin-islands-national-park-iba-virgin-islands-(to-usa).

interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4 below.

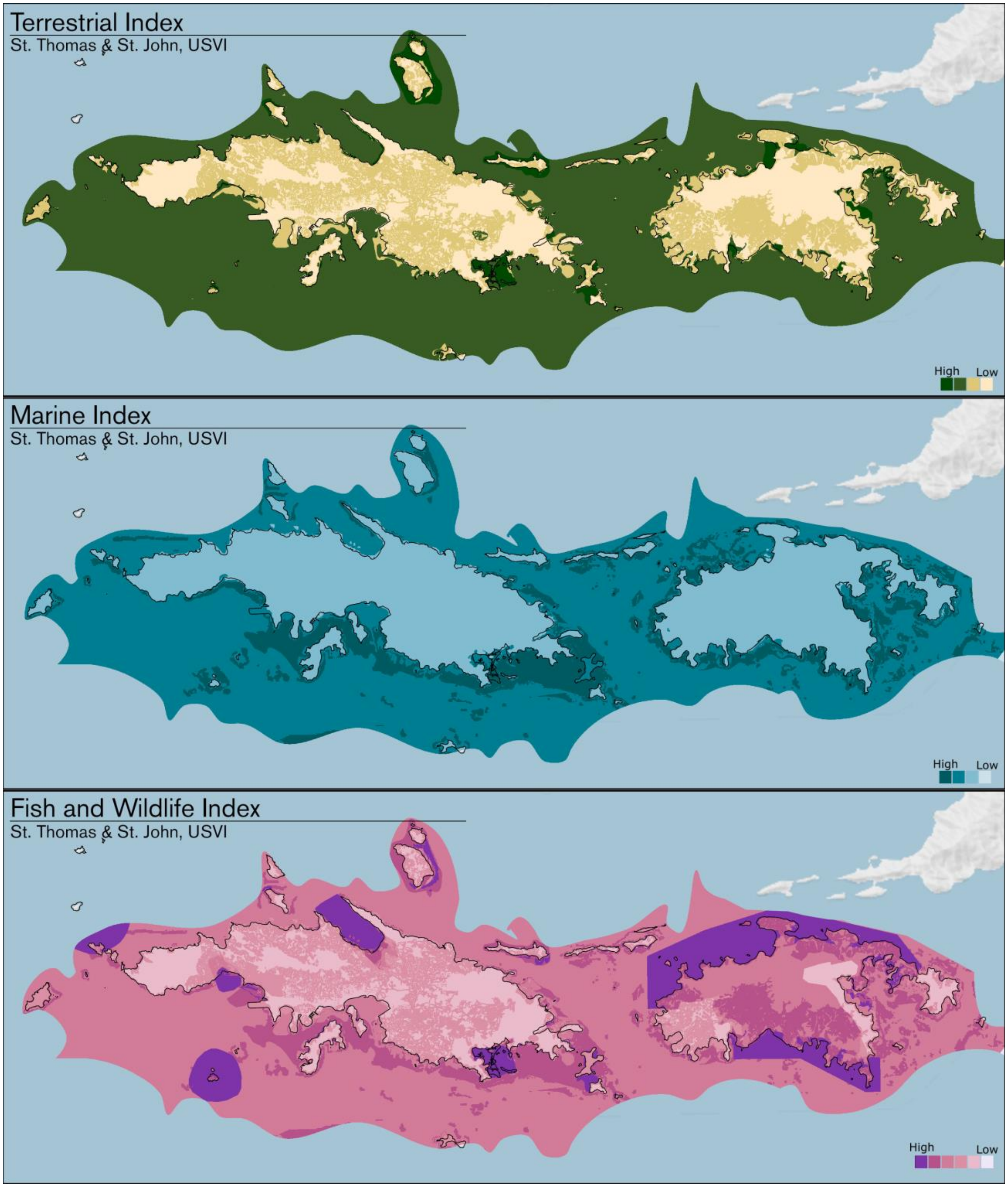


Figure 13. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for St. Thomas and St. John. Pockets of important habitat for terrestrial and marine species are found along the coast and in the nearshore marine environment.

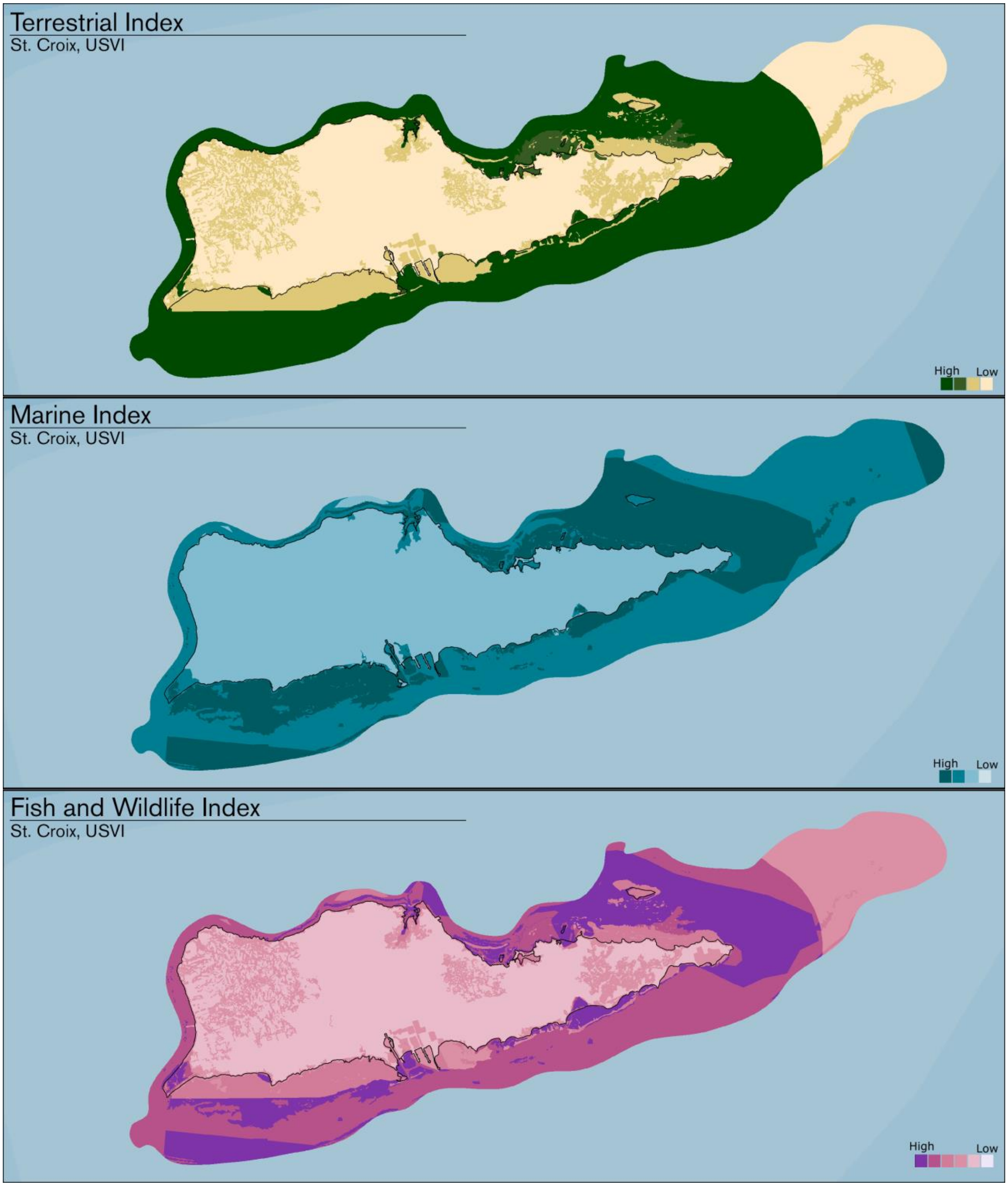


Figure 14. Terrestrial Index, Marine Index, and resulting Fish and Wildlife Index for St. Croix. Areas of high to very high values in the Fish and Wildlife Index are found along the coastline and directly offshore.

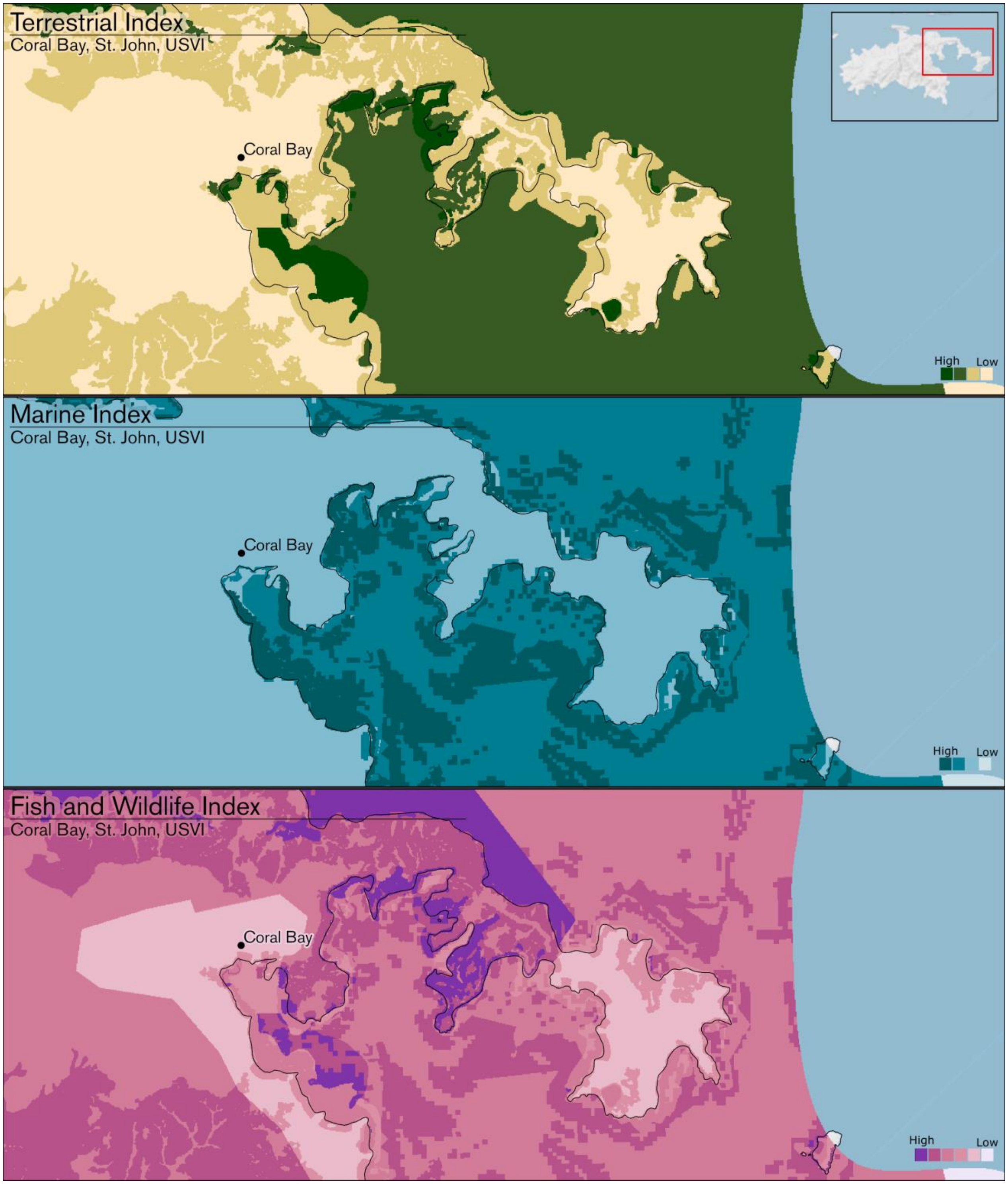


Figure 15. Terrestrial Index, Marine Index, and Fish and Wildlife Index for the Coral Bay area of St. John. The bay has high values in all three Indices, likely due to the presence of marine habitats and the preferences of terrestrial species such as sea birds and reptiles.

3.3 Resilience Hub Analysis

The analysis identified numerous Resilience Hubs throughout each island, with a significant concentration of Hubs along the immediate coastlines (Figures 16 and 17). While Hubs are found throughout much of St. John, there are fewer inland Hubs on both St. Thomas and St. Croix. However, in terms of Hub rankings, the highest values are dispersed fairly evenly across St. Thomas; in St. Croix, the highest values are largely found in the southwestern part of the island, though high-ranking Hubs are distributed throughout the island in a pattern that largely matches that found in the Community Exposure Index. In contrast, the highest values on St. John are concentrated along the northern coast, which is due in part to the presence of the Virgin Islands National Park and its influence on the high values of the Fish and Wildlife Index.

The final Resilience Hub *rankings* are the product of the Community Exposure Index and Fish and Wildlife Index. As described in the Methods section above, the actual boundaries of the Resilience Hubs are formed through the Green and Blue Infrastructure analysis, which identifies Green and Blue Habitat Cores. The following maps show the ranked Blue and Green Habitat Cores and how they are combined to create the final Resilience Hub ranking in St. Thomas and St. John (Figure 16) and St. Croix (Figure 17).

Due to the extensive presence of coral reef and seagrass habitat, the analysis revealed a large network of Blue Habitat Cores encompassing nearly the entire nearshore marine boundary (<10 meter depth) of each island. Since Fish and Wildlife Index values were highest along the coastlines and because the Community Exposure Index identifies numerous exposed areas along the coast, the analysis revealed a large number of highly ranking Resilience Hubs along the coastline and nearshore marine areas. Resilience Hubs found in nearshore areas also received a higher score if multiple habitat types are present in the same areas (within 1.5 kilometers). Since coral and seagrass are frequently found in close proximity, coastal Hubs frequently scored highly. For example, in Jersey Bay on the far southeastern coast of St. Thomas, there are corals, mangroves, and seagrass all present in the same general area, which increased the Blue Habitat Core score due to the increased cumulative coastal protection benefits associated with the presence of multiple habitat types (Guannel et al. 2016). This area may represent an opportunity to implement a suite of coordinated nature-based solutions to maximize the potential to protect surrounding coastal communities from storm and flood events.

While less widespread, there are also many Resilience Hubs in the interior sections of all three islands, particularly on St. John and St. Croix (Figures 16 and 17). The Green Infrastructure analysis revealed relatively few areas of intact habitat greater than 40.5 hectares (100 acres), which in turn resulted in relatively few Green Habitat Cores. There are several notable exceptions, including the Virgin Islands National Park on St. John, which offers largely intact habitat with few fragmenting features. Similarly, the northwestern and eastern regions of St. Croix have large tracts of open space resulting in a higher concentration of Resilience Hubs. Despite limited areas of open space, the presence of Resilience Hubs throughout the interior of all islands suggests there are ample opportunities to implement nature-based solutions.

The U.S. Virgin Islands Assessment was completed at a 10-meter resolution, facilitating a finer-scale analysis of the results. For instance, in the area surrounding Christiansted in St. Croix there are a range of Resilience Hub scores (Figure 18). There are numerous nearshore marine and coastal sites that may be suitable for nature-based solutions, such as coral reef or seagrass restoration (darker shades of blue and red in the Blue Habitat Cores and Resilience Hubs maps, respectively). Participants in the stakeholder workshop noted that flooding in rivers, streams, and ghuts poses problems for stormwater management, erosion, and water quality. Therefore, further inland, there are additional sites that may be well suited for stormwater management or coastal forest conservation or restoration projects. To explore the results of the analysis in more detail for any area of interest throughout the U.S. Virgin Islands, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4 below.

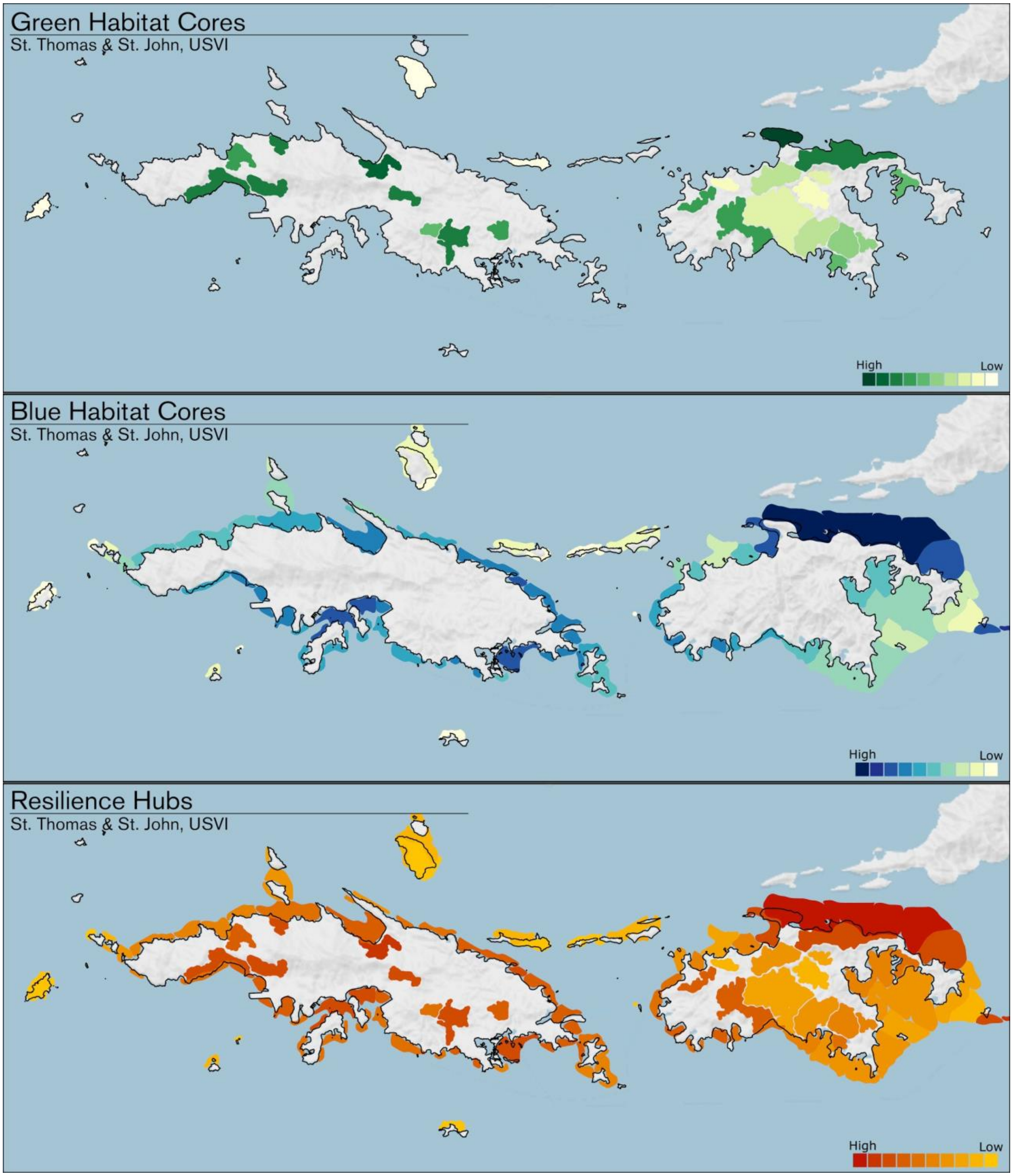


Figure 16. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for St. Thomas and St. John. Darkest shades show areas with higher potential for resilience building efforts that offer dual benefits to both human and fish and wildlife communities.

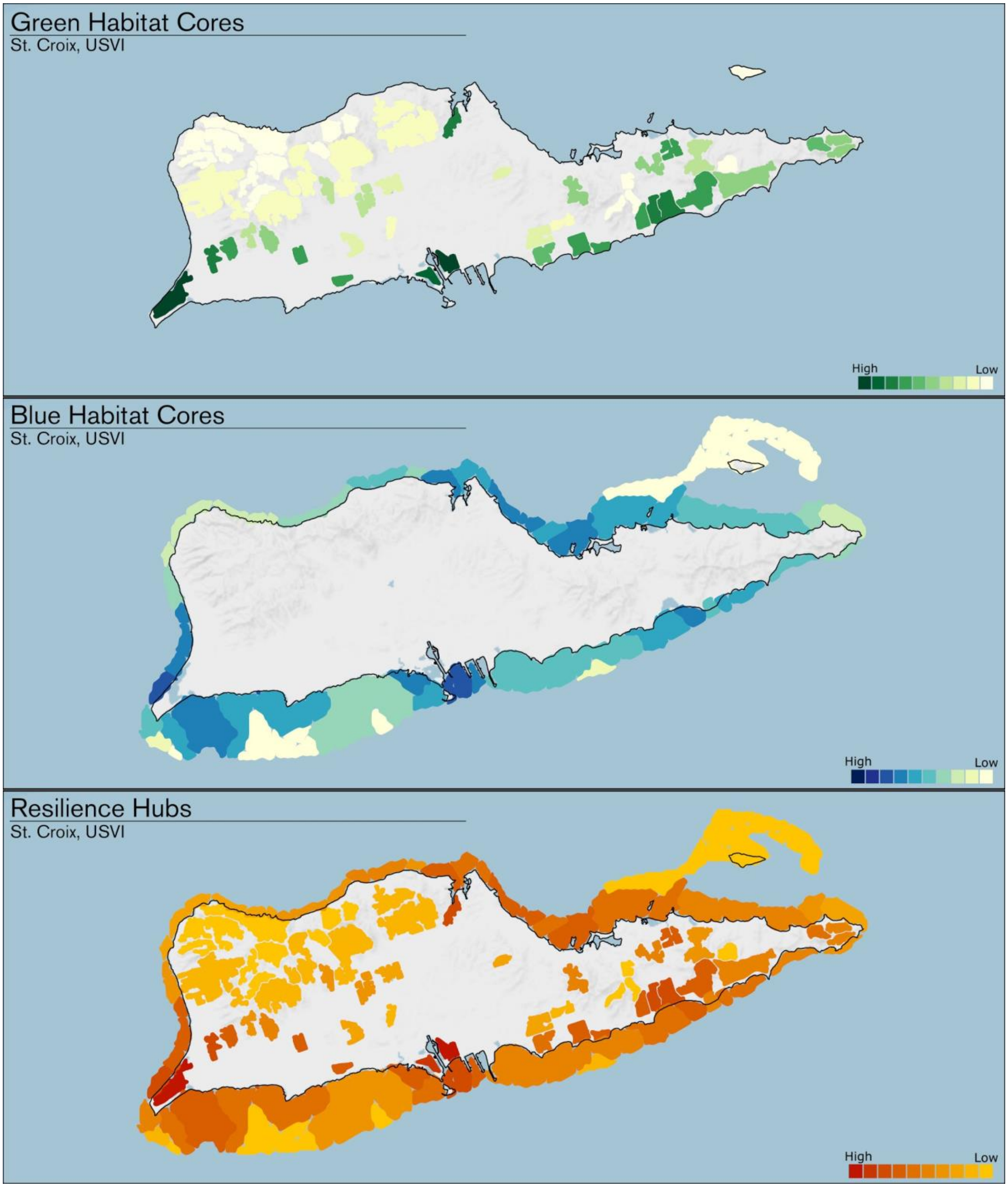


Figure 17. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for St. Croix. Darkest shades show areas with higher potential for resilience building efforts that offer dual benefits to both human and fish and wildlife communities.

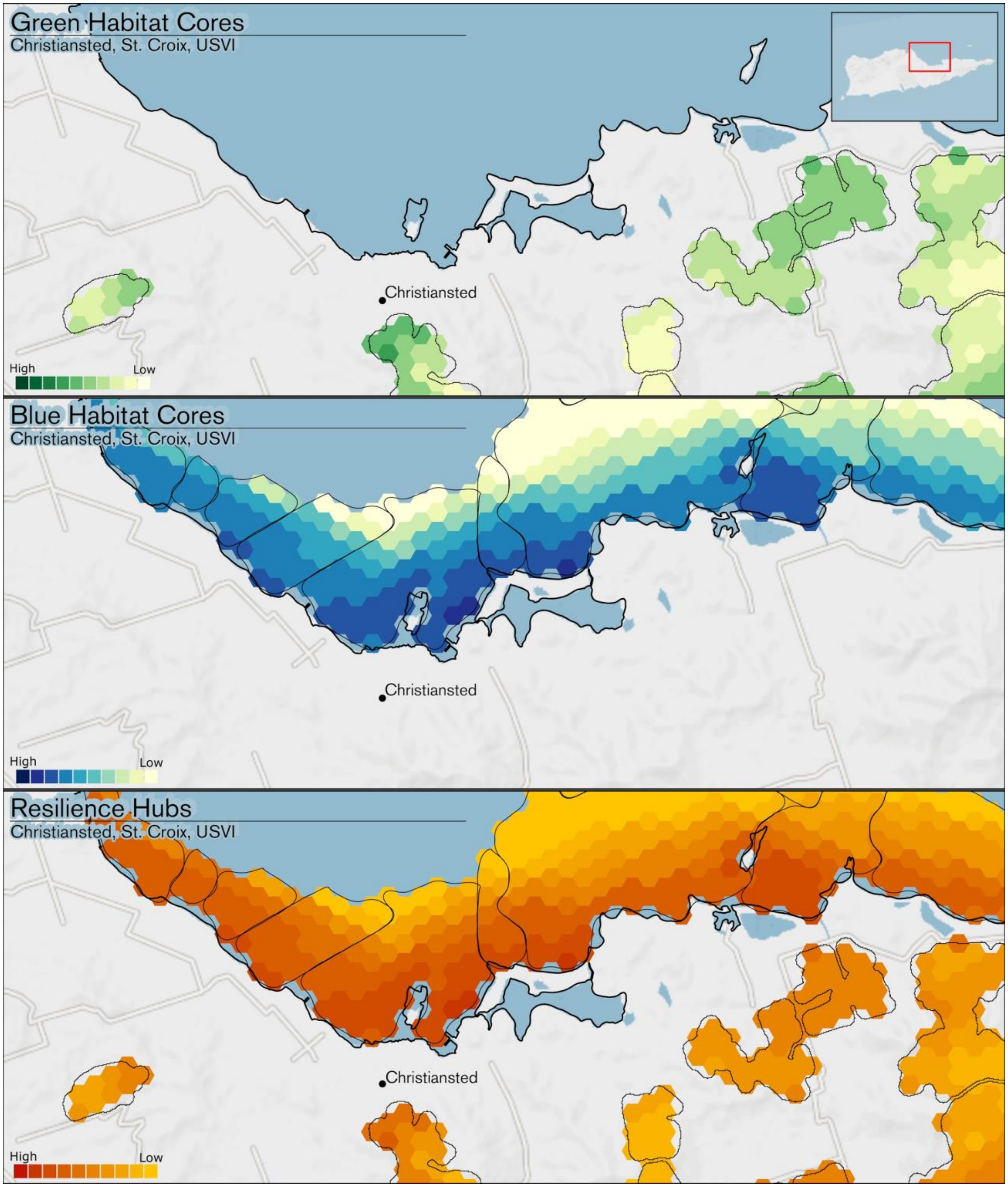


Figure 18. The area around Christiansted, St. Croix shows a range of ranked Resilience Hub scores.

3.4 Coastal Resilience Evaluation and Siting Tool

To provide an online interface to allow users to interact with key Assessment data, including input data and final models for the Community Exposure Index, Fish and Wildlife Index, and the Resilience Hubs, the Coastal Resilience Evaluation and Siting Tool (CREST) was developed as an accompanying GIS-based web tool (available at resilientcoasts.org). CREST helps users make informed decisions about proposed project sites and address other key questions about how to build resilience within their community. It also allows users to have full access to the U.S. Virgin Islands Assessment data so they may incorporate those data into their own GIS applications or other planning processes. Additionally, CREST provides access to the Assessment results even if the user does not have a GIS background or access to GIS software.

Users can directly access results of the U.S. Virgin Islands Assessment straight from the CREST homepage. In addition to simply exploring the results of the Regional Assessments, CREST allows users to analyze results for specific areas of interest. For instance, if a user has already identified a potential project location, they can draw or upload the project boundary within the tool to view site-specific results for the Resilience Hubs, Community Exposure Index, Fish and Wildlife Index, and the results for each of the model inputs. Alternatively, if a user does not have a specific project location in mind, but is interested in evaluating opportunities within a particular region, they can draw a broad area of interest to view results. In both cases, the user can view the results in CREST or download the results in tabular or GIS formats for additional analysis.

CASE STUDY

4.1 Building Resilience in the St. Thomas East End Reserves

Located on the eastern end of St. Thomas, the St. Thomas East End Reserves (STEER) is made up of 9.5 square kilometers of marine reserves and wildlife sanctuaries, including the largest remaining natural mangrove lagoon on the island. Figure 19 shows the general location of the STEER. This mangrove system protects the surrounding communities from storm surge and flooding, while filtering runoff and providing habitat for juvenile fish and other wildlife. Due to the physical structure of the prop roots and branches, mangroves are able to buffer wave and storm energy, offering critical coastal protection benefits. In addition, the structure of the trees holds the peat and sand in place along the coastline, helping to prevent erosion. In 2017, the mangroves were heavily damaged by storm surge, flooding, and wind during back-to-back hurricanes. Restoring and enhancing this wetland habitat after storm damage is very important for helping to protect human and wildlife communities during future storms.

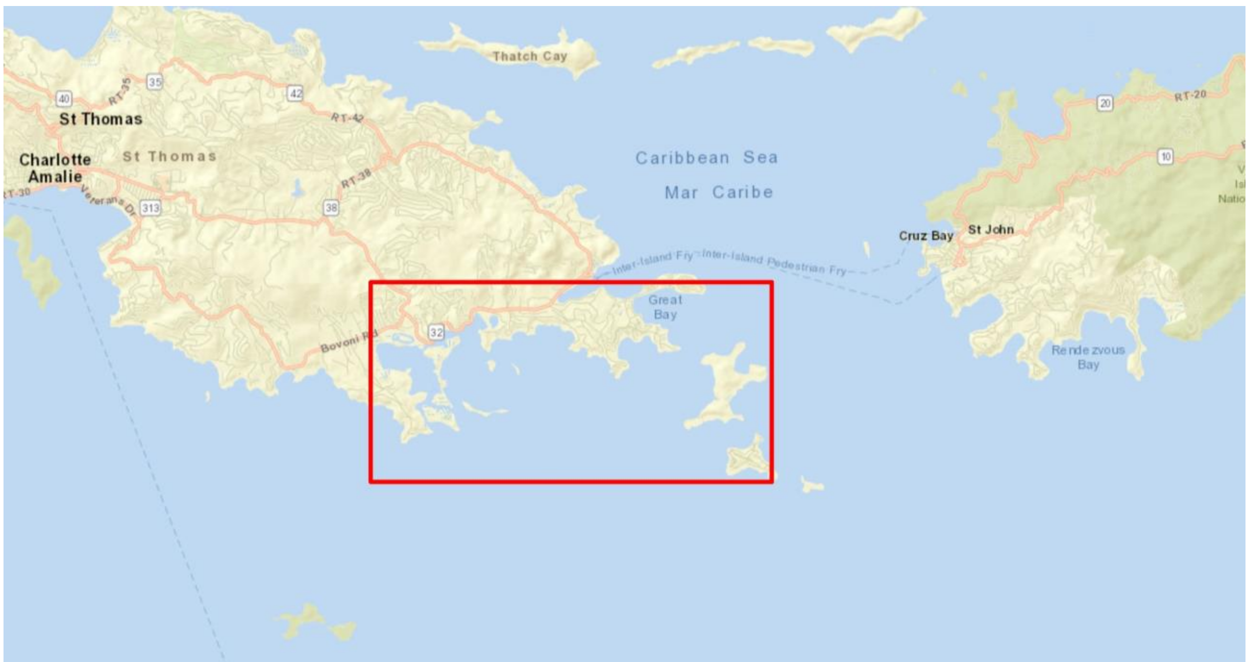


Figure 19. Reference map showing the general location of the STEER on the eastern end of St. Thomas.

In addition to the impacts of recent storms, the mangrove lagoon and other important habitat types found throughout the STEER are also compromised by poor water quality. Nearly 7 square miles of upland area drain directly into the waters of the STEER (HWG 2013). This densely populated area hosts nearly one-third of the population of St. Thomas, with significant development resulting in impervious surfaces covering over 20 percent of the watershed. Further compounding water quality concerns, the watershed includes numerous point sources of pollution, including an open-pit quarry, a Superfund site with contaminated groundwater, marinas, boatyards, and the Bovoni landfill. The results of the Community Exposure Index highlight concentrated areas with high exposure values near the edge of the lagoon area (Figure 20). Unsurprisingly, given the level of development in this area, higher exposure values are associated with areas that have higher concentrations of community assets and dense populations (Figure 21).

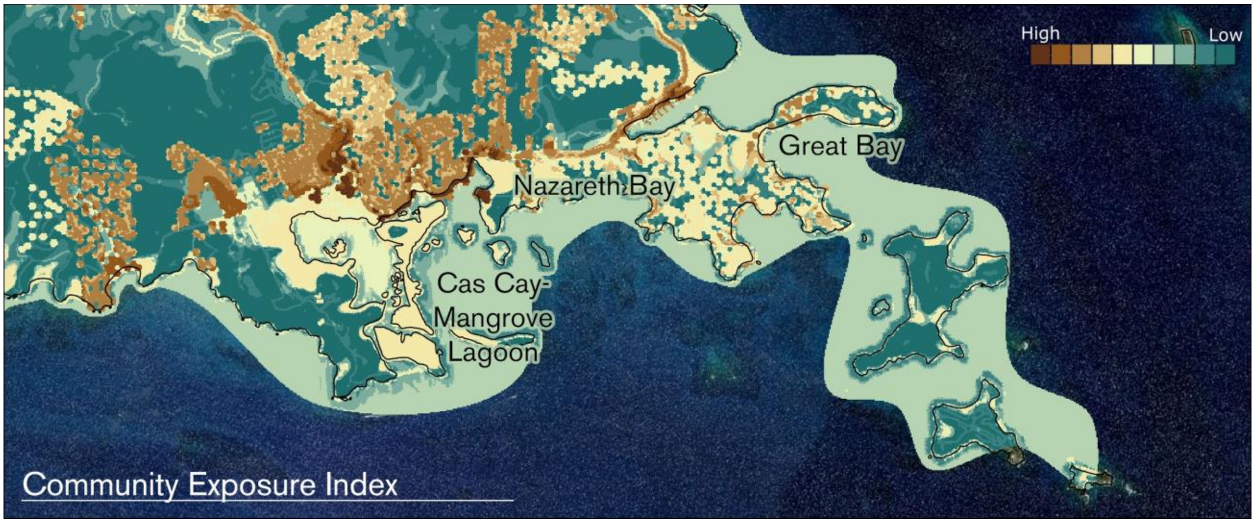


Figure 20. The Community Exposure Index in the location of the STEER on the eastern end of St. Thomas, Cas Cay-Mangrove Lagoon ("Cays"), Nazareth Bay, and Great Bay. Note that many areas near the coast exhibit higher amounts of exposure.

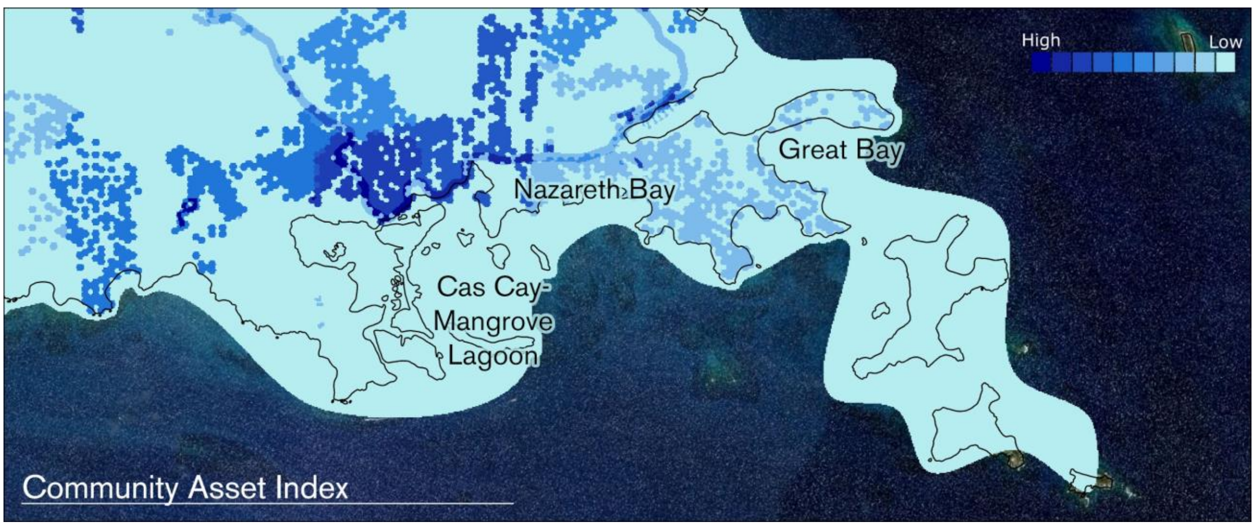


Figure 21. The Community Asset Index in the location of the STEER on the eastern end of St. Thomas. Note the high presence of community assets immediately near the shore.

This area is also subject to numerous flood-related threats, including sea level rise, and soil conditions conducive to flooding. Figure 22 below highlights how sea level rise is a major contributor to the overall coastal flood threat in this area and thus leads to higher exposure values, especially in the areas adjacent to the coastline. Figure 23 highlights the soil characteristics in this area and shows their level of impermeability. The higher the impermeability, the greater the chance for runoff during heavy precipitation events and flash flooding, further exacerbating overall flood events.

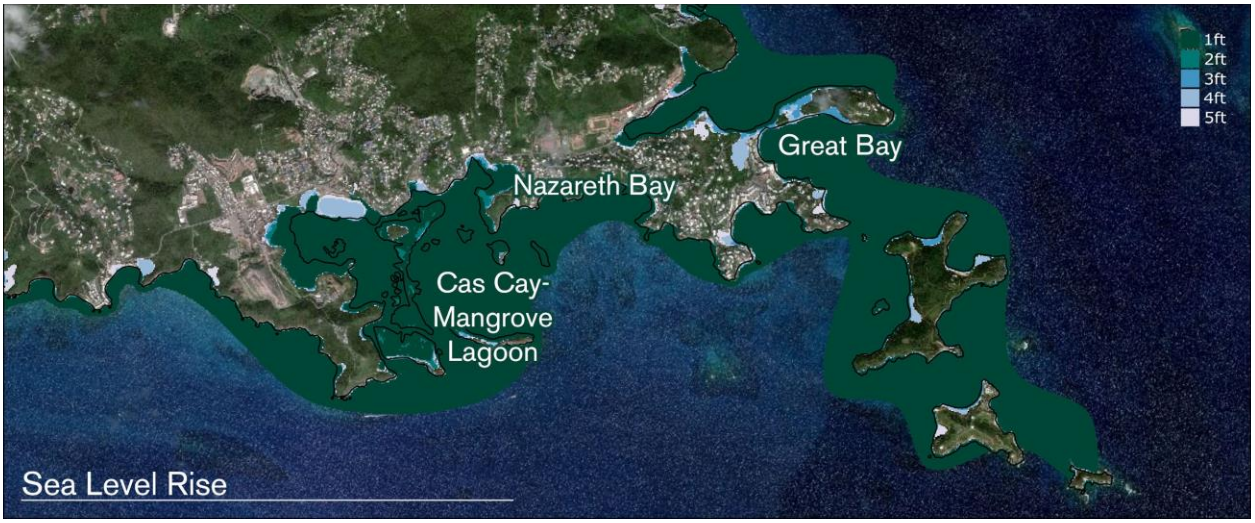


Figure 22. Sea level rise in the location of the STEER on the eastern end of St. Thomas. Sea level rise is a major contributing factor to the Threat Index and the resulting Community Exposure Index, which shows higher amounts of exposure in this area due to projected rising seas.

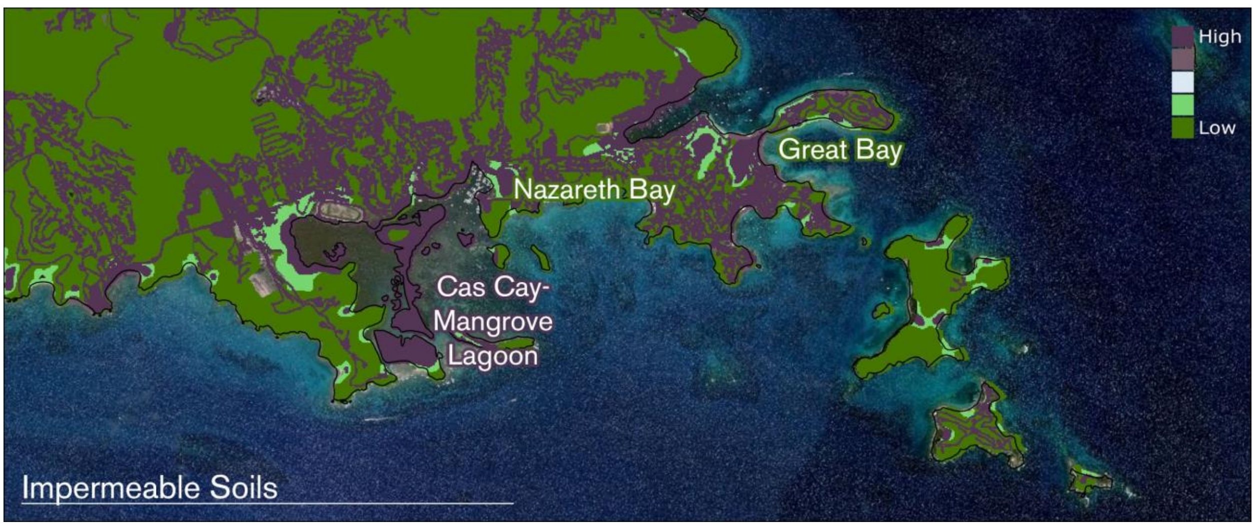


Figure 23. Soil conditions in the location of the STEER on the eastern end of St. Thomas. Soil conditions are a contributing factor to the Threat Index and the resulting Community Exposure Index, which shows higher amounts of impermeability in this area.

Given the size of the watershed and concentration of important marine habitats within the STEER, there are numerous opportunities for conservation and restoration projects. In 2013, and in coordination with NOAA, the Nature Conservancy, and the USVI Department of Planning and Natural Resources, the Horsley Witten Group prepared a Watershed Management Plan for the STEER (HWG 2013). The Plan details a suite of recommendations and strategic actions ranging from water quality improvements to wetland habitat restoration. For instance, improved stormwater management has tremendous potential to not only improve water quality, but also reduce flooding associated with uncontrolled runoff. Nearly 60 percent of the watershed drains through Turpentine Run, which, when coupled with a number of undersized culverts that drain large runoff volumes into the already swollen ghut, results in chronic flooding (HWG 2013). Efforts to restore natural hydrology, stabilize eroding banks, and enhance vegetated buffers along ghuts such as Turpentine Run have potential to provide both flood control and wildlife benefits (Figure 24). Furthermore, by minimizing land-based sources of pollution, the Watershed Management Plan aims to improve important coastal habitats, each of which have the potential to offer coastal protection benefits to nearby coastal communities. This section describes specific restoration activities undertaken in the STEER area, using the U.S. Virgin Islands Assessment results to demonstrate the utility of various outputs to evaluate potential locations to site resilience efforts.

Figure 24. Turpentine Run is subject to chronic flooding and poor water quality due to upstream urbanization. Efforts to restore ghut ecology and natural floodplains will provide flood reduction and wildlife benefits. Photo credits: Kristen Byler, NFWF.

To restore and protect this area, local organizations, including The Center for Marine and Environmental Studies at the University of the Virgin Islands (UVI), have led a marine debris clean-up of the Cas-Cay Mangrove Lagoon Marine Reserve and Wildlife Sanctuary and the Benner Bay area mangrove forests. Community volunteers have removed many tons of marine debris from the mangroves, including boats, docks, lobster pots, buoys, derelict fishing gear, and other forms of garbage (Figure 25). The cleanup was supported by the NOAA Marine Debris Program and the NOAA Coral Reef Conservation Program, and in partnership with many other local organizations. It is important to remove the debris because it can not only shade and smother seagrass, but it also crushes and degrades mangrove habitat. The mangroves trap trash, and by engaging the local community in the cleanup, the projects increase awareness and stewardship of this precious resource.

In addition to marine debris clean-ups that help to protect existing stands of mangroves, there are also numerous mangrove restoration efforts underway throughout the U.S. Virgin Islands, including projects in Watergate Village and the Ritz Carlton on the East End of St. Thomas. By planting mangroves along the shoreline, communities can build resilience to the effects of waves and storms. The Virgin Islands Marine Advisory Service has engaged students at local schools to help rebuild red mangrove forests on St. Thomas (Figure 25). The mangroves are raised at UVI until they are ready to be planted. By raising and planting the mangroves, the students help restore the habitat while learning about their shoreline protection and biodiversity benefits. This project provides a source of locally adapted mangroves for planting efforts, while also educating and engaging students in the collection, cultivation, and planting of these critical mangrove forests.

Figure 25. Mangroves provide an important level of protection to communities from storm surge and flooding while filtering runoff and providing habitat for juvenile fish and other wildlife. Left: The largest remaining stand of mangroves on St. Thomas by the Compass Point Marina in St. Thomas East End Reserves. Right: Volunteers and debris removed from the mangroves at the Virgin Island Ecotours ramp. Photo credits: Kristen Byler, NFWF (left) and University of Virgin Islands (right).

In addition to providing community protection and resilience, the STEER mangroves also provide critical habitat for fish and wildlife throughout the lagoon. The mangroves provide important nursery habitat for a range of recreationally and commercially important fishes, including snapper. The mangrove lagoon also helps to capture pollutants and sediments that would otherwise negatively impact nearby coral reefs. The coral reefs outside of the lagoon to the south not only harbor significant biodiversity, but also feature relatively healthy stands of threatened elkhorn and staghorn corals. The presence of corals, seagrass, and mangrove within the STEER all contribute to high Fish and Wildlife Index values, suggesting restoration efforts in this area will have significant benefits for a myriad of species (Figure 26).

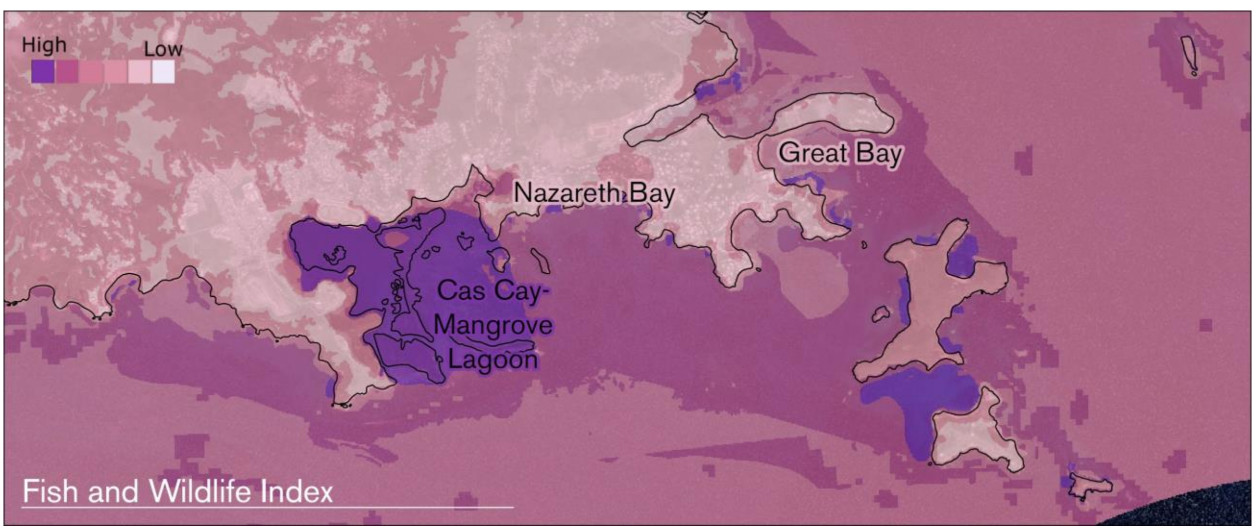


Figure 26. Fish and Wildlife values in the STEER lagoon are much higher than many of the immediate surrounding areas, indicating the higher presence of fish and wildlife species.

Given the presence of fish and wildlife assets coupled with dense populations, significant community assets, and numerous flooding threats, it is unsurprising that there are numerous Resilience Hubs within the STEER area (Figure 27). The presence of high-scoring Resilience Hubs can be used to help identify areas that may be more suitable for nature-based, resilience-building interventions. When considered in combination with priority actions already identified in the STEER Watershed Management Plan, the Resilience Hubs can help support the prioritization of natural and nature-based projects that can benefit both wildlife and surrounding communities.

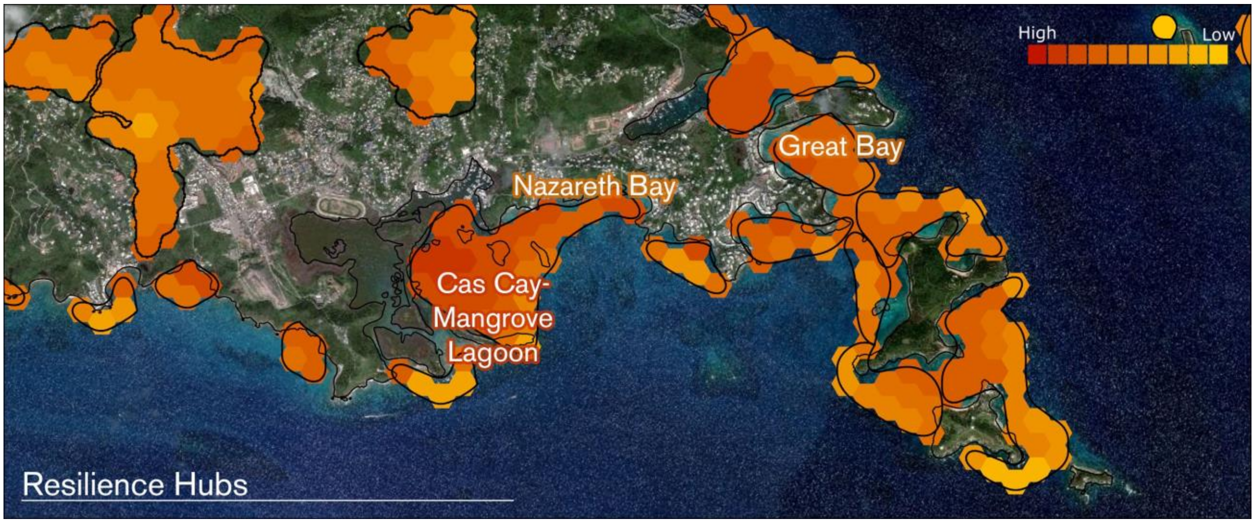


Figure 27. Resilience Hubs (black outlines) in this area indicate that there are multiple areas potentially well-suited for restoration projects. Note the 4-hectare (10-acre) hexagons show variation in scores within each Resilience Hub.

CONCLUSION

5.1 Summary and Key Takeaways

As communities across the U.S. Virgin Islands deal with current and future flood threats from natural events, tools such as this Coastal Resilience Assessment can help decision-makers and other stakeholders use data to make informed decisions about how to identify areas that may be suitable for resilience-focused and nature-based restoration projects. NFWF and NOAA remain committed to supporting programs and projects that improve community resilience by reducing communities' vulnerability to coastal storms, sea-level rise, and other types of coastal flooding by strengthening natural ecosystems and the fish and wildlife habitat they provide.

With nearly 200 kilometers of coastline combined across all islands, the U.S. Virgin Islands remain highly exposed to a variety of coastal-flood related hazards in many areas. This is compounded in areas with higher populations and community assets, such as in Charlotte Amalie, Red Hook, Cruz Bay, Frederiksted, and Christiansted. Inland communities are not immune to flood-related threats either, especially as they relate to heavy precipitation events and flash flooding of ghuts. Furthermore, the effects of coastal flooding are exacerbated when combined with heavy precipitation inland, suggesting efforts to build resilience should consider the benefits of a holistic, island-wide approach.

The U.S. Virgin Islands are ecologically diverse, with an abundance of wildlife assets, both in the terrestrial and marine environments. Combining the information in the Fish and Wildlife Index with the Community Exposure Index, the Assessment identifies Resilience Hubs, or areas where resilience-building projects may benefit both human and wildlife communities in the U.S. Virgin Islands.

5.2 Future Work

The Regional Coastal Resilience Assessments were developed through an iterative process supported by substantial guidance from technical and regional experts. The Regional Assessments and the associated Coastal Resilience Evaluation and Siting Tool (CREST) will continue to be updated, refined, and expanded in the future as appropriate. The overarching methodology will continue to be vetted and refined as needed through ongoing Regional Assessments across the United States. The application and continued development of the Assessments will assist NFWF and others in the implementation of nature-based solutions that build community resilience to flooding threats while benefiting fish and wildlife populations nationwide.

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APPENDIX

The following sections describe the data used for the U.S. Virgin Island Coastal Resilience Assessment in detail, as well as any regional deviations from the methodologies outlined in the Methodology and Data Report (Dobson et al. 2020).

The U.S. Virgin Island Assessment was completed at a 10-meter resolution, using the projection *NAD 1983 State Plane Puerto Rico Virgin Islands FIPS 5200* (WKID 32161).

A. Data Summary

A.1 Threat Index

The following is a comprehensive list of datasets used to create the Threat Index for the U.S. Virgin Islands Coastal Resilience Assessment. **Bolded layer names indicate the source data were specific to the U.S. Virgin Islands Assessment.**

Layer Name	Dataset and Source
Flood-prone Areas	FEMA National Flood Hazard Layers, USDA-NRCS SSURGO (2.2 or later)
Sea Level Rise	NOAA Office for Coastal Management Sea Level Rise Inundation Database (2015 or later)
Storm Surge	NOAA/NHC Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model (2014 or later)
Areas of Low Slope	USGS National Elevation Dataset, 10-meter resolution (most recent available)
Soil Erodibility	USDA-NRCS SSURGO (2.2 or later)
Impervious Surfaces	USDA-NRCS SSURGO (2.2 or later), NOAA Coastal Change Analysis Program Landcover (2012)

A.2 Community Asset Index

The following is a comprehensive list of datasets used to create the Community Asset Index for the U.S. Virgin Islands Coastal Resilience Assessment. **Bolded layer names indicate the source data was specific to the U.S. Virgin Islands Assessment**.

Layer Name	Dataset and Source
Population Density	U.S. Census Bureau, 2010 Decennial Census - estate geography
Social Vulnerability	U.S. Census Bureau, 2010 Decennial Census - estate geography; guidance from U.S. EPA EJSCREEN
Critical Facilities	Fire and Police Stations, Schools, and Medical Facilities spatial data received via Advisory Committee members
Building Footprints	Open Street Maps
Critical Infrastructure *(Various Inputs, see below)*	
Primary roads	*Open Street Maps*
Airport runways	*Data identified during stakeholder workshop*
Ports	*Data identified during stakeholder workshop*
Power Plants/Substations	*Data identified during stakeholder workshop*
Wastewater treatment facilities	*Data identified during stakeholder workshop*
Petroleum terminals	*U.S. Energy Information Administration: EIA-815, Monthly Bulk Terminal and Blender Report*
Hazardous Sites	*U.S. EPA Facility Registry Service (2016 or later)*

A.3 Terrestrial Index

The following table lists those datasets that were used to create the Terrestrial Index for the U.S. Virgin Islands.

Dataset Name	Source and Year
C-CAP Land cover	NOAA Office for Coastal Management (2012)
National Wetlands Inventory	U.S. Fish & Wildlife (most recent available)
National Hydrography Dataset	USGS (most recent available)
GAP Land cover	USGS (2007)
Important Bird Areas	BirdLife International (2020)
Environmental Sensitivity Index Species Habitat	NOAA Office of Response and Restoration (2000)
Critical Habitat Designations	NOAA & U.S. FWS (most recent available)
State Wildlife Action Plan species list	Platenberg & Valiulis for USVI Dept. of Planning and Natural Resources Division of Fish and Wildlife (2018)
Habitat Classification Scheme	IUCN Red List of Threatened Species (Version 3.1)
Protected Areas Database of the U.S. (PADUS)	USGS (Version 2.0)

A.4 Marine Index

The following table lists those datasets used to create the Marine Index for the U.S. Virgin Islands.

Dataset Name	Source and Year
Critical Habitat Designations	NOAA & U.S. FWS (most recent available)
Essential Fish Habitat	NOAA Fisheries (2018)
Essential Fish Habitat Areas Protected from Fishing	NOAA Fisheries (2018)
Habitat Areas of Particular Concern	NOAA Fisheries (2018)
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2015)
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program (STT & STJ: 2013, 2015; STX: 2015, 2017)
Global Mangrove Watch	UNEP and others (2010/2016)
Protected Areas Database of the U.S. (PADUS) - Marine Protected Areas	USGS (Version 2.0)

A.5 Resilience Hubs

The following table lists those datasets used to create the Resilience Hubs for the U.S. Virgin Islands.

Dataset Name	Source and Year
C-CAP Land Cover Atlas	NOAA Office for Coastal Management (2012)
National Wetlands Inventory	U.S. Fish & Wildlife (most recent data available)
National Hydrography Dataset	U.S. Geological Survey (USGS) 1:24,000
Bathymetry	NCEI's U.S. Coastal Relief Model
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program (2014, 2016)
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2015)
Global Mangrove Watch	UNEP and others (2010/2016)
National Elevation Dataset	U.S. Geological Survey (USGS), EROS Data Center
SSURGO Soils Survey	USDA, NRCS
Roads polyline	OpenStreetMap (latest data available)
Railroads polyline	OpenStreetMap (latest data available)

B. Detailed Methodology: Threat Index

The Threat Index for the U.S. Virgin Islands was created by following the methodology outlined in the Methodology and Data Report (Dobson et al. 2020). Any changes to the inputs used in this region, and their sources, are listed in Appendix A.1.

B.1 Calculating the Threat Index

The Threat Index was classified into 10 classes in order to multiply them and ultimately create the Community Exposure Index. Below is the classification that was used for the U.S. Virgin Islands Threat Index.

U.S. Virgin Islands Threat Index Distribution

Threat Index Break Value	0	1	2 - 5	6 - 9	10	11 - 12	13 - 14	15 - 17	18 - 21	22 - 30
Final Rank Value	1	2	3	4	5	6	7	8	9	10

C. Detailed Methodology: Community Asset Index

C.1 Population Density

Following the methodology for population density detailed in the Methodology and Data Report (Dobson et al. 2020), the distribution shown in the table below was used to rank population density in the U.S. Virgin Islands.

Population Density Distribution for U.S. Virgin Islands	Rank Value
0	0
<= 489.103	1
<= 719.453	2
<= 1655.156	3
<= 2481.193	4
<= 5915.21	5

C.2 Social Vulnerability

The U.S. EPA EJSCREEN dataset used for Social Vulnerability was unavailable for the U.S. Virgin Islands. However, the equation used in the methodology for that dataset can be replicated using data from the U.S. Census Bureau. The Demographic Index in EJSCREEN is a combination of percent low-income and percent minority. For each geography, these two numbers are averaged together as follows:

(% minority + % low-income) / 2 = Demographic Index

Using the 2010 Decennial Census data by the Estate geography, a demographic index for the U.S. Virgin Islands was created. After preparing these data, the input was created as outlined in the Methodology and Data Report (Dobson et al. 2020). The following distribution of values was used to rank the input for the U.S. Virgin Islands.

Social Vulnerability Distribution for U.S. Virgin Islands	Rank Value
0	0
<= 76.28	1
<= 79.029	2
<= 81.24	3
<= 82.413	4
<= 100	5

C.3 Modifications Made to the Critical Infrastructure and Critical Facilities Inputs

Specific critical infrastructure and facilities were reviewed for each region to identify any data that were non-applicable and/or any additional inputs that should be considered. The table in section A.2 identifies data source and data inputs that were included in the U.S. Virgin Islands Assessment.

Infrastructure and facility data inputs were included in the analysis following the same methodologies found in the Methodology and Data Report (Dobson et al. 2020).

C.4 Calculating the Community Asset Index

The Community Asset Index was classified into 10 classes in order to multiply them and ultimately create the Community Exposure Index. Below is the classification that was used for the U.S. Virgin Islands Community Asset Index.

U.S. Virgin Islands Community Asset Index Distribution

Asset Index Break Value	0	1	2	3	4	5	6	7	8	9 - 17
Final Rank Value	1	2	3	4	5	6	7	8	9	10

D. Detailed Methodology: Community Exposure Index

After classifying both the Threat and Community Asset Indices into 10 classes each, they were multiplied to create the Community Exposure Index. Exposure is the overlap of community assets and flood threats. As this multiplication results in a final index with values from 1-100, the Community Exposure Index was further classified to make it easier to work with and understand the results. The distribution used for the Community Exposure Index in the U.S. Virgin Islands is shown below.

U.S. Virgin Islands Community Exposure Index Distribution

Exposure Index Break Value	0 - 2	3	4	5	6 - 7	8 - 10	11 - 17	18 - 30	31 - 54	55 - 100
Final Rank Value	1	2	3	4	5	6	7	8	9	10

E. Detailed Methodology: Fish and Wildlife Index

E.1 Calculating the Terrestrial Index

The Terrestrial Index for the U.S. Virgin Islands is based on the same methodology described in the Methodology and Data Report (Dobson et al. 2020). However, because of regional differences, the taxonomic groups between regions may differ. Taxonomic groups included are dependent on the species of concern as determined by each region's State Wildlife Action Plan and species listed under the Endangered Species Act. Habitat preferences for those species were then identified in the IUCN Red List of Threatened Species. The following taxonomic groups and associated species were incorporated into the Terrestrial Index for the U.S. Virgin Islands.

Amphibians

Virgin Islands Coqui
Yellow Mottled Coqui

Birds

Antillean Crested Hummingbird	Masked Booby	Scaly-naped Pigeon
Antillean Nighthawk	Peregrine Falcon	White Crowned Pigeon
Audubon's Shearwater	Red-billed Tropicbird	White-tailed Tropicbird
Bridled Quail Dove	Red-footed Booby	Caribbean Martin
Brown Booby	Roseate Tern	Least Tern
Brown Pelican	Sandwich Tern	Magnificent Frigatebird

Freshwater Fauna

American Eel
Freshwater Crab

Terrestrial Mammals

Antillean Fruit-eating Bat	Red Fig-eating Bat	Cave Bat
Greater Bulldog Bat	Fisherman Bat	Red Fruit Bat

Reptiles

Greater St. Croix Skink	Puerto Rican Racer	Lesser Virgin Islands Skink
Green Turtle	St. Croix Dwarf Gecko	Loggerhead Turtle
Ground Snake	Slipperyback Skink	Virgin Islands Worm Lizard
Leatherback Turtle	Virgin Islands Blindsnake	

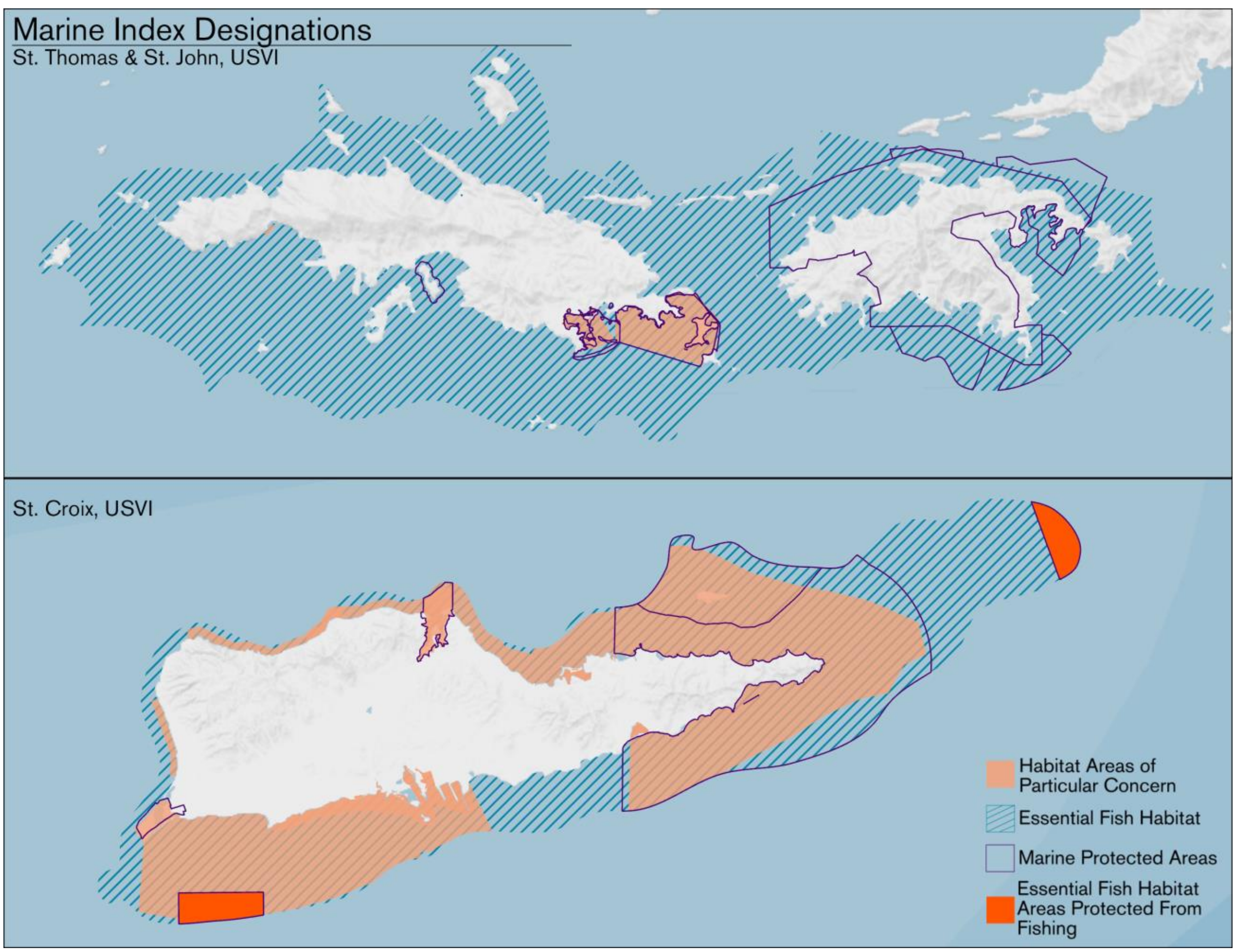
The distribution for the U.S. Virgin Islands Terrestrial Index is displayed below. The final rank value for the Index was determined using a quantile distribution and was then combined with the Marine Index to create the Fish and Wildlife Index.

U.S. Virgin Islands Terrestrial Index Distribution

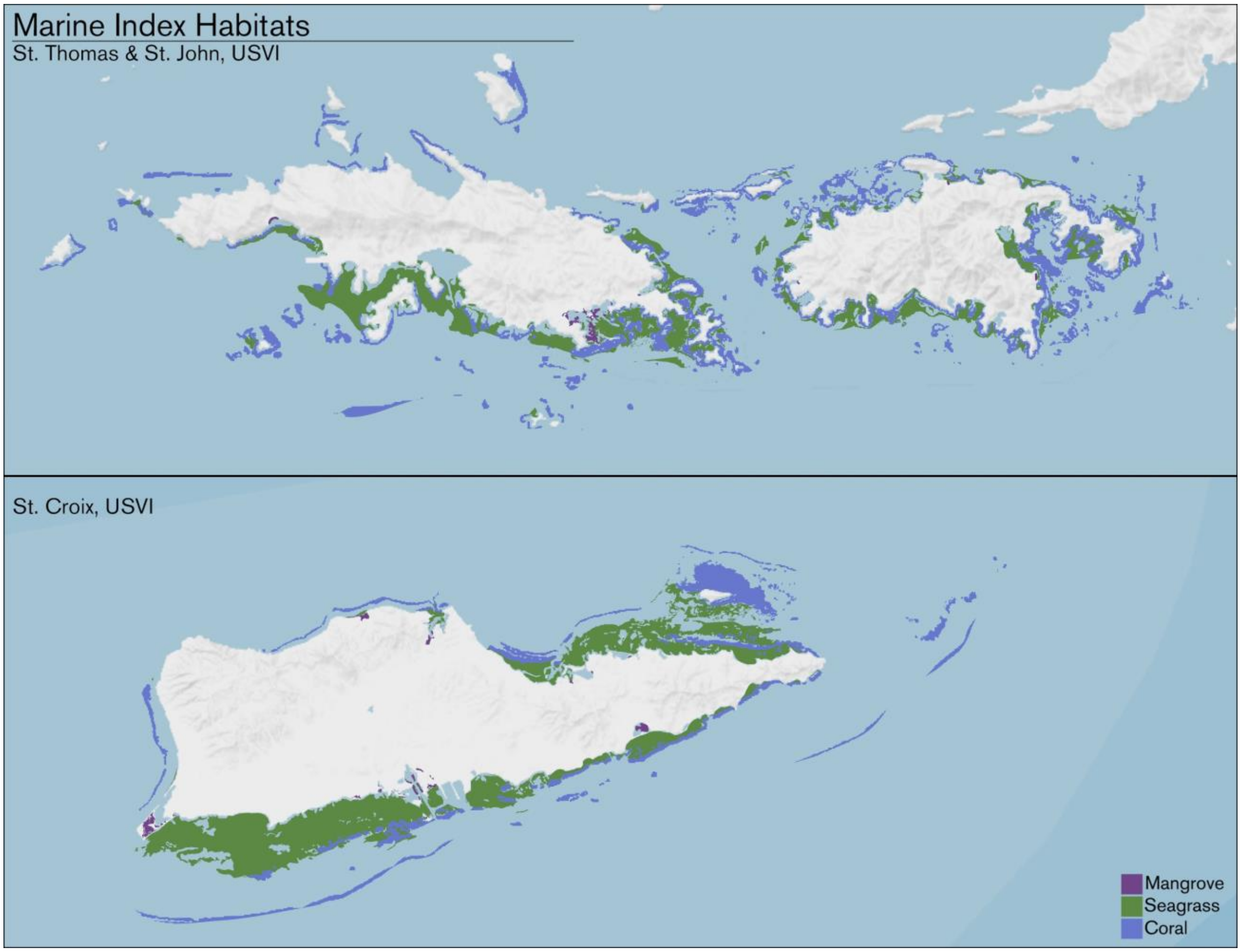
Terrestrial Index Break Values	0	1 - 5	6	7 - 12
Final Rank Value	1	2	3	4

E.2 Calculating the Marine Index

The methodology outlined in the Methodology and Data Report (Dobson et al. 2020) was followed exactly for the U.S. Virgin Islands. The only deviation was to exclude one Essential Fish Habitat Area, the Caribbean EEZ Gear Restriction area, as it was irrelevant to the goals of this Assessment. Additionally, Essential Fish Habitat for Atlantic Highly Migratory Species (HMS) was included in the Caribbean; higher values were given to larval, juvenile, or neonate life stages for HMS as compared to adult life stages. As there are multiple highly migratory species with EFH in and around the U.S. Virgin Islands, areas with EFH for multiple species/lifestages received a higher value. See Appendix A.4 for details on datasets used in this analysis and the map below for the distribution of Essential Fish Habitat, Essential Fish Habitat Areas Protected from Fishing, Marine Protected Areas, and Habitat Areas of Particular Concern used in the Assessment.



The spatial extent of coral reefs, seagrass beds, and mangroves included in the U.S. Virgin Islands Assessment are shown in the map below. Rankings for coral cover and seagrass cover are shown in the tables below, using data collected from 2013 to 2017. These distributions differ by region. Note that coral cover was ranked on a 5-class scale to match that of seagrass cover.



Percent Coral Cover in USVI	Rank Value
0	0
<= 4.44	1
<= 7.04	2
<= 7.97	3
<= 9.81	4
<= 10.86	5

Seagrass Cover in USVI	Rank Value
0	0
Patchy, 10 - <30%; Patchy, 10 - <50%	1
Patchy, 30 - <50%	2
Patchy, 50 - <70%; Patchy, 50 - <90%	3
Patchy, 70 - <90%	4
Continuous (90 - 100%)	5

The distribution for the Marine Index is displayed below. The final rank value was determined using a natural breaks distribution for the Index and was then combined with the Terrestrial Index to create the Fish and Wildlife Index.

U.S. Virgin Islands Marine Index Distribution

Marine Index Break Values	0 - 1	2 - 3	4 - 7	8 - 20
Final Rank Value	1	2	3	4

E.3 Calculating the Fish and Wildlife Index

Below is the distribution for the U.S. Virgin Islands Fish and Wildlife Index. As discussed in the Methodology and Data Report (Dobson et al. 2020), the Terrestrial and Marine Indices were classified into four classes before they were added together to create the Fish and Wildlife Index.

U.S. Virgin Islands Fish and Wildlife Index Distribution

Fish & Wildlife Index Break Values	2	3	4 - 5	6	7	8 - 11
Final Rank Value	1	2	3	4	5	6

Using a quantile distribution, the Fish and Wildlife Index was reclassified to remain consistent between Regional Assessment regions and allow readers to more easily distinguish values.

F. Detailed Methodology: Resilience Hubs

The methodology outlined in the Methodology and Data Report (Dobson et al. 2020) for creating the Resilience Hubs was followed exactly for the U.S. Virgin Islands.