U.S. Virgin Islands Ecosystem Services Approach to Support Hazard Mitigation and Resilience Planning

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Executive Summary

The University of the Virgin Islands (UVI), in collaboration with the Virgin Islands Territorial Emergency Management Agency (VITEMA), is leading a multi-year effort to update the Territory's Hazard Mitigation Plan. The updated and adopted USVI Territorial Hazard Mitigation Plan (Plan) will result in a set of recommendations to identify and integrate principles and elements of resilience, sustainability, and climate adaptation planning for the U.S. Virgin Islands (USVI). With formal adoption of the Plan, financial support through the Federal Emergency Management Agency (FEMA) for the USVI's hazard mitigation efforts can be applied. FEMA's Disaster Mitigation Act requires that State Mitigation Plans be updated and submitted to FEMA for approval every 5 years to maintain eligibility for non-emergency assistance. However, in addition to meeting the terms of FEMA's requirements for the Plan, the goal is to provide a consistent and Territory-wide approach to assessing hazards and risks through technical analyses and community engagement. These assessments, in partnership with stakeholders, are part of the planning process and provide the basis for a comprehensive evaluation of the Territory's status in terms of resilience (HMRP, 2020).

Following the adoption of the Plan, hazard mitigation and resilience activities and efforts will build momentum, projects will be identified for funding, and decisions will be made to advance the goals set out in the Plan, both in the short and long term. These activities include continued post-hurricane development and rebuilding of the USVI, which will alter the natural and built environments, the islands' social systems, and ultimately, the wellbeing of USVI residents. The main objective of the Planning team is to evaluate how risks are interlinked with social, economic, cultural, and ecological factors (HMRP, 2020). With particular focus on the ecological factors coupled with human wellbeing in the USVI, the results of the activities reported within this document aim to inform that objective.

Specifically for this project, an ecosystem services assessment was conducted to better understand the human wellbeing benefits gained from the natural environment of the USVI as it pertains to hazard mitigation and resilience. Resilience and hazard mitigation are terms that are often interpreted in multiple ways. For the purposes of this assessment, resilience refers to the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions. Hazard mitigation is defined as the process of taking measures to minimize and potentially eliminate the impact of hazard events on human life and property. Additionally, ecosystem service assessments can be conducted with various methodologies depending on location and local stakeholder needs. For this assessment, subject matter experts were consulted, and communities participated in a series of workshops to discuss natural resource management and hazard mitigation scenarios within the context of a resilient and sustainable future. Select components of the "ridge to reef" island ecosystem were characterized, along with inferred changes in provision of ecosystem services.

An overall profile of forests, ghuts, farmland, wetlands, and coral reefs reveals that with the loss – and change in quality – of these key ecosystem components, comes loss in the services they have traditionally provided to residents of the USVI. Key findings include:

- The services wetlands provide (especially mangroves) will continue to degrade without intervention, and their extent will continue to be threatened by future development.
- Urban development in areas designated as prime farmland has increased by over 400% from 1985-2018, reducing the amount of farm-able land, and impacting food security.
- Despite anthropogenic stressors and poor local management practices that reduce the mitigation services provided by ghuts, some ghuts can retain many of their ecological functions and interactions.
- Significant decreases in forest cover combined with development and spread of invasive species have decreased the extent and quality of local forests, and by extension, some of the services they provide.
- Both shallow and mesophotic reefs are under severe threat from multiple stressors (ocean warming, storms, disease, pollution, etc.) and it is likely that the ecological services that coral reefs provide will decrease if impacts continue to contribute to future coral die-offs and overall coral decline.

Despite significant changes to ecosystems and ecosystem services over time, results of this project include suggestions for a path toward resilience:

- Island communities, or community liaisons, must be engaged as leads or co-leads from the beginning of hazard mitigation and resilience project or program planning and continue leading throughout the planning, implementation, and evaluation process.
- Decision-makers should use the local community's feedback to identify wellbeing outcomes that are important to the community, as well as in identifying priority ecosystem components and mitigation activities.
- Decision-makers can intentionally target human health outcomes as a starting point in hazard mitigation and resilience planning.
- Decision-makers should invest in hazard mitigation activities that will most likely benefit multiple habitats and that influence wellbeing outcomes important to many people (e.g. human health).
- Consistent, well-planned long-term monitoring of paired terrestrial and marine ecosystems is necessary to gain a clear picture of how the whole ridge to reef ecosystem changes over time.
- More local socio-ecological systems research is needed to connect ridge to reef ecosystem changes to human wellbeing outcomes.
- Developing a human wellbeing monitoring protocol that captures physical, mental, economic, and other health metrics in tandem with natural resource metrics would allow for a more holistic assessment of resilience, consistently over time.

1. Introduction

The natural environment provides a multitude of benefits to people. For example, healthy, functioning ecosystems offer provisioning services, or the provision of natural resources and raw materials, like food and water. Ecosystems also offer regulating services, or the maintenance of essential ecological processes and life support systems for human wellbeing such as flood and disease control. Additionally, cultural services that enhance emotional, psychological, and cognitive wellbeing are derived from ecosystems, as are supportive services that maintain the conditions for life on Earth, such as photosynthesis. These benefits we receive are known collectively as ecosystem services and underpin human quality of life (Table 1; Millennium Ecosystem Assessment, 2005).

Table 1. The four types of Ecosystem Services. For full list of ecosystem service types and examples, see Appendix 1. (Adapted from Harte Research Institute, 2020.)

Provisioning	Regulating
Fresh water	Air quality regulation
Food (e.g. fruit/vegetable crops, fish, etc.)	Climate regulation
Raw materials (e.g. plant fibers, oils, lumber, dyes, etc.)	Water regulation (run-off, flooding, etc.)
Genetic resources (e.g. genes for biotechnology)	Natural hazard regulation (e.g. storm protection)
Medicinal resources, pharmaceuticals	Pest regulation
Ornamental resources (e.g. shells, flowers, feathers)	Disease regulation
	Erosion regulation
	Water purification and waste treatment
Cultural	**Supportive**
Cultural heritage	Soil formation
Recreation	Primary production
Tourism	Nutrient cycling
Aesthetic value	Gas sequestration, storage, and production
Spiritual and religious value	Water cycle
Inspiration of art, folklore, architecture, etc.	Photosynthesis
Social relations	Habitat
Science and education	Pollination and seed dispersal

People derive benefits from the natural environment whether they intentionally use the environment or not; these values are known as use values or non-use values, respectively. Use values include provisioning, regulating, cultural, and supportive services (Table 1). Non-use values (more appropriately known as passive values) include bequest value, which is value people place on knowing that future generations will have the option of using an ecosystem good or service, as well as existence value, the value people place on knowing that a certain ecosystem good or service exists. Additionally, option value is value people place on knowing that they have the option of using or benefiting from a certain ecosystem service or good at some point in the future (Harte Research Institute, 2020).

Ecosystem services help frame the way that we assess the impacts and consequences of our interactions with the natural environment. These services also influence how we choose to manage the natural environment as well as the many human activities taking place within the natural environment. In order to identify management options (e.g. to preserve, conserve, or develop an area) the natural environment needs to be integrated into the decision-making process. In doing so, managers and community members can work together to identify management options that maximize public benefit and minimize risks associated with excluding ecosystem services from the management decision. Decisions are incomplete and inefficient if they do not include all benefits and costs, including those from the environment.

An ecosystem services assessment is the first step toward incorporating ecosystem services into the decision-making process. It is an evaluation of the condition of a local ecosystem, the potential supply of services, and their relation to human wellbeing. The assessment is a mechanism for delineating the value people – in this case USVI residents – place on their environment. This enables a process to determine which service or set of services is valued by people and how to develop approaches to maintain those services by managing the natural and human built systems sustainably.

In the short-term, ecosystem service assessments can guide community leaders and decision-makers as activities that will alter the ecosystem are selected, and over the long-term, will allow communities to adapt and align projects as progress is made. Importantly, the assessment process, as well as its results, not only helps people understand the connections between environmental wellbeing and human wellbeing (Figure 1), but helps them make informed decisions about how, where, and when they might make changes to the natural and human built environments over time.

It is well documented that climate change combined with changing land use practices in the USVI have altered the biophysical functioning of the "ridge to reef" ecosystem (the integrated land and seascape) (Virgin Islands EPSCoR, 2021). However, it is not as well documented how these changes in the ecosystem have been altering the wellbeing benefits humans receive from diverse ecosystems. Before further development occurs, and as hazard mitigation activities are identified for funding, the current interdependence between the ridge to reef environment and islander wellbeing needs to be clarified for informed decision making in the Territory. To realize the goals of a resilient and sustainable future, island residents need to identify and prioritize habitats that can realistically provide hazard mitigation services to them now and in the future.

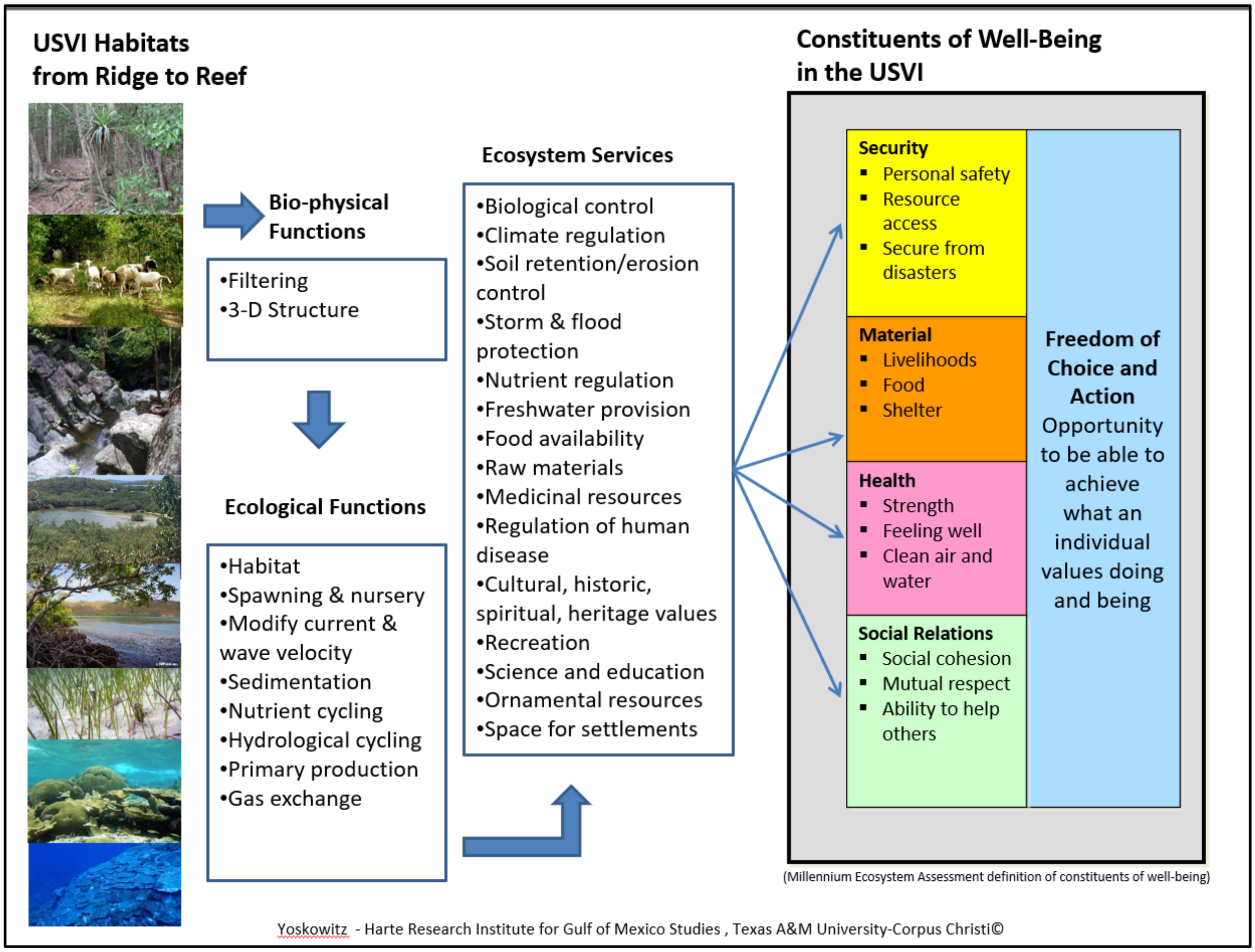

Figure 1. Understanding the linkages between natural habitats of the USVI and the wellbeing of island residents can help guide decision-making related to hazard mitigation and disaster preparedness. (Infographic adapted from Millennium Ecosystem Assessment definition and Harte Research Institute.)

1.1 Methods

1.1.1 Literature review

A literature review was conducted with focus on hazard mitigation services and resilience associated with the USVI ridge to reef ecosystem. The review included relevant peer-reviewed academic literature and government or institutional reports related to human use of and reliance on island ecosystems and ways those ecosystems, services, and benefits have changed over time. While the USVI Territory was the primary area of interest, literature about ecosystem services relevant to other Caribbean islands and regions was also collected, as appropriate. This literature review, paired with subject matter expert feedback (below), created a foundational understanding of previous research into ecosystem services focused on the USVI, helped identify components of the ridge to reef ecosystem that support resilience and offer hazard mitigation services, and identified information gaps.

1.1.2 Subject matter expert discussions

Local knowledge from subject matter experts regarding the current state of the USVI ridge to reef ecosystem was collected through an online discussion process during the months of March through May 2021. Open-ended questions for discussion were designed by the project team ahead of time and conversations were conducted using the online Microsoft Teams© video-conferencing platform to solicit feedback in an open discussion format. Discussion questions are available in Appendix 2. Based on initial recommendations from the Hazard Mitigation and Resilience Plan partners and using a snowball sampling method (also known as chain sampling, where existing subjects suggest names of other subjects to contact), 40 individuals considered to have local expertise or knowledge pertaining to ecosystems across the entire Territory were emailed an invitation letter to contribute their knowledge. Of the 40 invited, 16 responded and provided input. Each discussion lasted approximately one hour, and with permission from participating experts, all responses were documented by a note-taker while another teammate facilitated the conversation. Through this process, experts identified components of the ridge to reef ecosystem – such as habitats and species – that have value for hazard mitigation services or support resilience and suggested potential indicators for resilience. Experts also commented on ways communities that are reliant on ecosystem services can be engaged in developing mitigation strategies and decisions. Responses were used to direct research into natural resources with hazard mitigation and resilience value in the USVI, to create ridge to reef natural resource profiles, and to inform the development of community workshops. Subject matter expert feedback was de-identified to protect anonymity and confidentiality, and summarized using MAXQDA©, a software program for qualitative and mixed methods research. Summaries of feedback are provided in the Results section.

1.1.3. Ridge to reef profiles

To provide an overall profile of natural resources in the Territory, the extent of select ecosystem components and land use was characterized with a focus on indicators of ecosystem health and function that are tied to resilience. To characterize how change in land cover and inferred land use patterns have impacted the provision of ecosystem services, and identify areas with potential for local, targeted management, with the aim of the sustainable use of the Territory's natural resources, maps were created using the most recent and available natural resource or land use extent data for select ridge to reef ecosystem components of the three main USVI islands. Additionally, select components are described, including extent, condition, associated ecosystem services, and the relation of the identified habitat or land use to human wellbeing. This enabled general quantification of human wellbeing benefits that USVI residents currently gain or do not gain from the natural environment as it pertains to hazard mitigation and resilience. The profiles are included in the Results section.

The selection of the profiles characterized in this report – forests, ghuts, wetlands, coral reefs, and farmland – was based on subject matter expert feedback, literature review results, and data availability. It is important to note that the ridge to reef ecosystem in the USVI is not limited to only those four habitat types and land use is not limited to farms; there are many other habitat types such as rocky beaches, sandy beaches, seagrass beds, shallow coral reef, mesophotic reef, shrublands, grasslands, etc. Likewise, there are additional land uses such as pastureland, developed or built environment, and conservation and preservation areas that are critical to making decisions about long-term sustainability. For the purposes of this assessment, the selected ecosystem components (habitats and land use) were identified by subject matter experts as important to resilience in terms of ecosystem function and hazard mitigation (see Results section for expert feedback summaries). Additionally, focus on this set of habitats and land use enabled efficient use of time in conducting a Relative Ratings (ranking) analysis with USVI workshop participants as described in the following section.

1.1.4. Community workshops

In partnership with the Hazard Mitigation and Resilience Plan team, three separate and island-specific workshops were planned and co-hosted for the communities of St. Thomas, St. John, and St. Croix in July 2021. The goals for the workshops were to:

1) Identify ways that the communities that are reliant on ecosystem services (e.g, farmers, fishers, ecotourism businesses, dive shops, recreational boating industry, etc.) can be engaged in developing mitigation strategies and decisions.
2) Identify ways in which the Territory can strengthen the underlying positive factors and enhance the resilience of the USVI's ecosystem services for the Territory's benefit.
3) Conduct a trade-off analysis on ecosystem service provision given land use changes - using one or two specific sites that local stakeholders and the project team identify as priority - to present various development and management options within the framework of a resilient and sustainable future.

Initially, these workshops were planned to include in-person, full-day interactions with volunteer participants from each island community. However, due to complications resulting from the Covid-19 pandemic, and in the interest of maintaining the safety of participants, the planned in-person workshops were not feasible. All workshops were reduced to half-day and re-formatted for a virtual experience using the Zoom© video-conferencing platform, and also shared live through USVI Hazard Mitigation Plan's Facebook account. These changes had implications for the above-mentioned objectives. In particular, the methodology for the trade-off analysis was initially planned to include a Stated Preference approach. This approach is a market research technique that allows researchers to understand how consumers value different ecosystem products and/or services. It involves asking consumers to rate, rank, or how much they would be willing to pay or accept for a certain ecosystem good or service. The choices made by consumers help determine how they value a certain product or service. Examples of this technique include contingent valuation, conjoint analysis, and choice experiment (Harte Research Institute, 2020). This method typically involves full-day workshops where participants work together in groups, interacting with physical props (items representing money, tokens, or other units of value) with guidance from facilitators. This method is not easily transferrable to a virtual platform, so the project team adapted two different approaches that were more conducive to the web-based format: The Relative Ratings approach, and the Ecosystem Service Logic Model Framework.

With the Relative Ratings method, individuals rate natural resources as a means of estimating value. For example, if a wetland provides erosion control and erosion control is highly valued, then the individual would rate the wetland with a 5, which would represent the highest level of relative importance (Harte Research Institute, 2020). Additionally, the Ecosystem Service Logic Model Framework (Figures 2 and 3) represents the way a management action (such as a hazard mitigation project) cascades through an ecological system and results in ecosystem services and human wellbeing impacts.

In these logic models, a management action is linked to multiple changes in the biophysical and ecological environment, or in model terms, the "intermediate components" (see gray box in Figure 2). This change – whether it is increased, decreased, or stays the same isn't immediately important – is only depicted in the logic model if it has been tested or vetted in the scientific literature. These science-based linkages are depicted with arrows in the model. Additionally, the intermediate components in the model are then linked to changes in human activity, depicted in the model as light blue boxes. These changes in human activity then influence human wellbeing or socio-economic outcomes, such as economic activity, mental health, or socio-cultural shifts (GEMS, nd.). Logic models are a useful tool to compare actions across locations to match likely outcomes with stakeholder goals. Evidence that accompanies these models can be used to clarify uncertainties that need to be considered and to identify critical research gaps. If standardized, these models can provide a consistent platform for planning, management, or hazard mitigation approaches and help increase monitoring efficiency (GEMS, n.d.).

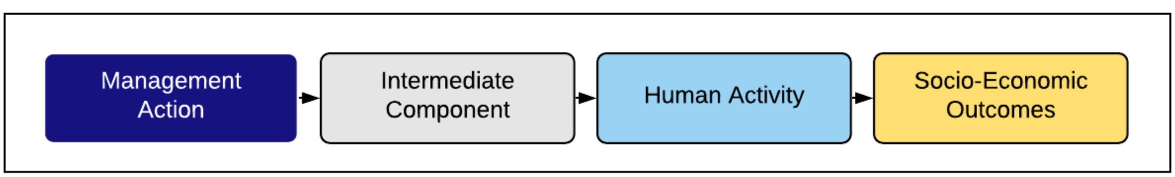

Figure 2. The basic components of an Ecosystem Services Logic Model. (Adapted from GEMS, n.d.)

Through research and application, it is known that some outcomes of mitigation activities, such as habitat restoration or water quality infrastructure improvements, can be associated with community resilience. Resilience refers to the ability to prepare for and adapt to changing conditions and to withstand and recover rapidly from disruptions. These disruptions can include hurricanes, sea-level rise, flooding, drought, earthquakes, disease and other natural and manmade threats and issues common in the Caribbean region. A community can be resilient in diverse ways, but in general includes economic, structural, social, and cultural resilience. Some factors of resilience have been found to correspond with many of the outcomes linked to hazard mitigation actions, particularly restoration (Table 2; GEMS, n.d.). These outcomes do not capture all aspects of community resilience but can be used as targets when planning, implementing, and monitoring hazard mitigation projects, or other resilience activities, in the USVI.

Thus, for each island workshop, Ecosystem Services Logic Models (ESLMs) were used to illustrate the complex connections between making changes in the ridge to reef ecosystem and human wellbeing outcomes of those changes. The project team designed case study scenarios for each island workshop, using simplified logic chains (pulled from fully developed models) to walk through hypothetical, but applicable and realistic, examples of management actions within specific locations that islanders are familiar with, and that experts recommended. For St. Thomas, two scenarios were presented: mangrove restoration in Magens Bay (Figure 4), and drought management techniques in the Bordeaux area. Logic models were presented, and human wellbeing outcomes of these management actions were identified. Likewise, for the St. John workshop, participants were presented with building and restoring trails and boardwalks (Figure 5), as well as native forest restoration, as management options in the Coral Bay area. For the St. Croix workshop, salt pond restoration for the Great Pond location was presented (Figure 6), as was coral reef restoration for the Cane Bay area.

Using the Mentimeter© interactive polling device, facilitators applied the Relative Ratings approach to solicit feedback from participants regarding what components of the ecosystem they value, what types of hazard mitigation and natural resource management activities they deem important, and what human wellbeing outcomes they think decision-makers should prioritize for their island. Finally, Mentimeter© was also used to gather insights from participants about obstacles in and solutions for engaging communities in decisions that affect ecosystems as well as their own wellbeing. All workshop feedback is summarized in the Results section and synthesized for the trade-off analysis in the Discussion section. The three workshops were held on July 6th, 7th, and 9th, 2021, respectively; see Appendix 3 for each workshop agenda. Visit the USVI Hazard Mitigation and Resilience Plan team's YouTube.com channel "ResilientVI" to view each of the recorded workshop sessions (or click here directly for St. Thomas, St. John and St. Croix).

Table 2. Socio-economic outcomes associated with resilience. This list is specific to restoration projects, and the outcomes do not fully capture all aspects of resilience. These outcomes can be used as targets when planning, implementing, and monitoring hazard mitigation projects, or other resilience activities, in the USVI. (Adapted from GEMS, n.d.)

Socio-economic outcome	Resilience relevance
Economic activity	Increased economic activity in a particular community through jobs, labor, and income allow that community to be more resilient to external shocks that harm the economy.
Jobs	When people in the community are employed, they enjoy greater levels of economic resilience and respond better to unexpected shocks. Also, diverse job markets are known to be more resilient because the community does not depend on one industry.
Costs	Damage to property is a direct reflection of structural resilience, and repair costs for property damage similarly link to the property owner's economic resilience.
Expenditures	Increased spending at businesses in a particular community allow that community to be more resilient to external shocks. If spending takes place at businesses outside of the target community, then this may not affect local resilience.
Property protection from flooding or erosion	The ability for shoreline property to withstand external stressors like flooding and erosion represents a facet of structural resilience.
Human health	Community members' health and associated capabilities are essential to resilience; a healthy community is better able to respond to and cope with external shocks.
Cultural values	When community members gain increased knowledge and understanding of their environment in the context of threats to resilience, this can help spur increased public support for future similar restoration projects that would add to resilience. Strengthened (or maintained) cultural values can be linked to community ties and increased social capital, which in turn lead to increased social resilience.
Property value	Increases in property value can be linked to an individual household's economic resilience, and at a larger scale increases in a community's property values (which can lead to a larger tax base) can be linked to economic resilience at the community level.
Social disruption	Critical facilities (e.g. hospitals, schools, government buildings) are important for a community's ability to respond to hazardous events, therefore changes in their closure rate impact a community's resilience.

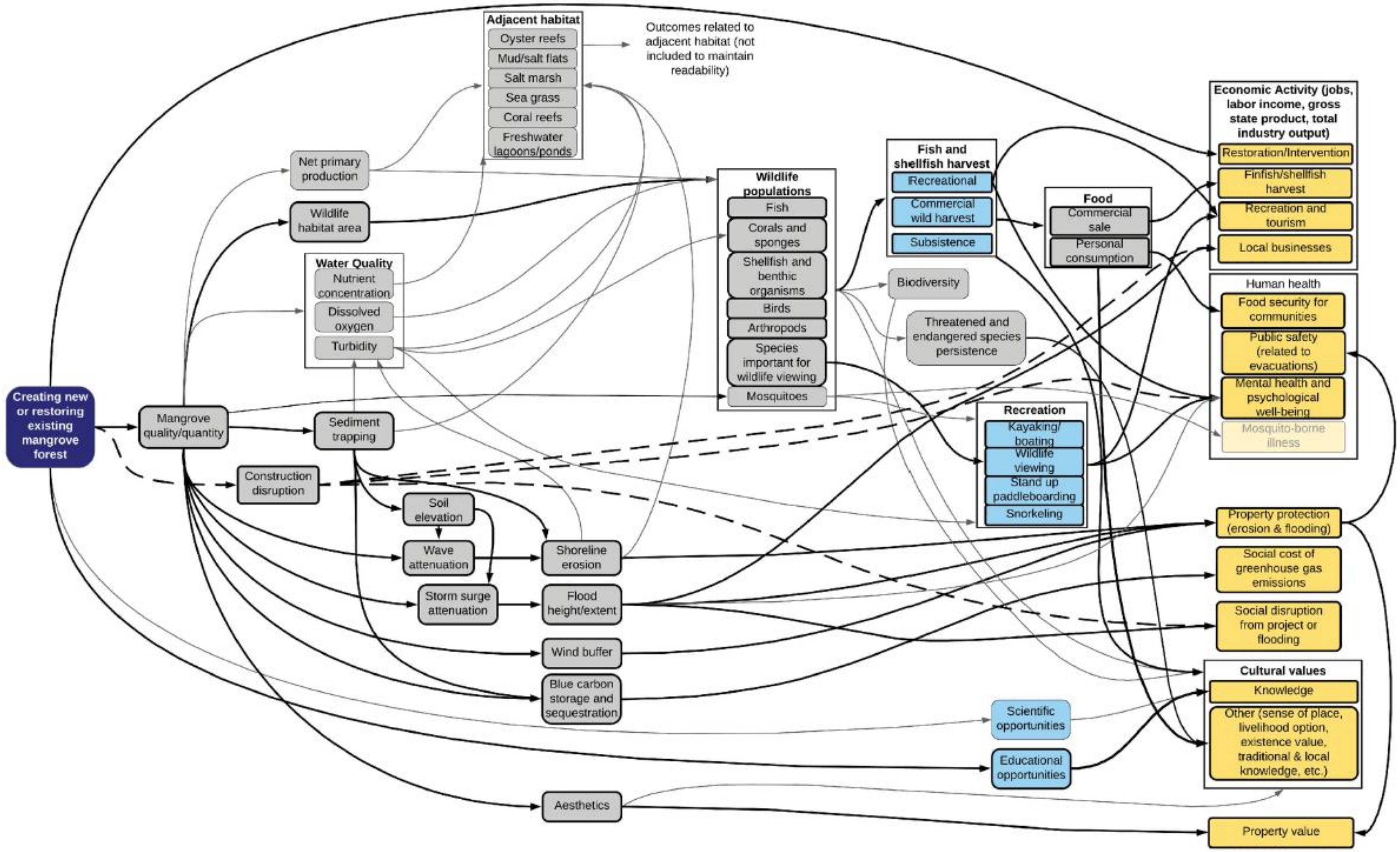

Figure 3. A fully developed Ecosystem Services Logic Model representing the outcomes from the management action of mangrove restoration (dark blue box). Key pathways to strongly linked socioeconomic outcomes (yellow boxes) are indicated with bold arrows as well as with bold outlines around the intermediate components (gray boxes) and human activity outcomes (light blue boxes). Solid arrows indicate long-term effects and dashed arrows indicate short-term effects. The faded-out yellow box indicates weakly linked socioeconomic outcomes, whereas non-faded or bold yellow boxes indicate strongly linked outcomes. (GEMS, n.d.)

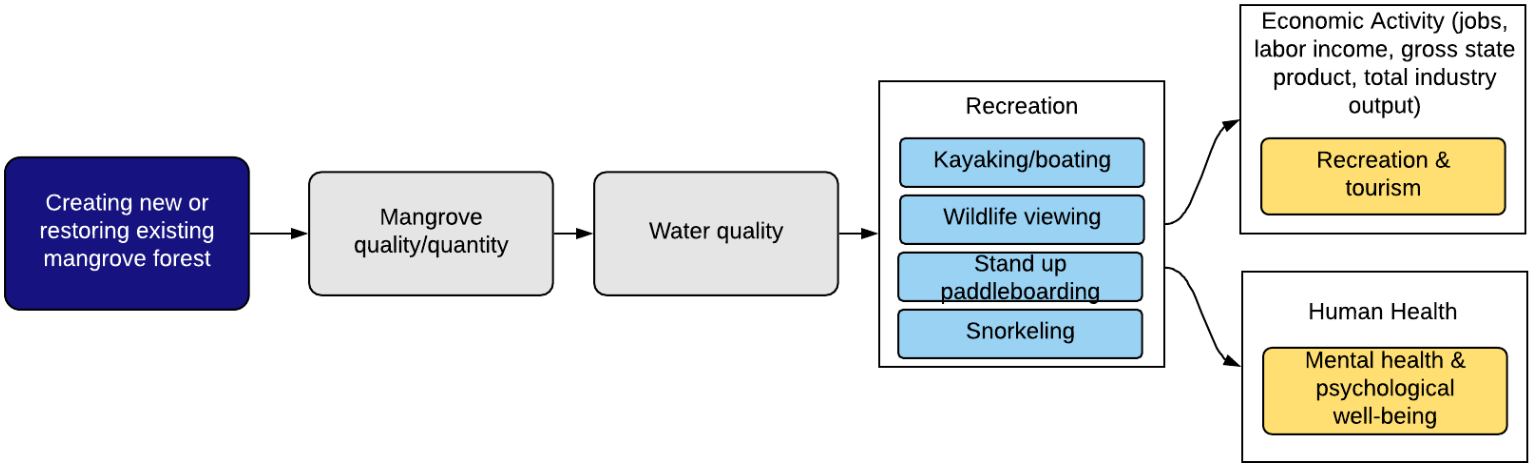

Figure 4. For the Magens Bay scenario, a simple logic chain was built for the St. Thomas workshop participants showing some of the human wellbeing outcomes of restoring mangroves in Magens Bay. (GEMS, n.d.)

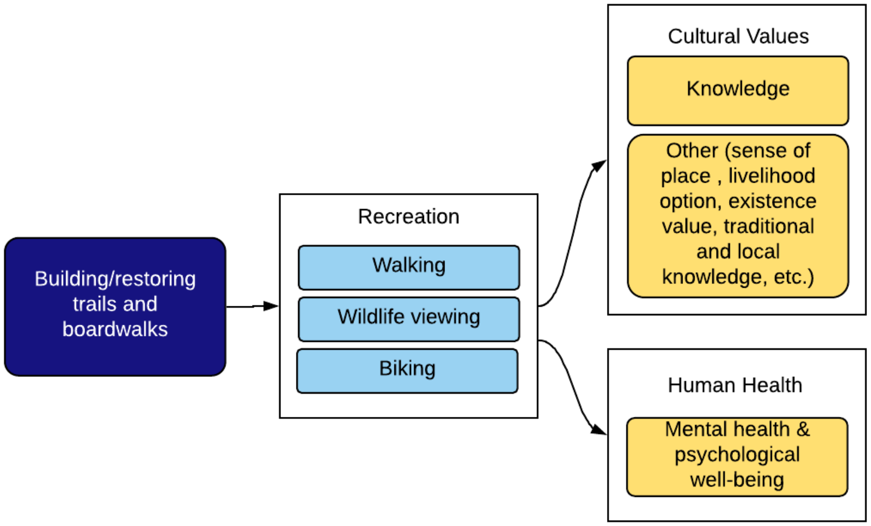

Figure 5. For the Coral Bay scenario, a simple logic chain was built for the St. John workshop participants showing some of the human wellbeing outcomes of building new or restoring existing trails and boardwalks in the Coral Bay area. (GEMS, n.d.)

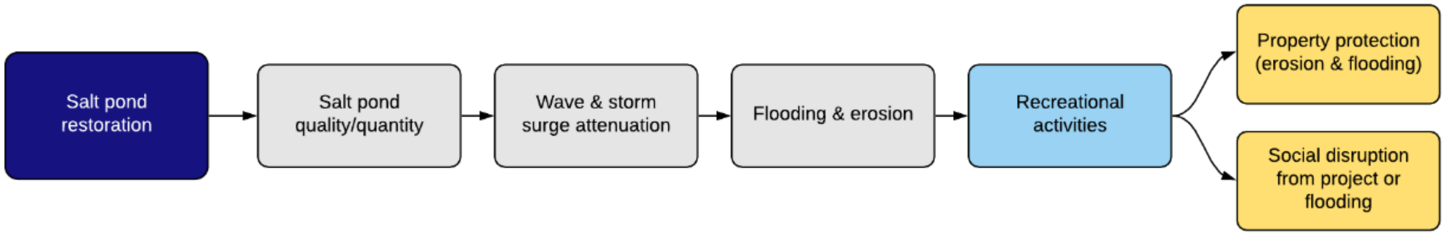

Figure 6. For the Great Pond Bay scenario, a simple logic chain was built for the St. Croix workshop participants showing some of the human wellbeing outcomes of salt pond restoration in Great Pond. (GEMS, n.d.)

2. <u>Results</u>

2.1 Subject matter expert feedback summaries

Discussions with subject matter experts were initiated with a set of pre-determined, open-ended questions, yet the conversations were not bound to only those questions. Feedback collected from experts was used to direct research and workshop development. The input from those conversations was noted consistently across the 16 discussions with experts, where the notetaker documented responses to each question asked (see Appendix 2 for questions). A project team member sorted and coded segments of the conversations, to identify the following:

- Key themes related to ecosystems, hazard mitigation, and resilience
- Components of the ridge to reef ecosystem with hazard mitigation and resilience value
- Potential indicators of resilience
- Community engagement challenges, solutions, and ideas

Table 3 provides a summary of the key themes as well as how frequently the themes appeared in the discussion notes. The most common theme revolved around issues and threats, for example these could include issues and threats related to management and policy, human use of natural resources, natural hazards, ecosystems or parts of ecosystems, socio-cultural and economic issues, and communications. For a breakdown of the common issues and threats mentioned by experts, see Table 4, along with select coded segments as examples.

Additionally, the "issues and threats" segments of conversations were further analyzed to understand what specific habitats and land uses were mentioned in association with those issues and threats (Table 5). Commentary regarding "development" was the most frequent issue that emerged in conversations. Within the context of issues and threats, the habitats (or natural resources) and/or land uses experts most frequently discussed were wetlands, forests, and coral reefs. Ghuts and whole watersheds, fresh water, harvest/fishing/farming, were also mentioned. Beaches and paved surfaces were mentioned as well, but did not emerge as frequently in conversation.

Similarly, all conversations were analyzed for mention of habitats, components of the ecosystem, or land uses that provide human wellbeing benefits or with hazard mitigation and resilience value (Table 6). In addition to broad discussion about ecosystem services and benefits that people derive from the environment in general, the idea that the whole watershed (or ridge to reef ecosystem) provides a multitude of benefits to people surfaced as a frequent consideration; some experts felt strongly that the entire ridge to reef ecosystem, in its natural state is most beneficial in terms of successfully mitigating disaster and supporting resilience. Additionally, experts frequently mentioned that islanders benefit from specific components of the ecosystem that relate to food, coded in Table 6 as, "Harvest/fishery/farmland". Other habitats, components of the ecosystem, and land uses repeatedly mentioned by subject matter experts as providing human wellbeing benefits or with hazard mitigation and resilience value were forests, mangroves, the marine ecosystem, and coral, in addition to others mentioned less frequently.

To gain an understanding of potential indicators of resilience, experts were asked, “How do we know when the island ecosystems (or natural habitats) have changed? What are the indicators (signs)?” The most frequent idea expressed was related to change in biodiversity and species (Table 7). In other words, experts felt that in general, monitoring biodiversity and species change (e.g. changes in species population numbers, changes in species richness) in the ridge to reef ecosystem will allow for resilience signals to be perceived. Experts also had more specific ideas; birds, coral health, native vs. non-native species, fish and fisheries, and prevalence of droughts and floods were mentioned the most often as key indicators of resilience (Table 7).

Experts were also asked to comment on community engagement in the USVI. Specifically, they were asked, “Are communities involved in decisions concerning the USVI ecosystem (or natural habitats)? How so? If not, how can they be?” The most common idea expressed in response to this set of questions was coded as “Attitudes, perception, and/or behavior”. For example, one respondent described how there was little concern for terrestrial biodiversity in USVI or other smaller Caribbean islands and that typically terrestrial biodiversity is more important in the geographically larger islands. As a result, this respondent expressed that we are losing “huge benefits” when we place value on terrestrial biodiversity, and the need to change perception of this in the USVI. Additionally, communication was mentioned often, and usually within a negative context, by experts as an important aspect of community engagement. For instance, some experts shared that information on public hearings related to natural resource management is hard to find, and that the Department of Planning and Natural Resources website is particularly hard to navigate. One comment described a language disconnect, in that information doesn’t reach all the diverse communities that make up the USVI; Haitians, people from the Dominican Republic are large parts of the community who may not get contacted effectively. Other comments on community engagement frequently touched upon issues related to improving education and/or awareness concerning the environment and its connection to human wellbeing. Some experts discussed ideas related to galvanizing pride in the local environment and ways to engage and increase support, coded as “Pride/support/engaged”. Coded summaries with examples are provided in Table 8.

Taken together, this subject matter feedback helped the project team determine what habitats or land uses to consider describing for the ridge to reef profiles, and what ecosystem components to develop for creating ecosystem services logic models, case studies, and conducting rankings exercises and discussion sessions at the three workshops.

Table 3. Key themes that subject matter experts in the USVI expressed during individual discussion sessions. Experts responded to pre-determined, open-ended questions. Frequency = number of mentions in coded segments of conversations.

Key themes	**Frequency** (n=976)
Issues and threats in the USVI	290
Community engagement	107
Ecosystem condition	101
Benefits	94
Solutions	87
Indicators	64
Hazard mitigation	53

Table 4. The key theme of "Issues and threats in the USVI" were coded to evaluate the most common issues and threats mentioned by subject matter experts. Frequency = number of mentions in coded segments of conversations.

Issues and threats	**Frequency** (n=473**)**	**Example coded segment from conversations**
Development and/or built environment	60	*We continually replace natural resources with human development.*
Drainage, run off, and/or flooding	39	*Roadways cutting across hillsides "messes up" natural waterways; causes vertical flooding.*
Waste management and/or pollution	35	*The trash issue on the island; Waste management has an issue with pickup and waste overflow; a lot of the dumpsites are located near ghuts and heavy rains carry trash to the coast.*
Storms and/or hurricanes	30	*Hurricanes have damaged forests, their structure and foliage.*
Attitudes, perception, and/or behavior	27	*VI pride is not necessarily connected to our local land and nature, but to cultural values/notions and historical ideas. Should be related to both, make connections in both.*
Education and/or awareness	26	*People aren't always aware of different solutions/ways of doing things in regards to protecting their property; natural solutions like planting trees could help limit erosion but people just do what they are used to.*
Drought and/or water availability	25	*Number of short-term droughts has increased dramatically, but annual rainfall has not changed dramatically. There is more periods of extremely dry weather followed by heavier rain periods.*
Enforcement and/or regulation	24	*We regularly don't follow laws; e.g. VI code states that you should not build within 30 ft. of any watercourse, but this is not followed.*
Community engagement and/or communications	21	*Public hearings don't typically let the community get involved, dismissive of local input, testimony.*
Invasive vs. native species	18	*Replanting areas with non-native plants; don't cope with drought well; leads to sediment runoff.*
Climate change	13	*Climate change and the Sahara dust now negatively impacts locals.*
Harvest/fishing/farming	13	*Gardening, and farming are trendy at the moment, have led to conversations about food resilience. But it is superfluous and abstract, it doesn't connect consistently to the environment.*
Sedimentation	12	*Water flow from rain now flows straight into the ocean, carries all the sediment into the ocean; we need to find out how to get water to stay in the watershed.*
Deforestation	10	*Invasive vegetation. When you clear vegetation, it makes room for invasive seeds to make their way in and inhabit this cleared land; a lot of the shrubs become invasive and not endemic.*
Disconnect between locals and nature	10	*General public may be confused or ignorant (in true sense of the word meaning not aware) of connections between ecosystem services and natural resources.*
Species decline	10	*Reduction in certain species of organisms (cushion sea stars used to be more common in the past).*
Short-term vs. long-term	9	*Need more long-term planning & management in the VI to deal with issues.*

Table 5. Habitats, land use, or resource use most often mentioned in relation to the issues and threats to USVI ecosystems and human wellbeing. Frequency = number of mentions in coded segments of conversations.

Habitats & land use related to issues & threats	**Frequency** (n=193)
Development	60
Wetlands (mangroves, ponds, lagoons, seagrass)	36
Forests (plants, vegetation, trees, shrubs, grasslands)	23
Coral reefs	17
Ghuts & watersheds	13
Fresh water	13
Harvest/fishing/farming	13
Beaches	11
Paved surfaces	7

Table 6. Habitats, components of the ecosystem, and land uses mentioned by subject matter experts as providing human wellbeing benefits or with hazard mitigation and resilience value. Frequency = number of mentions in coded segments of conversations.

Habitats & land uses that benefit humans in the USVI	**Frequency** (n=239)
General benefits & services	66
Whole watershed/ridge to reef	41
Harvest/fishery/farmland	28
Forest	19
Mangroves	18
Marine ecosystem	13
Coral	12
Water quality	11
Seagrass	8
Beaches	8
Shoreline	5
Preserved land	4
Ghuts	4
Salt ponds/lagoons	2

Table 7. Potential indicators of resilience mentioned by subject matter experts. Frequency = number of mentions in coded segments of conversations.

Potential indicators of resilience	**Frequency** (n=76)
Species change & biodiversity	12
Birds	9
Coral health	8
Native/non-native species	6
Fish & fisheries	6
Droughts & floods	4
Bats	3
Beaches	3
Frogs	3
Change in fruiting & blooming of plants	3
Mangroves	3
Land cover and use change	3
Access to nature	2
Challenges (lack of data; should be ecosystem based)	2
Fresh water availability	2
Plants	2
Water quality	2
Wetlands	2
Soil retention levels	1

Table 8. Ideas related to community engagement in the USVI mentioned by subject matter experts. Frequency = number of mentions in coded segments of conversations.

Community engagement ideas	**Frequency** (n=170)	**Example coded segment from conversations**
Attitudes, perception, and/or behavior	49	*People have opportunities to get involved but there is a disconnect, inconsistent attention to projects that are legally approved, there is typically a snowballing effect, outrage on one issue leads to outrage on other issues that occurred under the radar. People tend to care intensely for a short period of time but them give up. How do we make people care AND see connections to the ecosystems?*
Communications	31	*Notification is not consistent for persons who live near development. E.g. North side community was not notified about supermarket being built in the area.*
Education and/or awareness	30	*Community may not understand how decisions are made in the USVI.*
Pride/support/engaged	24	*The general population only gets involved in ecosystem issues when their favorite places or places with cultural value are being threatened by development. E.g. Mandahl area wasn't used much; had scrap and old tires there. After development was slated to occur there; people came together try to stop this development. Speaks to the level of ecosystem awareness/ ecosystem consciousness in the Territory; all action is reactionary.*
Organization/Coordination	21	*Fishermen, banded together after the storms, especially some that were not accustomed to working together. A positive response.*
Disconnect	11	*Language disconnect, information doesn't reach all communities, USVI community is diverse, Haitians, Persons from the Dominican Republic are large parts of the community who may not get contacted effectively.*
Social media	4	*Public hearings may be one of the major ways to get through to the government, social media posts are common, but issues may not actually be addressed by relevant officials.*

2.2 Ridge to reef profiles

2.2.1 Territory overview

The United States Virgin Islands (USVI) are part of the Leeward Islands of the Lesser Antilles, located to the east of Puerto Rico and west of the British Virgin Islands (Figure 7). The USVI includes the three main islands of St. Thomas, St. John, and St. Croix, as well as more than 50 smaller offshore cays. The Danes controlled the area during the 17th and early 18th centuries when sugarcane, produced by African slave labor, drove the islands' economy. In 1917, the United States purchased the islands which have since remained an organized, unincorporated Territory of the United States. In terms of land area, St. Thomas, St. John, and St. Croix combined total approximately 353 km^2 (137 square miles) (Platenberg & Valiulis, 2018). St. Thomas and St. John are situated 64 km (40 mi) to the north of St. Croix. The most recent human population estimate for the Territory is 106,405 (U.S. Census, 2020). Between 2.5 and 3 million tourists visit the Territory per year, with most arriving from cruise ships. Tourism, trade, and other services are the primary economic activities, accounting for nearly 60% of the Virgin Island's GDP and about half of total citizen employment (CIA World Factbook, 2021). The Territory's capital is Charlotte Amalie on the island of St. Thomas.

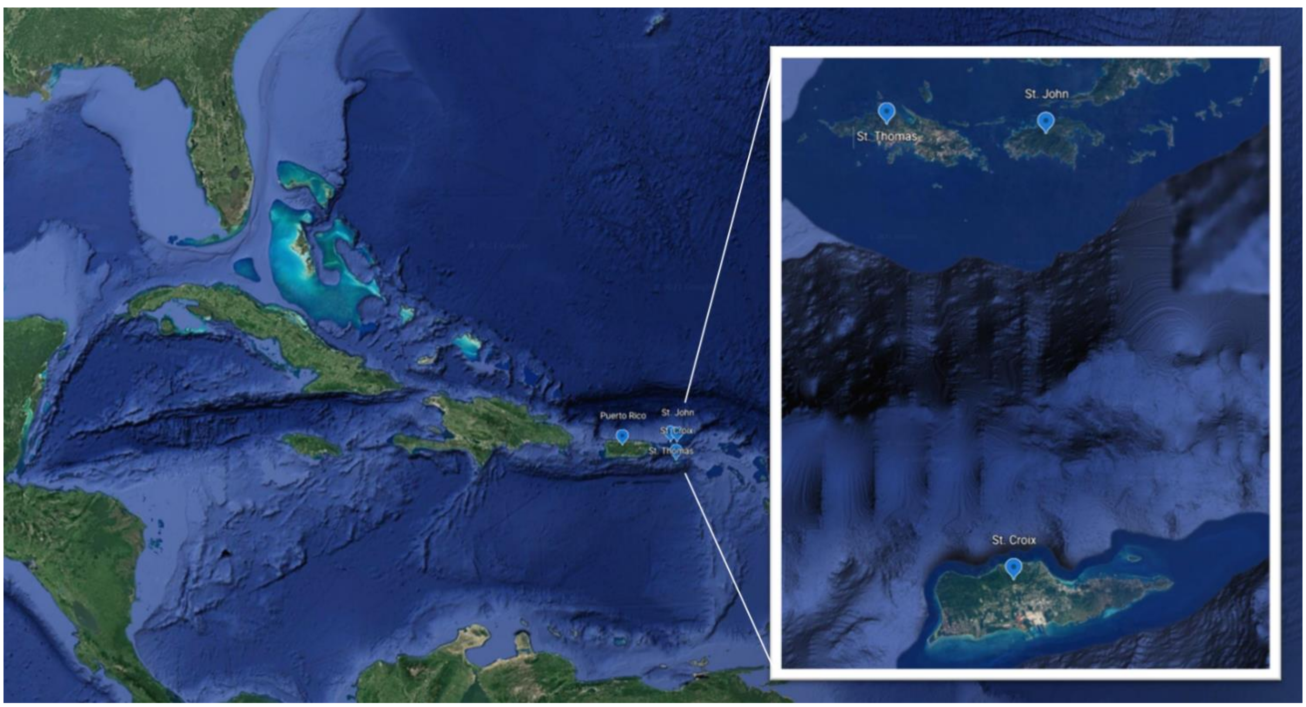

Figure 7. Location of the U.S. Virgin Islands. Image adapted from Google Earth.

While St. Thomas, St. John, and St. Croix have a shared history, each maintains a distinct culture influenced by characteristics of the land and sea unique to each island. St. Thomas is mountainous, with a land area of 74 km^2 (29 mi^2). It is highly developed and with a population of 51,634 considered densely populated (U.S. Census, 2010). Tourism-related industries drive St. Thomas's economy, with marinas, hotels, restaurants, shopping districts, and a major cruise ship port as key players. St. Thomas also hosts many U.S. businesses that take advantage of Economic Development Commission benefits while providing economic support to the local community (Platenberg & Valiulis, 2018). St. John is around 50 km^2 (19 mi^2), making it the smallest of the three islands, and with a human population estimated to be less than 4,170, also the least populated. The Virgin Islands National Park owns approximately two thirds of the land area on St. John, and with significant prehistoric sites on almost every beach and in every bay in the Park, it is regarded as one the most comprehensive and undisturbed Caribbean landscapes (National Park Service, 2021). Tourism is important to the economy of St. John, though because it is not as easy to access (visitors must fly into St. Thomas first, then take a ferry over to St. John), tourists are more likely long-stay visitors who rent villas or camp at the National Park or private campsites. (Platenberg & Valiulis, 2018). Spanning 217 km^2 (84 mi^2) and nearly double the size of St. Thomas, St. Croix is the largest of the three islands, though its population (50,601) is similar in size to St. Thomas (U.S. Census, 2020) . Agriculture has dominated the landscape of St. Croix, both historically and currently, and for many Crucians, farming and harvest is not only important economically, but contributes significantly to cultural identity (Jackson & Barrios, 2020). In 1966, Hess Corporation built a large petroleum refinery on the south shore of St. Croix, which for a long time contributed to the economy of St. Croix, until it was shut down in 2012 (Johnson, 2019). It was reopened by Limetree Bay Terminals, but the Environmental Protection Agency (EPA) recently revoked the operator's permit after an accidental oil vapor release that impacted the health of residents in the community, along with multiple other environmental and health concerns (United States Department of Justice, 2021) Tourism also supports the economy of St. Croix, with active restaurant and hotel industry primarily in the island's two major towns, Christiansted and Frederiksted.

The USVI continues to endure challenges associated with climate change, such as drought, flooding, hurricanes, earthquakes, and landslides. In September 2017, Hurricane Irma passed over St. Thomas and St. John, severely damaging structures, roads, the airport, communications, and electricity. Less than two weeks later, Hurricane Maria passed over Saint Croix, causing substantial damage with heavy winds and flooding rains. Illness, such as mosquito-borne Dengue fever and Chikungunya, or the recent Covid-19 pandemic, are significant public health concerns in the USVI. Changing land use practices, particularly increased development, impact the environment as well as human wellbeing in the USVI. Importantly, the Territory does not currently have a comprehensive land and water use plan to guide development or other land and water use decisions. Territorial government agencies and partners have drafted plans over the years, but those have not been formerly adopted by the government (Farrelly, 1993).

Looking at spatial land use data from 1985 through 2018 (Figure 8), it is evident that as development increased, less space has become available for the natural environment. Given that the natural environment has changed, and continues to change, the many beneficial services that ecosystems provide change too, ultimately influencing human wellbeing. The following section describes five components of the ridge to reef ecosystem that are associated with human wellbeing in the USVI: Ghuts, wetlands, forests, farms, and coral reefs. The most recent and available data about the extent and health of these ecosystem components is shared, along with inferences about how the services provided by these areas has changed over time.

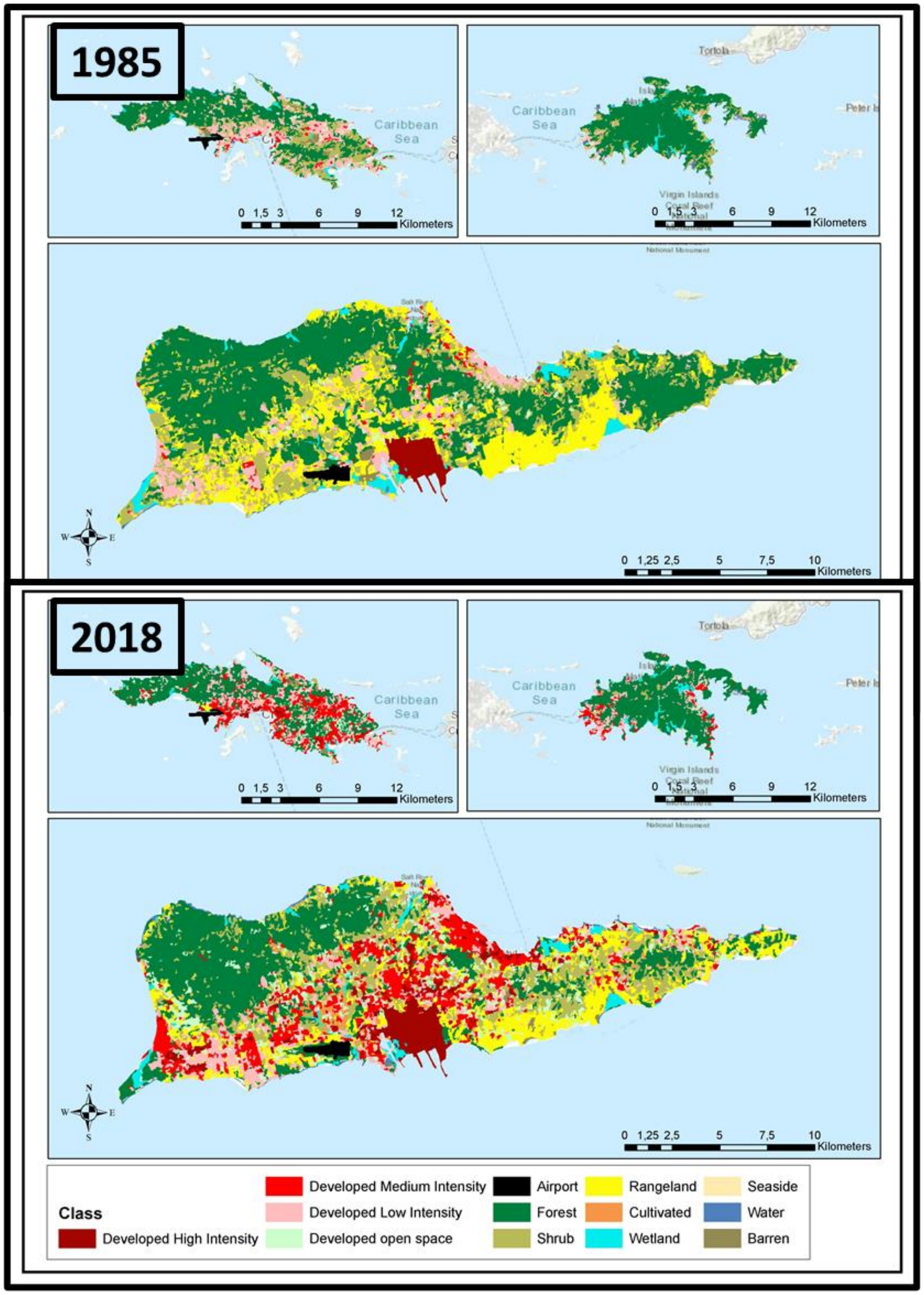

Figure 8. Land use in St. Thomas, St. John, and St. Croix, USVI, in 1985 (top) vs. 2018 (bottom). Data from the Caribbean Green Technology Center.

2.2.2 Ghuts

Watercourses, known in the United States Virgins Islands as ghuts, are well defined natural channels formed overtime by the action of rain and stormwater flowing over impermeable rock (Figure 9) (DPNR, 2018). Ghuts are a defining characteristic of the terrain of the USVI, where two of the three major islands (St. Thomas and St. John) are mostly "ridges and ghuts" (Gardner, 2008; Gardner et al., 2008). Additionally, the lack of gentle sloping land has made ghuts the major source of fresh water on the islands (Platenberg, 2006). Furthermore, many of the ghuts on the islands connect vegetated upland and marine systems since they drain from hills directly towards the ocean (Gardner et al., 2008).

Many upland, relatively undisturbed ghuts in the Territory are forested, with gallery shrubland and gallery moist forest being the dominant forest types present. (Platenberg & Valiulis 2018; Gardner et al., 2008; DPNR, 2018). The forests that exist in these ghuts include a variety of native plant species, and some are considered rare. Gardner et al. (2008) noted that the endangered plant species, Egger's Cock's-Spur (*Erythrina eggersii)*, was present in ghuts and many of the plant species were yet to be inventoried. Additionally, vegetated ghuts can form "habitat corridors" that some species may use for migration where ghuts overlap with urban areas. Platenberg & Valiulis (2018) noted that the endangered Virgin Islands Tree Boa (*Chilabothrus granti)* uses vegetated ghuts as a corridor on St. Thomas's East End. Some examples of notable vegetated ghuts on each major island are Caldonia Ghut on St. Croix, Reef Bay on St. John, and Bonne Resolution Ghut in St. Thomas.

Ghuts in the Territory are key habitats for a variety for wildlife. They provide nursery and nesting areas, are used for foraging, and are important watering holes and migration corridors (Gardner et al., 2008; Thomas & Devine, 2005). Some have permanent freshwater pools (particularly during the rainy season) that are home to a variety aquatic species such as native freshwater shrimp (*Machrobrachium spp., Xiphocaris elongate, Atya spp.*) native fish species such as the Goby (*Sicydium plumieri*), Mountain Mullet (*Agonostoma monticola*), American eel (*Anguila rostrata*) and non-natives such as Guppy (*Poecilia reticulata*) and Tilapia (*Oreochromis spp.*) (Platenberg & Nemeth, 2007; Platenberg & Valiulis, 2018; DPNR, 2018). Freshwater shrimp species also move between downstream marine waters and upstream freshwater habitats (Thomas & Devine, 2005). Some species of freshwater shrimp filter stormwater by trapping organic debris with their modified claws (Thomas & Devine, 2005). Terrestrial species such as bats, migratory birds (warblers), iguanas, deer, bees, goats and water-associated invasives like the Cane toad (*Rhinella marina*) and Cuban tree frog (*Osteopilus septentrionalis*) rely on ghuts as a fresh source of water.

Ghuts have long benefitted the people of the USVI. Historically, ghuts were the major source of water for settlers in the USVI from the colonial era up to the 1960's in some areas (Gardner et al., 2008). Most of the settlements in the past were placed near ghuts to provide easy access to water that was primarily used for domestic, industrial, and agricultural purposes (mostly sugar production). Many ghuts were also used as food source in the past in the recreational practice of catching freshwater shrimp (Gardner et al., 2008). Some ghuts that have historical significance and archaeological significance include Savan Ghut, Water Gut, Bethlehem Ghut, Living Ghut, Fairplain Ghut, Saly, Magen's Bay Ghut, and Turpentine Run (Conservation Data Center, 2010).

Currently, ghuts are used still used recreationally for hiking, nature walks, and professional tours (Gardner et al., 2008). Nature walks and hikes have also been used as ideal segue ways into educational and learning opportunities for students at the elementary and junior high level. Students and faculty at the university level have also made ghuts and associated habitats the foundation of their research in the areas of water quality, gut biodiversity, and wildlife (Gardner et al., 2008; Conservation Data Center, 2010; DPNR, 2018). Importantly, ghuts mitigate the potential for flooding. As natural stormwater channels, torrential downpours produced by storms and hurricanes drain straight down the ghuts, to the bay, and out to sea (Reiblich & Ankersen, 2016; Gardner et al., 2008). Furthermore, the gallery moist and gallery shrubland forests associated with ghuts prevent soil erosion and the sedimentation of downstream habitats (coastal wetlands, coral reefs) as well as filter any other potential runoff from pollutants. (Platenberg & Valiulis, 2018; Benoit & Nemeth, 2011).

Many of the ghuts in the Territory have been infringed upon and degraded. Currently, there are variety of legal protections that may be applied to ghuts in the Territory. One in particular is VI Code Title 12 Chapter 3 which prohibits "the cutting or injury of any tree or vegetation within 30 feet of the center of any natural watercourse or 25 feet from the edge, whichever is greater, without written permission from the Commissioner" (VIC 12 Chapter 3; Gardner et al., 2008, Platenberg, 2005). Despite this, lack of enforcement allows development to continue, vegetation is regularly removed from ghuts, and ghut boulders moved by property owners, impacting ghut banks, channels, and water flow (Platenberg & Valiulis, 2018; subject matter experts pers. comm., 2021). During their surveys, the Center for Watershed Protection (2008) stated that there were "a number of instances" where they observed ghuts being encroached upon in the Coral Bay Watershed. Gardner et. al (2008) surmised that the land use practices detrimental to ghuts could be explained by ignorance and indifference, greed, lack of stormwater management, and the limited space that a small island provides. Many ghuts were previously paved over in the past and now exist in highly trafficked areas, and many intersect with major roadways (Figure 9). The storms of 2017 further exacerbated the anthropogenic issues many of the ghuts were already experiencing since rapid water flows caused them to be filled and blocked with debris, severing their natural connections to coastal wetlands and the marine systems. Downed and defoliated ghut vegetation also caused ghut temperatures to rise in the immediate aftermath of the storms, encouraging algal growth (Platenberg & Valiulis, 2018). Other issues that continue to negatively impact ghuts in the Territory range from changed drainage patterns via development, improper solid waste disposal (both residential and commercial), loss of rare plant species, sewage disposal, agricultural waste disposal, and bacterial and nutrient contamination (Gardner et al., 2008). Overall, the anthropogenic stressors combined with poor local management practices have led to a decrease in some of the mitigating factors that ghuts provide (subject matter experts pers. comm., 2021). However, some ghuts are able to retain many of their ecological functions and interactions despite external negative pressure (Platenberg & Valiulis, 2018).

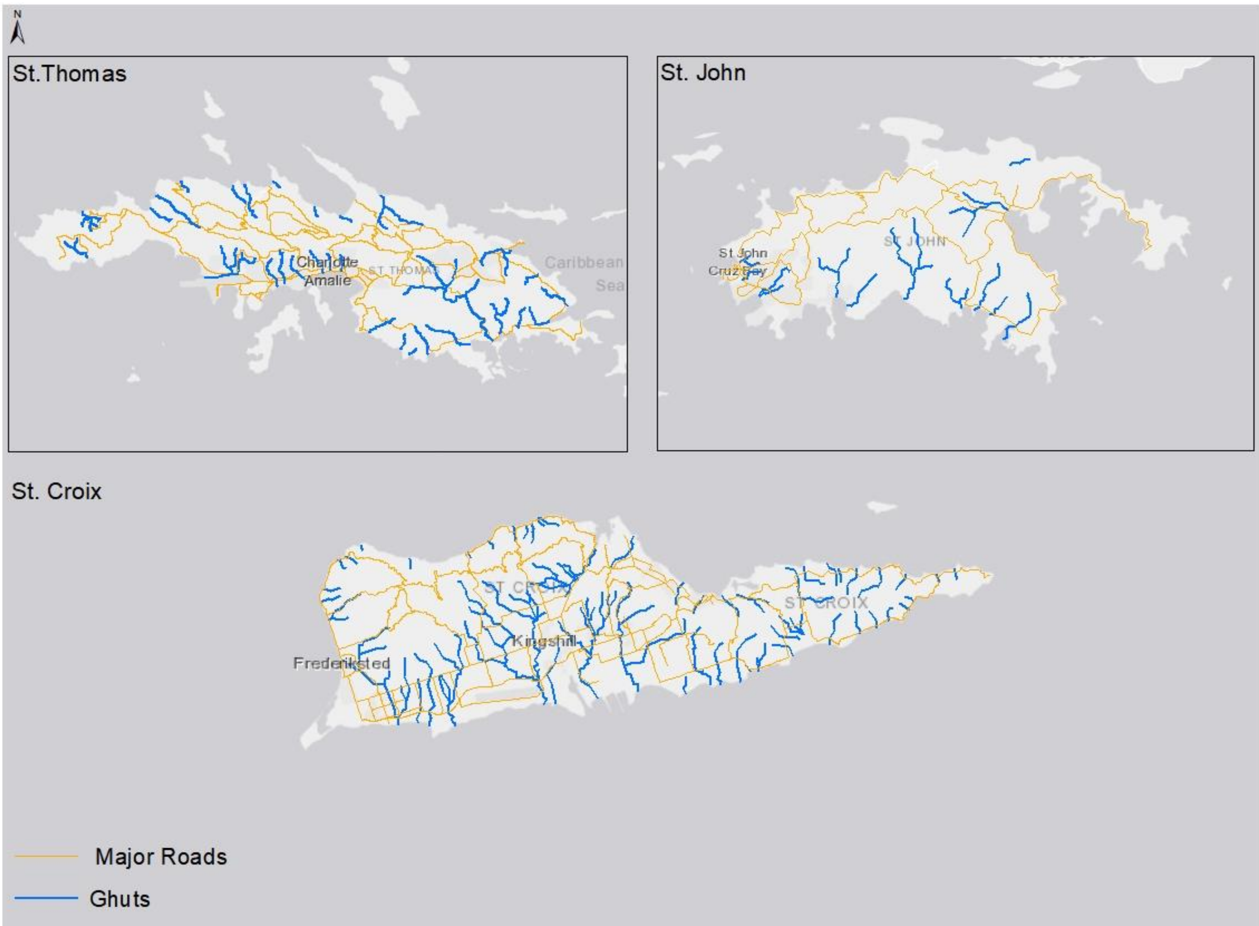

Figure 9. Locations of major ghuts in the U.S. Virgin Islands. Data from: ArcGis Online Server "USVI Ghuts Revised".

2.2.3 Wetlands

Wetlands are areas with inundated or waterlogged soil that typically support vegetation that is adapted to living in these specific conditions (Platenberg & Valiulis, 2018). Although some freshwater ponds exist in the USVI, wetland areas are typically found near the coast (UVI & VIMAS, 2009) or in the case of ghuts, lead to the coast. Overall, there are five (5) major types of wetland areas found in the Territory: mangroves, salt ponds, salt flats, freshwater ponds, and ghuts (Figure 10). Because ghuts emerged in subject matter expert discussions as a uniquely important habitat component regarding mitigation and resilience, they were discussed in the previous section.

Mangroves

"Mangrove" is a term used to describe trees, shrubs, and other types of vegetation that persist in saline and brackish conditions. Mangroves are found in tropical climates and seven (7) species can be found in the Caribbean (Platenberg, 2006). Four (4) species of mangroves can be found in the USVI: the Red Mangrove (*Rhizophora mangle*), Black Mangrove (*Languncularia racemosa*), White Mangrove (*Avicennia germinans*), and Buttonwood (*Conocarpus erectus*). In a mangrove community, there may be distinct zonation of mangrove species due to their special adaptations. Red Mangroves are found in calm, shallow ocean waters, followed by Black Mangroves (extremely salt tolerant) near the water's edge. White mangroves are found in moist soils further inland or near salt ponds, while Buttonwood prefers the drier soils on the fringe of the community.

Mangroves are integral parts of the ecosystems they help create. They serve as nursery areas to many juvenile fish and bird species which all have varied recreation and commercial importance (Platenberg, 2006). Mangroves in Hurricane Hole, St. John have even sheltered and fostered the growth of a variety of coral in between their prop roots (Rogers, 2019). They also provide nutrients to some of these organisms within and near to these habitats due to the detritus produced from their leaf litter. The Great Land Crab (*Cardisoma guanhumi*) uses the leaves of buttonwood, red, and white mangroves as its primary food source (Platenberg, 2006). Mangroves also support many species of resident and migratory birds in the Territory. It is estimated that about 90% of the resident and migratory birds in the USVI use mangrove wetlands for feeding, nesting, or roosting (Philibosian & Yntema, 1977) and up to 75% of the 121 species on St. Croix use mangrove habitats in some way (Platenberg, 2006). In fact, many of the Important Bird Areas (IBAs) in the USVI have or are associated with mangrove habitats (Corven, 2009).

Mangrove habitats also perform numerous physical functions beneficial to nature and humans in their associated ecosystems. Mangroves and mangrove forests help to sequester carbon in their biomass which can help to reduce the impacts of climate change (Mcleod et al., 2011).

Mangroves trap and stabilize sediment between their roots, helping to prevent coastal erosion (UVI & VIMAS, 2009). Mangroves also protect low-lying inland areas by acting as a buffer from storm surge and similar wave action since they reduce the amount of oncoming wave energy (Granek & Ruttenberg, 2008). On St. John, residents typically anchor their boats in the Hurricane Hole area (that is filled with fringing mangroves) since it has historically offered adequate protection from storm surge (Rogers, 2019). Mangroves also help maintain surrounding water quality by trapping oncoming runoff and removing harmful pollutants from the water and soil (Alongi & McKinnon, 2005; Chakroff, 2010; Mcleod et al., 2011). Sediment studies in the St. Thomas East End Reserve (STEER) have shown that the mangroves in the Mangrove Lagoon may be acting as a buffer, preventing toxic metals and other pollutants from entering the marine areas east of the landfill (Pait et al., 2016).

Currently, the mangroves in the Territory are still recovering from the cumulative impacts of Hurricanes Irma and Maria in 2017. At Hurricane Hole, most of the fringing mangroves were uprooted and destroyed (Rogers, 2019). The slow growth of mangroves makes it challenging to restore them to their pre-hurricane state, but mitigating external stressors (pollution, removal of dead or decaying mangroves) is beneficial for the recovery process (Platenberg & Valiulis, 2018). The ecological services mangroves provide will certainly continue to degrade without intervention (Department of Homeland Security, 2020), and their extent (whose decrease is confirmed by aerial imagery) will continue to be threatened by future development (Platenberg & Valiulis, 2018).

Salt Ponds and Salt Flats

Salt ponds are small bodies of saltwater that form intertidal basins. There are over sixty (60) salt ponds in the Territory (Rennis et al., 2006), making them the dominant type of wetland found in the USVI (UVI & VIMAS, 2009). Salt flats differ from salt ponds since they are not always inundated with water, but rather have muddy soils that are periodically submerged by tidal waters. Many salt ponds and salt flats in the Territory have mangroves and other salt tolerant plants growing near or around them and their general conditions (size, salinity, oxygen concentration, temperature, water depth) are heavily influenced by rainfall and evaporative processes (Division of Fish and Wildlife, 2005; Platenberg & Valiulis, 2018).

Due to their high salinity, salt ponds make good substrate for black and white mangroves in the Territory. It is estimated that 71% of the salt ponds have White mangroves, 45% have Black mangroves and 80% have Buttonwood (Stengel, 1998). Their close association with mangroves allows them to support a variety of wildlife and it also makes them the premium habitat for resident and migratory birds in the islands (Division of Fish and Wildlife, 2005). Salt ponds and salt flats also prevent marine sedimentation by trapping runoff and pollutants that flow down the steep terrain toward the ocean (Rennis, 2006). This process protects coral reef or seagrass beds that may be located in the shallow waters nearby. Salt ponds also help to alleviate coastal flooding from storm surge by acting as a catchment system for oncoming waves (Department of Fish and Wildlife, 2005).

Salt ponds have significant cultural value in the Territory. Historically, salt ponds were important for local and recreational fishing, and people would visit salt ponds to collect mangrove roots and branches to design fish traps (Platenberg & Valiulis, 2018). Salt harvesting was also a common practice in the hypersaline ponds in the Territory, and when conditions allow, still occurs at Salt Pond in St. John (Platenberg, 2006).

Salt ponds were heavily impacted by saltwater intrusion due to storm surge from the 2017 hurricanes. Storm surge, along with strong winds and heavy rain, introduced pollutants and debris into these ponds and severely damaged their associated mangroves (Platenberg & Valiulis, 2018). Additionally, the berm of Great Pond on St. Croix was breached by the storms, linking it to the ocean for a number of months, potentially changing the hydrology and ecology of the pond (subject matter experts pers. comm., 2021). It is difficult to assess the current quality of salt ponds in the territory (last complete inventory was Stengel in 1998) but issues with sedimentation, encroachment, and rising sea levels have likely lead to a decline in their water quality and sediment retention capabilities (Rennis et al., 2006; Platenberg & Valiulis, 2018; subject matter experts pers. comm. 2021).

Freshwater Ponds

Due to the steep topography and shallow soils of the USVI, many of the freshwater ponds that currently exist are manmade. Most of the ponds exist on the relatively flat island of St. Croix (which has about 130 ponds), many of them being impoundments (Conservation Data Center, 2010; Platenberg and Valiulis, 2018). Many of the ponds in the Territory were created for agricultural purposes historically by forming dams and impoundments, and currently some farms have ponds as their predominant source of water e.g. Bordeaux Pond on St. Thomas (Department of Planning and Resources, 2010).

Unlike salt ponds, freshwater ponds in the Territory are not generally found near vegetation, but some ponds do have algae, macrophytes and non-native plants (UVI & VIMAS, 2009). Two exotic species of fish, Guppy (*Poecilia reticulata*) and Tilapia (*Oreochromis mossambicus*) are commonly found in many of the freshwater ponds in the Territory (Platenberg & Valiulis, 2018). Many indigenous and migratory waterbirds, such as the Least Grebe (*Tachybaptus dominicus*), the Blue- Winged Teal (*Spatula discors*), the White-Cheeked Pintail (*Anas bahamensis*) and the Green Heron (*Butorides virescens*) use freshwater ponds as habitats, and some native (five bat species) and non-native mammals (deer, mongoose) use the ponds as source of freshwater (Platenberg & Valiulis, 2018).

Freshwater ponds in the Territory are mostly used in agriculture for irrigation and as water source for livestock (Platenberg, 2006). A farmer living in Bordeaux, a relatively isolated community in St. Thomas, mentioned that farmers in that area rely on a freshwater pond to irrigate their farms (ResilientVI, 2021). Man- made ponds capture agricultural runoff and sediment and prevent it from entering marine systems (Division of Environmental Protection, 2018).

Many of the freshwater ponds in the territory are improperly maintained are home to invasive species such as the Water Hyacinth (*Eichhornia crassipes*), the Cane toad (*Rhinella marina*) and the Red-eared slider (*Trachemys scripta*) (Platenberg & Valiulis, 2018). Some ponds with agricultural uses are cleared by the farmers that use them for water, but there is no policy that dictates this for all ponds (Platenberg & Valiulis, 2018). Freshwater water ponds were also subject to sedimentation and an influx of stormwater, pollutants, and various forms of debris from the 2017 hurricanes (Platenberg & Valiulis, 2018).

The U.S. Caribbean region (Puerto Rico and the USVI) is expected to become drier and have longer periods between significant precipitation events (Gould et al., 2018). Within the last year, U.S. Drought Monitor data has shown extended periods of abnormally dry weather occurring in each of the three islands, especially in St. Croix (National Drought Mitigation Center, 2021). Drier climatic conditions and poor management may lead to a reduction in the water levels of many of these freshwater ponds, thereby reducing their ecological and agricultural functionality.

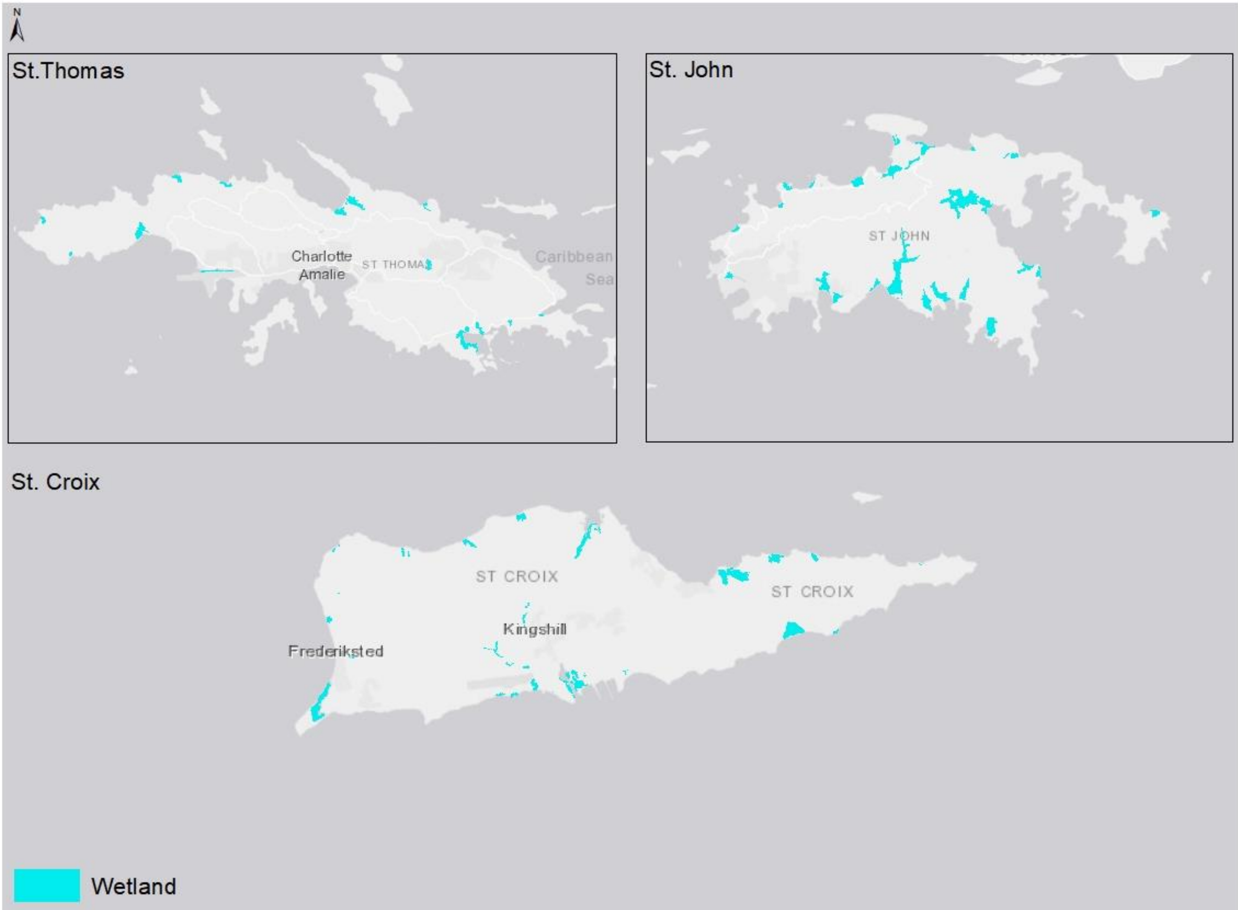

Figure 10. Extent of wetland areas in the U.S. Virgin Islands including mangroves, salt ponds, salt flats, and freshwater ponds. Data from: Caribbean Green Technology Center.

2.2.4 Forests

Forests in the United States Virgin Islands (USVI) are typically defined as areas of land not slated for agricultural use spanning at least 0.5 hectares, with trees five (5) meters or higher, and over 10% canopy cover in situ (Brandeis & Chakroff, 2010). There are an estimated 118 live species of trees in the USVI; with the non-native species Tan Tan (*Leucaena leucephala)* having the highest biomass of all trees (Marcano-Vega & Williamson, 2017). Land use and topography have had a distinct effect on the forest cover of each island (Figure 11). About two thirds (2/3) of St. John is a part of the Virgin Islands National Park (VINP), allowing the island to remain 81% forested (Marcano-Vega & Williamson, 2017). St. Croix, a more industrial and agricultural island, is 56% forested, with most of these forests being centered on the northwestern end of island while St. Thomas- the most densely populated island- is about 44% forested (Brandeis & Turner, 2013; Marcano-Vega & Williamson, 2017).

The forests in the Territory are mostly comprised of subtropical dry forests found at lower elevations and subtropical moist forests found at higher elevations, but some overlap between forest types is common. Subtropical dry forests in the USVI are typically comprised of semi deciduous dry forest, dry woodland. Native tree species such as Lignum Vitae (*Guaiacum officinale*), Turpentine Tree (*Bursera simaruba)*, Torch Wood (*Amyris elemifera*) and Jamaican Caper (*Capparis cynophallophora*) are commonly found in the subtropical dry forest system (Platenberg & Valiulis, 2018; Brandeis & Chakroff, 2010). Broad-leaved, evergreen trees, upland moist forest, gallery moist forests (near ghuts), and basin moist forests are all associated with subtropical moist forest systems on the island. Common trees found in this forest type are Dog Almond (*Andira inermis*), Black Mampoo (*Guapira fragans*), Dog Plum (*Spondias mombin*), Gre Gre (*Bucida buceras*), Sandbox Tree (*Hura crepitans*), Kapok Tree (*Ceiba petandra*), Cigar Box Cedar (*Cedrela odarata*), Bayrum Tree (*Pimenta racemosa*), Royal Palm (*Roystonea borinquena*), Stinking Toe (*Hymanaea courbaril,* Pumpwood (*Cecropia schreberianal*), and Pink Poui/White Cedar (*Tabeuia heterophylla*) (Brandeis & Chakroff, 2010; Platenberg & Valiulis, 2018).

Forests provide many important ecosystem services in the Territory and are a critical habitat for many of the terrestrial animal species (birds, bats, frogs, lizards, snakes, insects, other invertebrates) that persist in the islands (Platenberg & Valiulis, 2018). McGinley et al. (2017) stated that up to 16 terrestrial mammal species, 99 bird species, and 8 amphibian species were associated with forest habitats in the USVI and that as many as 1,769 insect species were documented living on the islands. Additionally, 22 animal and 13 plant species native to the Territory are on the IUCN's Red List (IUCN, 2015). Forests also help to sequester carbon in their biomass (stems, leaves, etc.) which is critically important in mitigating the effects of global warming and climate change. In 2014, it was estimated that for trees whose stems were at least an inch in diameter, live tree carbon was 12.1 tons per acre in dry forests and 15.4 tons per acre in moist forests, with a total of 611,622 tons overall in USVI forests (Marcano-Vega & Williamson, 2017). Another estimate from 2009 stated above ground living tree biomass was 609,000 tons, and below ground was 737,000 tons (McGinley et al., 2017).

The topography in the USVI (many hills, little flat land) makes forests incredibly important in erosion control and in the prevention of sediment runoff. Forests help to control water flow in their watersheds and filter sediment from runoff (Platenberg & Valiulis, 2018; McGinley et al., 2017; Benoit & Nemeth, 2011). Many of the forest areas in the Territory also overlap with and are cut through by urban development, and fragmented forests in these areas provide shade, reduce noise pollution, absorb radiating heat from roads and sidewalks, and potentially trap some of the CO_2 produced by vehicles (Platenberg & Valiulis, 2018). Slatton et al. (2012) stated that there were 9,929 trees near roads in St. Croix, and urban forests constitute 30.5% of the forests in St. Thomas and 17% in St. Croix (Allerton & Van Bloem, 2018). Some species of trees in these forests such as mahogany (*Swietenia spp*.) and Tibet (*Albizia lebbeck*) were used for craft and building material in the 1990's, producing up to 189,000 board feet per year. Non-wood products, such as fruits and medicinal plants, are still commonly produced by these forests today (McGinley et al., 2017). Some examples of medicinal plants that may be found in or adjacent to local forests are worrywine (*Stachytarpheta jamaicensis*) and inflammation bush (*Verbesina alata*) (Palada et al., 2003; UVI Center for Complementary and Alternative Medicine, 2021).

Many of the forests in these USVI are intrinsically valuable to the Territory's residents for their overall wellbeing. These forests have significant cultural and spiritual value, whether via aesthetics (lush, green views) and recreation (nature walks, hiking, forest trails). Hiking also becomes an economic driver via ecotourism, where many tourists enjoy walking on these trails during their visits. Magens Bay, a popular tourist beach on St. Thomas, has a nature trail and an arboretum (which closed after the 2017 storms) where residents and tourists were able to use for relaxation or to view various flora and fauna (Platenberg & Valiulis, 2018).

Forests in the USVI were significantly damaged by the 2017 hurricanes, and many trees were left with little to no leaves, broken branches, and stems, or uprooted altogether (Platenberg & Valiulis, 2018). Prior to this, many of the forests in the Territory were already plagued by a variety of other issues. Brandeis and Turner (2009) stated that 85% of the forests are dominated by many small diameter trees (2.5cm at the stem at 1.4m high). Many trees also suffered from minor stem decay (54%) and defoliation was a significant issue in seedlings (Marcano-Vega & Williamson, 2017). Other notable challenges for USVI forests ranged from natural hazards (fire, drought, hurricanes/storms, flooding, climate change), animal damage (white tailed deer, wild hogs, Indian mongoose, goats, rats), anthropogenic stressors (urbanization and forest fragmentation) and invasive plant species (Allerton & Van Bloem, 2018). Significant decreases in forest cover (down 20% from 1985 to 2018 via GIS Data) combined with the anthropogenic stressors (development and invasives like tan tan) have decreased the extent and quality of local forests, and by extension, some of the services they provide.

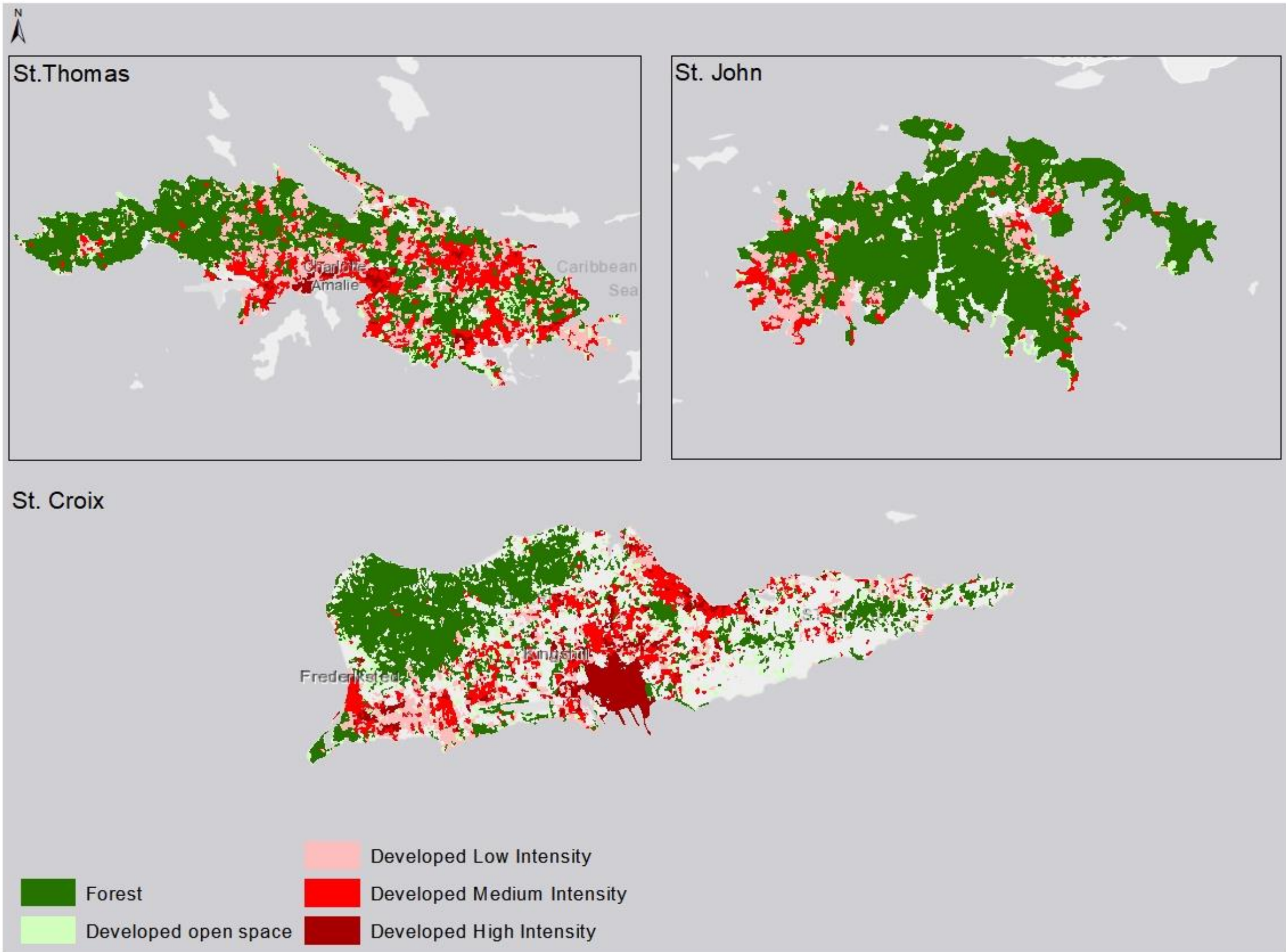

Figure 11. Extent of forested areas in relation to development in the U.S. Virgin Islands. Data from: Caribbean Green Technology Center.

2.2.5 Coral Reefs

Coral reefs are underwater structures formed by a community of coral polyps, which form hard skeletons of calcium carbonate on a hard, solid substrate. Coral polyps are living organisms, and they can form a variety of complex structures. Coral reefs are found in the waters of the USVI since they meet the conditions that coral needs to persist (water is 20-32℃, clear, clean, and stable). The National Oceanic and Atmospheric Administration (NOAA) estimated that existing coral reef hardbottom only in the USVI was 299.014 km^2. If associated vegetation (algae and seagrass) is included in the coral reef ecosystem, the extent is estimated to be 463.841 km^2 (NOAA, 2009). There are at least 40 different species of coral living in the Territory (Pittman et al., 2014), mostly comprised of scleractinian corals (hard or stony species) and *Millepora* species. (Rogers et al., 2008).

There are several different reef structures that can be found in the USVI. Fringing reefs are generally near the shore and are linear. Patch reefs are small and isolated reefs typically separated from more complex reef structures by sand, seagrass, and other seafloor elements. Spur and groove reefs are parallel ridges of reefs (spurs) separated by channels (grooves). Further offshore reef structures are barrier (lagoon separates reef from the shoreline), shelf reefs (form platform reefs that rise to the water's surface), submerged shelf reefs, and mesophotic reefs. Mesophotic reefs are found in waters generally 30-100m deep and account for a large portion of the reefs in the Territory (Platenberg & Valiulis, 2018). Mesophotic reefs ($204km^2$) in the USVI are thought to be the most well developed mesophotic reef ecosystems in the Caribbean (Ennis et al., 2019), and account for more than double the total area of shallow reef ecosystems ($71km^2$) in the Territory (Holstein et al., 2019; Smith et al., 2019).

Coral reef ecosystems support some of the highest biodiversity found in the USVI. Besides a variety of coral species, many different species of fish, algae, seagrass, marine invertebrates, and other marine organisms can be found living in and around reef systems (Platenberg & Valiulis, 2018). In 2019, the Territorial Coral Reef Monitoring Program (TCRMP) recorded 148 species of fish at their monitoring sites in St. Thomas and St. John, and 128 species at the sites in St. Croix (Ennis et al., 2019). Due to their high biodiversity, many commercial and local fishermen have used waters near coral reefs as their favorite fishing spots. These reefs support a variety of economically important species such as conch, whelk, spiny lobster, snapper, and grouper (Ennis et al., 2019). Fishermen involved in coral fisheries produced about $6.6 million in 2007 dollars, which was $8 million in 2015 dollars (Pendleton et al., 2016).

Coral reefs are a significant part of the USVI's tourism driven economy. In 2016, over 2.5 million people visited the USVI and tourism-related expenditures were more than $1.3 billion (Bureau of Economic Research, 2018). Coral reef ecosystems provide many recreational opportunities for tourists who visit the islands, such as snorkeling, diving, and ocean tours. Sports fishing and charter boats are also common in Territorial waters (Ennis et al., 2019). Edwards (2013) estimated that coral reefs provided a total value of $210 million in 2012 dollars, through tourism, recreation, cultural value, amenities, coastal protection, and commercial fishing. Economic value from snorkeling and diving alone was estimated to be $12.8 million annually (Van Beukering et al., 2011).

The physical structures of coral reefs perform very essential functions as well. Coral reefs reduce oncoming wave energy which aids in preventing coastal erosion and reduces the effects of storm surge and elevated wave action (Taylor et al., 2009). Coastal protection from reefs in the Territory was estimated to be $1.2 million annually (Van Zaten et al., 2014). Storlazzi et al. (2019) stated that by reducing the impacts of wave action, coral reefs directly protect people, buildings and economic activity in the Territory. They estimated that reefs directly protected $22 million in buildings, 340 people, and $25.3 million in economic activity (Storlazzi et al., 2019).

Coral reefs in the Territory, like most in the Caribbean region, have experienced a significant number of die-offs and stressors in the last few decades. NOAA's 2020 status report for corals in the USVI declared that they are in "fair condition" since they are in moderate decline and there is human awareness and beneficial intervention to improve their overall condition (NOAA, 2020). However, coral cover is still not near the level it was just two decades prior. Many of the corals in the Territory were significantly reduced by the 2005 coral bleaching event and were further stressed by bleaching events in 2010, 2012, and 2019 (Ennis et al., 2019). Bleached and damaged corals have been competing with macroalgae for substrate, with species such as the invasive *Ramicrusta* outcompeting and effectively killing coral on some reefs (Ennis et al., 2019). Coral reefs were also significantly damaged by the 2017 hurricanes, and complex and unique coral systems such as the mangrove/coral system at Hurricane Hole, St. John, were lost (Rogers, 2019). The Territory's corals are also under the threat of disease, and more recently (2019), Stony Coral Tissue Loss Disease has been documented at many of the coral monitoring sites around the island of St. Thomas (Ennis et al., 2019) and is continuing to spread to St. John, St. Croix, and outlying cays (Brandt, 2021). Other factors that affect USVI coral reefs are mostly anthropogenic and are related to overfishing, influx of people via tourism, pollution, invasive species (e.g. lionfish) and global climate change (Jackson et al., 2014). Overall, the combination of stressors continues to keep both shallow and mesophotic reefs under threat (Smith et al., 2016; Ennis et al., 2019). Although some success stories exist (Ennis et al., 2019) it is likely that the ecological services that coral reefs provide will decrease if impacts of ocean warming, storms, disease, and preventable anthropogenic stressors continue to contribute to future coral die-offs and overall coral decline (Platenberg & Valiulis, 2018).

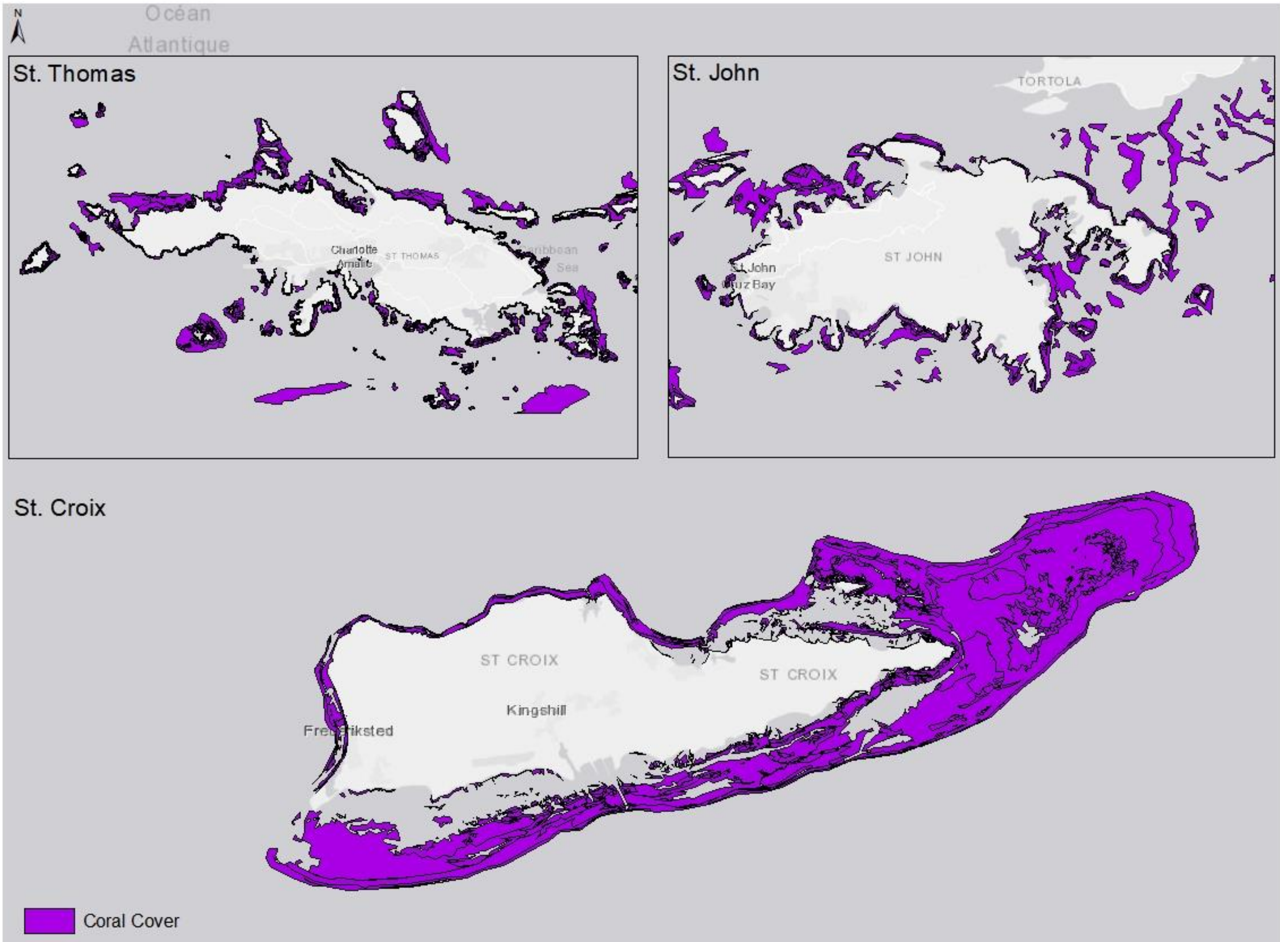

Figure 12. Coral cover in the USVI. Data from The Nature Conservancy (2017). For further details on the complex array of mesophotic reefs that exist along the Puerto Rican Shelf, see Smith et al. 2019.

2.2.6 Farmland

USVI farmland is defined as “any agricultural operation where $500 dollars or more of agricultural products were produced and sold (or would normally be sold) in a 12-month period” (USDA, 2018). The USDA’s 2018 census of agricultural activity in the Territory stated there were 565 active farms (up from 219 in 2007) totaling 9,324 acres (37.7km^2) of land (16.5 acres/0.668km^2 per farm) (Figure 13). Out of those farms, 415 were designated for crops (400 were harvested), 224 had pasture or grazing land, 53 had woodland, and 333 had land designated for other use. Many farms use private irrigation systems (247 farms) supplied mainly by cisterns and wells, but some also use ponds and other public water sources (USDA, 2018).

Most farms in the USVI produce three (3) main types of crops: field/forage, vegetables, and fruits (USDA, 2018). Common field crops include cassava, dry corn, hay nut, sugarcane, sweet potatoes, taniers and yams. The vegetable crops produced include cabbage, carrots, celery, cucumbers, eggplant, green beans, lettuce, okra, onions/chives/scallions, peppers, spinach, squash, tomatoes/cherry tomatoes, sorrel, and herbs. Fruit crops are avocados, bananas, breadfruit, coconuts, grapefruit, lemons, limes, mangoes, oranges, papayas, pineapples, plantains, nuts and ornamental plants. Many farms also produce a variety of livestock such as cattle (cows, calves, and bulls), sheep and lamb, goats, pigs/hogs, and poultry (chicken, turkey, ducks, geese) (USDA, 2018).

Farms in the USVI directly support the USVI economy. The USDA stated that farms in the in Territory produced $3.33 million in 2018, more than double than $1.3 million produced in 2007 (USDA, 2018). Despite recent increases in agriculture, the USVI still relies heavily on imports for its food supply. It is estimated that the USVI imports at least 95% of its raw and processed food (Laurencin, 2017), and the Office of Management and Budget (OMB) stated that fresh fruits and vegetables account for $4.4 million of the $110.3 million the Territory currently spend on food product imports (OMB, 2020).

Local agriculture is also important to the Territory in other ways besides food production. Agriculture as a practice is a significant part of local culture and identity. Farming in some families on St. Croix is held in high regard and is a generational practice (Laurencin, 2017). It also allows some farmers to feel closer with their ancestors who farmed before them (Laurencin, 2017). On a larger scale, agriculture can have some tourism- related activities in the USVI to a limited extent. Many tourists tend to purchase produce locally grown and sold by small vendors that may not even identify as farmers (Laurencin, 2017). Local restaurants prefer to buy local produce to use in the dishes they sell and would prefer if they were more readily available (Crossman et al., 2008). St. Croix's annual "Taste of St. Croix" event invites famous U.S. chefs to use local produce to create their most notable dishes (Laurencin, 2017). Proper management practices of farms in the Territory can maintain soil quality, prevent soil erosion, and inhibit weed growth via cover cropping (Weiss et al., 2017).

Farming in the Territory is hindered by a variety of factors. The USVI has moved away from its reliance on agriculture as its major economic driver since the 1960's (McElroy & Alburquerque, 1984) and transition to a tourism and service-based economy left has local agriculture with little governmental investment. Farming on small islands is always very limited by lack of available land, and the steep topography of the islands (mainly St. John and St. Thomas) significantly limits the availability of farmable land (Pluke, 2008). Furthermore, arable land in the USVI is typically encroached upon by other land use practices such as the erection of buildings and impervious surfaces (Chakroff, 2010). As a result, over 70% (407/565) of the existing farms in the territory are less than 9 acres, and many are less than 3 acres (268). Many of the farmers also have not adopted more modern farming techniques and tools in part due to the age of the farming populace (average farmer age is 61) and lack of revenue (USDA, 2018). Less than half the farms in the Territory (244/565) have implemented computerized systems to help manage their business (USDA, 2018). Other limitations farmers in the Territory experience range from relatively high labor costs, low profitability of produce, water availability, and lack of farming resources (Pluke, 2008). Unfortunately, farming as a practice has generally been forgotten by the majority USVI residents, and urban development in areas designated as prime farmland has increased by over 400% from 1985-2018, reducing the amount of available farm-able land (Figure 13; Laurencin, 2017; USDA, 2018).

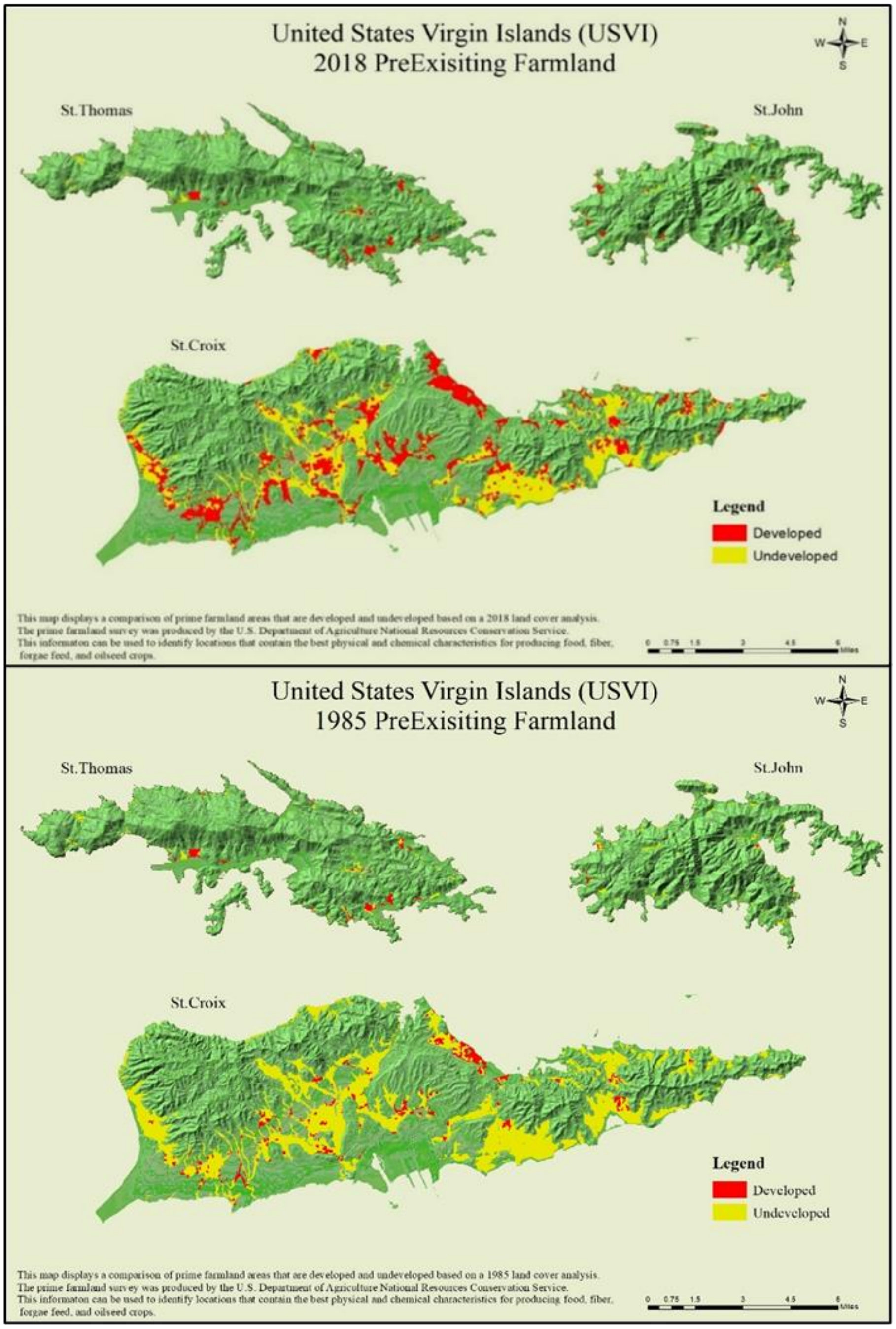

Figure 13. Areas of pre-existing USVI prime farmland in 1985 (top), compared to 2018 (bottom). Red areas designate low, medium, and high-density urban development. Yellow areas are undeveloped prime farmland (prime farmland is determined by USDA soil surveys). Data from USDA Natural Resources Conservation Service and Caribbean Green Technology Center (2021).

2.3 Community workshops

2.3.1 Wellbeing outcome rankings

Participants in each island workshop were asked to "Rank the human wellbeing outcomes that you think decision-makers should prioritize for your island community." The options they were presented with are some of the human wellbeing outcomes often associated with community resilience and hazard mitigation activities such as restoration (Table 2). Across all three workshops, the highest rank was unanimous: Human health. In fact, the rankings were almost the same for each workshop (Table 9). Cultural and heritage values and property protection also received high rankings. At the bottom of the ranked list was Property value. In terms of resilience outcomes of management actions (e.g. habitat restoration), the "property value" outcome refers to increases in property value that can be linked to an individual household's economic resilience, and at a larger scale increases in a community's property values (which can lead to a larger tax base). Property value can be linked to economic resilience at the community level. Group discussion at the St. Thomas workshop revealed some possible explanation for why property value might not be as important in terms of managing ecosystems for improved resilience. One participant explained that in the islands, most people rent their homes or can't afford to own, so management decisions that might affect the value of a home that they are not financially or legally responsible for may not concern them as much as management decisions that affect their health, which is essential to resilience; a healthy community is better able to respond to and cope with external shocks.

Table 9. Participants responses to "Rank the human wellbeing outcomes that you think decision-makers should prioritize for your island community." *Note that "Culture and heritage values" was unintentionally left out of the choices for the St. John workshop. The error was pointed out to participants, who discussed that they would have ranked it highly, had it been on the list of options.

Rank	***St. Thomas***	***St. John***	***St. Croix***
1st	Human health	Human health	Human health
2nd	Cultural and heritage values	Property protection	Cultural and heritage values
3rd	Property protection	Economic activity	Property protection
4th	Social disruption	Social disruption	Economic activity
5th	Costs & expenditures	Costs & expenditures	Social disruption
6th	Economic activity	Jobs	Costs & expenditures
7th	Jobs	Property value	Jobs
8th	Property value	**see note in caption*	Property value

2.3.2 Habitat selections

Participants in each island workshop were asked the open-ended question, "What habitat do you value as most important for hazard mitigation and resilience?" While they had been presented with information specific to ghuts, wetlands, forests, farms, and coral reefs, they were encouraged to list any USVI habitats that they felt were most valuable. All feedback was coded and summarized in Figure 14.

Forests/terrestrial vegetation, mangroves, and coral reefs emerged as the top three choices across all of the workshops. Ghuts were also important to all participants across the three workshops, although participants in the St. John workshop placed coastlines/shorelines slightly above ghuts, and in St. Croix, mangroves received slightly more votes than ghuts. Even though mangroves are technically included in the "wetlands" category – and participants could have selected "wetlands" to include all types of wetland habitats in their choice – mangroves emerged as important enough to mention as a habitat to focus on separately from the rest of the wetland types. Spatially, mangroves only occupy a very small proportion of land when compared to other habitats and land uses, but the services they provide are significant in terms of hazard mitigation and resilience. The whole watershed was mentioned as important to St. John and St. Croix participants. In all three workshops, discussion ensued about how difficult it was to choose because the interactions within the whole system were important. Additionally, some participants did not respond with habitats, but mentioned types of species (e.g. sea turtles), land use (e.g. historical properties, conservation areas), and actions (e.g. erosion control, soil protection) as important.

2.3.3 Hazard mitigation activity selections

Participants in each workshop were asked the multiple-choice question, "If you had to pick one, which type of mitigation activity do you feel would benefit your island community the most?" (Figure 15). Native forest and plant/vegetation restoration emerged as the top choice across all three workshops, but especially in St. Croix. Drought management came in second place as most important in St. Thomas and St. Croix, but not for St. John participants, which could be explained by the fact that most of farming activity (which is significantly impacted by drought) takes place in St. Thomas and St. Croix. St. John workshop participants had slightly more interest in wetland restoration. Interest in coral reef restoration was lowest in all three islands.

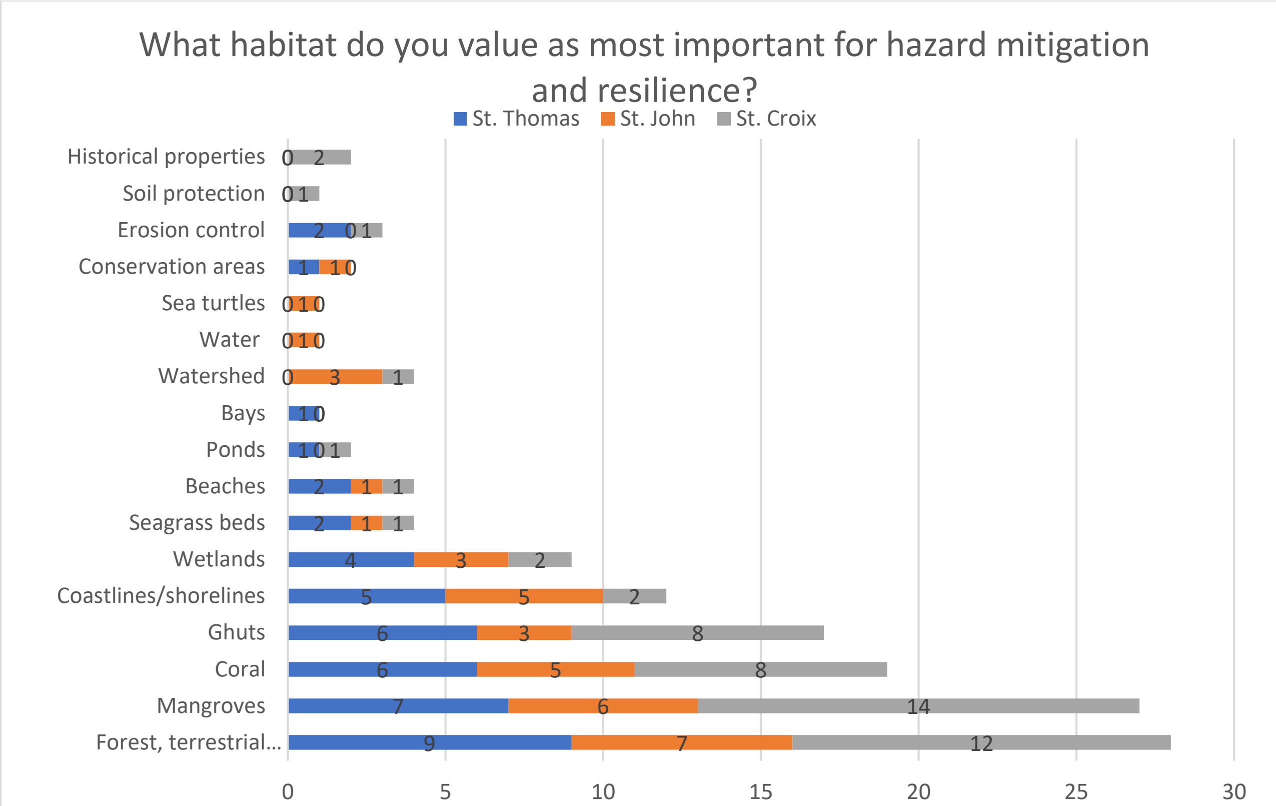

Figure 14. Responses from all participants across three island workshops to the open-ended question, "What habitat do you value as most important for hazard mitigation and resilience?" are along the Y axis. The X axis represents total combined number of responses across all three islands. Numbers in colored bars represent total responses per individual island for that habitat.

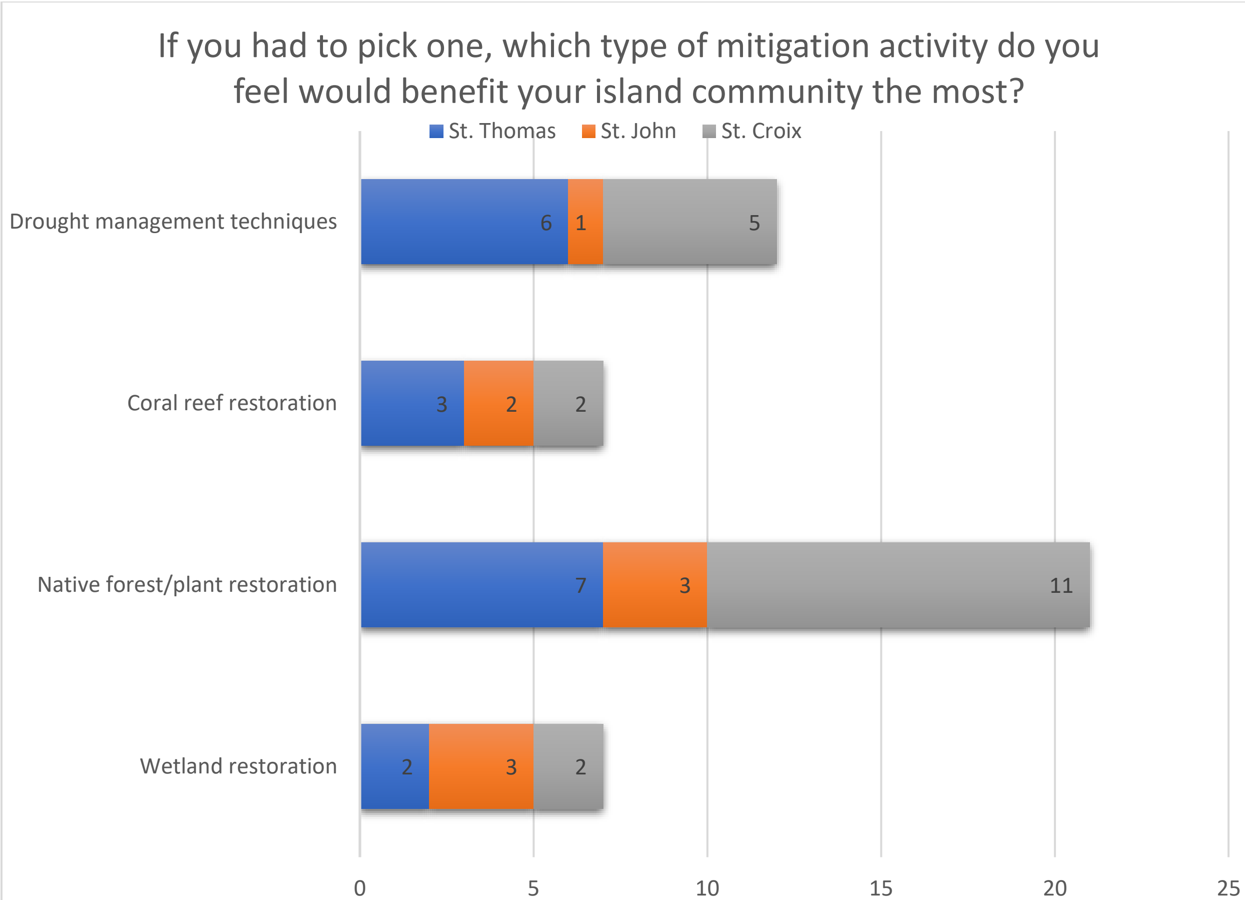

Figure 15. Total responses from all participants across three islands, separated by island workshop, to the multiple-choice question, "If you had to pick one, which type of mitigation activity do you feel would benefit your island community the most?" The X axis represents total combined number of responses across all three islands. Numbers in colored bars represent individual responses per island.

2.3.4 Community engagement discussion results

Following the ratings exercise, participants in each island workshop were asked to discuss obstacles affecting community engagement with ecosystem management decisions (Table 10) and to share ideas for how people can get more involved (Table 11). In general, responses were similar to the feedback collected from subject matter experts. Major obstacles mentioned included poor communication, lack or education or awareness, and a general disconnect from environmental issues and decisions. Policy, lack of government enforcement, and power structures/sense of powerlessness were also mentioned as obstacles. As for how to get the community more involved, ideas included getting involved with local organizations or working groups, attending public hearings, and traveling/going to communities ("meet where we live and play") to listen and learn from them directly.

Additionally, to encourage discussion about solutions and how to build on success, participants were asked to share any success stories concerning local ecosystems and where community engagement resulted in positive change. In St. Thomas workshop, the St. Thomas East End Reserve was pointed out as a successful collaborative effort between citizens, academia, and local and federal government. In St. John, one participant mentioned that the U.S. Fish and Wildlife Service and local partners are removing invasive plants starting a propagation program for endangered species. In St. Croix, the coral restoration effort led by The Nature Conservancy and other partners was mentioned as an example of positive change. The full list of examples is available in Table 12.

Table 10. Responses divided by island workshop to the discussion question, "What obstacles keep individuals or communities from being involved in decisions that affect ecosystems? Answer with three words or phrases."

St. Thomas	*St. John*	*St. Croix*
hardship; awareness; positivity	poor telecommunications; cultural differences; diverse values	awareness avenues opportunities
poorly organized; distribution	Lack of knowledge	poor communication; lack of awareness; sense of powerlessness
availability; access; isolation	unaware lack of information management	power structures
lack of knowledge; lack of connection	Lack of notice; Not understanding issues	time; discrimination; knowledge
lack of information; poverty; despair	Local Government enforcement of laws; Poor communication	Lack of education; Collaborative environment; Mutual respect
Silos; Resistance; Financial Interests	Governance Awareness Money	Toxic runoff; Shareholder profit; Silencing
Never asked; Education; Economic hardship	Values void of Nature; No value for Nat Resources; Lack Education	awareness; finances; apathy
apathy or frustration; uneducated in environment; selfishness	Government; Big Investors Dollars	Access or inclusion; Funding to lead projects
disenfranchisement education political decisions		Time; Education; Policy
Lack of information; Failure to speak up		lack of knowledge; lack of transparency; awareness
Persistence Awareness disenfranchisement		Lack of Knowledge; Concerns more pressing; lack of gvt collaboration
disinterest; small worldview timescale ignorance		outreach; situational awareness
lack of knowledge; lack of interest		No respect for nature; Teacher Education; Public education
Lack of awareness; Political framework		lack of engagement; cultural obstacles; racial economic poverty
political apathy; voicelessness; diverse expectations		no power to effect change
Education; Lack of Public Outreach; Lack of Interest		
Lack of engagement by gov; Perceived powerlessness; Again gov doesn't engage		
Uphill battle; lack of knowledge; awareness; hard to work in groups		

Table 11. Responses divided by island workshop to the discussion question, "How can people get more involved in decisions concerning the USVI ecosystem and their wellbeing? Answer with three words or phrases." (Responses not corrected for spelling/grammar.)

St. Thomas	*St. John*	*St. Croix*
invite them; education; more enforcement	band together; speak out; do it yourself	community engagement; place-based conversations; meet where we live play
include in cultural event	Better networking; Government transparency; Government accountability	More public forums; multi-medium platforms; Increased Collaboration
more access opportunities; more outreach; demonstrate successes	go to them; listen to them; connect them to wellbeing	Time; Outreach
Join Community Groups; Talk with Neighbors	Read local news; Engage w nonprofits; Vote	pay attention; join enviro organization; network
vote; speak up; ask questions	Value Nature; Get Involved; Be Informed	Collaborative workshops; Community interaction; Community Champion sector
Get connected; Read newspaper or social; Listen to the radio	Work with NGOs; Go to town halls and mtgs; Self-educate	Challenge VI Govt; Teacher Education; Parent Education
Adopt a small plot; Call your senators; Press groups to cooperate	word of mouth	pay attention
Follow relevant outlets; Attend public meetings; Leverage advocacy NGOs		trust that voice is heard; public forums; collaboration by orgs
go to them; listen to them; talk to kids		Speak Up; Stay with the process; Lead
Explain the benefits; Your involvement important; Sell quality of life		attend public hearing; listen open minded; react to everything
join influential boards; join non-profits		outreach at public fairs; outreach in shopping area
Join an environmental org Advocate with legislators Network with relevant off		
Connection to the Land; Teacher Education; Parent Education		
find like-minded; make concerns heard		
early education		
publicize what going on		
grass roots efforts; school curriculum; community influencers		

Table 12. Participant responses to the open-ended discussion question, “Are there any success stories concerning local ecosystems, where community engagement resulted in positive change?” (Responses not corrected for spelling/grammar.)

St. Thomas	*St. John*	*St. Croix*
Cas Cay	mangrove clean ups in Coral Bay Get Trashed clean ups around the island	SEA purchase of Southgate!
STEER	Cleaning up of mangroves	Salt Pond, Salt River
Awareness of Coral ecosystems by Stony Coral Tissue Loss Disease Research	Montessori has done a lot of work with beach cleanups. It's mostly gauged towards the school students, but it can certainly be replicated elsewhere.	The establishment of Smith Bay Park on St. Thomas
development of a management plan for Cas Cay involved students and the community and VIG in 1980s.	Yes, CBCC as an NGO has become a watershed mgt agency and has engaged in a number of projects that have worked. more needs to be done, as always - particularly to recover from hurricane damage.	decision NOT to build an aerospace facility at Great Pond east (now EEMP office)
In the 60's the north side stopped condos from being built on Hull Point	Blocking Summers End	Tulipan Park in Estate Welcome
Stony coral tissue loss disease awareness	distribution of water filters for cistern use after Hurricane Irma	Volunteers help plant endangered *Agave eggersiana* at Sandy Point NWR, Southgate Coastal Reserve, and onto private properties on STX.
St Croix Enviro Assoc purchase of land for conservation easement at Chenay Bay, STX	huge amount of volunteer work, and supported by donations from generous people to remove debris from ecosystems	Coastal Clean Ups!
stopping hotel development near private (at the time) portion of Magens Bay	USFWS is partnering with the Friends of the VIIS to remove invasive plants and to start a propagation program for listed species on STJ.	Mangrove planting in Salt River
Mandahl bay development constrained	Huge amount of volunteer work to remove debris - and donations of dollars too	Coral restoration at TNC
Volunteers planting trees to enhance the habitat of Buck Island Cay NM. St. Croix Environmental worked with Cub Scouts and local volunteers to plant over 100 endangered *Agave eggersiana* at Southgate.	Newspaper online & print, word of mouth	The establishment of drinking water vending machines, which encourages plastic bottle recycling
		mangrove cleanups
		Outreach/fundraising to targeted local neighborhood allowed our org to cover the cost for us to take ownership of forest and ephemeral pond property to ensure long term protection.

3. <u>Discussion</u>

In general, a trade-off involves losing one quality or quantity of something in return for gaining another quality or quantity. In terms of ecosystem services, trade-offs occur when management decisions are made that directly or indirectly affect the potential provision of an ecosystem service. For example, a decision is made to restore mangroves in a particular bay to help reduce storm-caused erosion, but that would mean displacing some sea grass which provides soil stabilization, among other things. Another important point is that ecosystems and ecosystem services can be highly interdependent in space and time.

Trade-offs of ecosystem services can be categorized along three axes: spatial scale, temporal scale, and reversibility. “Spatial scale” refers to whether the effects of the trade-off are local or distant. “Temporal scale” refers to whether the effects of the trade-off happen quickly or over a longer period. “Reversibility” refers to whether the ecosystem service will return to its original state (Rodriguez et al., 2006; Howe et al., 2014). For example, overharvesting of fish today, in their spawning aggregation area, can impact catch elsewhere in the region (spatial) as well as future catch and recreational opportunities (temporal), and intense overharvesting could jeopardize the ability of the stock to rebound (reversibility), putting at risk connected ecosystem services.

On the other hand, a synergy amongst ecosystem services exists when the enhancement (or degradation) of one ecosystem service directly increases (or decreases) the provision of another service. For example, the protection of coral reef areas for recreational (non-extractive) purposes positively impacts fish abundance, which increases algal grazing and thus protects the coral (Bennett et al., 2009). There can also be a decrease in multiple services when synergies are present. For example, property owners might decide to remove trees and clear vegetation for building on an island hillside. This activity will impact downstream water quality because the roots of trees and vegetation keep sediment in place, and without that forest, the sediment flows down the hillside and into the bay. Therefore, recreation (e.g. hiking, bird watching) previously associated with that forested area will be impacted, as well as in the downstream area, such as beaches, bays, and reefs where swimming, fishing, or tourism activities take place.

Management for – or enhancement of – ecosystem services for resilience involves managing the habitats (systems) that services are supplied from and the demand – and expectations – that people have for these services. Critical to making resource allocation decisions for the restoration or protection of habitats that provide services and enhance resilience is understanding what communities want or need, and from a resource management perspective, what is feasible to achieve within a given time frame and budget. At that point trade-offs between services may occur or synergies may develop. The Relative Ratings polling that was conducted to elicit workshop participants’ professional opinion on what wellbeing outcomes should be prioritized provides important information on what services – and by extension what habitat(s) – should be enhanced or protected.

Specifically, across all island workshops, participants unanimously selected human health as the wellbeing outcome that decision-makers should prioritize (Table 9). Although this workshop series was an exercise and does not represent the perspectives of the whole USVI population, it is safe to say that human health could be a value shared across the entire Territory when it comes to planning for a more resilient future. As discussed previously, community members' health and associated capabilities are essential to resilience; a healthy community is better able to respond to and cope with external shocks (Table 2). Of course, "human health" can mean different things to different people, as it encompasses the many physical, mental, emotional, psychological, and spiritual aspects of living in the USVI. People gain or access health benefits from their natural environment in different ways (e.g. swimming, wading, trail walking, meditating, socializing, source for nutrition). Despite the diversity of health-related outcomes and approaches to those outcomes, decision-makers can intentionally target human health outcomes as a starting point.

With this target in mind, it follows that decision-makers can then identify which habitats and mitigation activities are known to be linked to or result in the desired wellbeing outcomes (in this case, human health; Table 9). There are science-based tools that can help decision-makers do that (e.g. GEMS tool) but importantly, those decision-makers should use the local community's feedback to identify the habitats and mitigation activities that are important to them. For example, across all the island workshops, participants selected forests, mangroves, and coral reefs as habitats that they value the most in terms of providing ecosystem services. Native forest restoration was the most preferred type of hazard mitigation activity. However, coral reef restoration was rated low for preferred mitigation activities even though coral was rated highly on the habitat poll. So, in consideration of their community's interests, should decision-makers focus on forest restoration or coral restoration? What about mangrove restoration, since communities rated mangroves highly, too? This is where tradeoffs and synergies must be considered alongside best available science.

As discussed previously in Section 2.2 (Ridge to reef profiles), it is likely that the ecological services that coral reefs provide will decrease if ocean warming, storms, disease, and anthropogenic stressors continue to contribute to future coral die-offs and overall coral decline (Platenberg & Valiulis, 2018; Ennis et al., 2019). Also, significant decreases in forest cover combined with the anthropogenic stressors (urban development and invasives species) have decreased the extent and quality of local forests, and by extension, some of the services they provide. Decision-makers could choose to focus hazard mitigation efforts on forests, knowing that by doing so, the positive effects of restoring native plants and forests will not only benefit the forests, but will also benefit downstream mangroves and coral reefs (e.g. reduces erosion, sedimentation, and pollution). Forests, mangroves, and coral reefs were all highly valued by workshop participants, so choosing and investing in hazard mitigation activities that will likely benefit multiple habitats and outcomes that are important to many people (e.g. human health) increases community engagement and support.

One way to synthesize this feedback into a science-based blueprint for resilience planning is to apply the Ecosystem Services Logic Model (ESLM) framework as discussed previously and as presented in the local island workshops. While the models were adapted from ongoing efforts in the Gulf of Mexico, the ESLM framework, the process for creating the models, and the models themselves can certainly be applied to projects and programs in the USVI. However, to effectively link ridge to reef ecological changes to human wellbeing outcomes using best available science, more local socio-ecological systems research is needed in the USVI. Additionally, the subject matter experts consulted in this project suggested many ideas about ecological indicators that can and should be used for resilience monitoring (Table 7). In gathering data layers and discussing the health and function of the USVI ridge to reef ecosystem with local experts for this project, it became clear that consistent, well-planned long-term monitoring of paired terrestrial and marine ecosystems is necessary to gain a clear picture of how the whole ridge to reef ecosystem changes over time. While the Territorial Coral Reef Monitoring Program continues to deliver consistent and useful data for management decisions, coral reefs are just one component of the larger ridge to reef ecosystem. There is no equivalent in the Territory for terrestrial monitoring and assessment. However, there are many examples of local experts and resource managers that have been working to identify issues and develop solutions on the whole-ecosystem scale, such as the Watershed Management Project.

To comprehensively understand the connections between environmental change and human wellbeing, human wellbeing should be monitored. Developing a human wellbeing monitoring protocol that captures physical, mental, economic, and other health metrics in tandem with natural resource metrics would allow for a more holistic assessment of resilience, consistently over time. For example, in the Gulf of Mexico, a region that continues to experience issues and threats like the USVI, a Community Health Observing System (CHOS) is being developed to assess adverse human health consequences of future disasters like well-established environmental observing systems (Sandifer et al., 2020). If the ESLM framework is to be applied, USVI resilience planning leadership will be able to determine which socio-behavioral-economic indicators to focus on, and which metrics will effectively capture the changes in the socio-ecological system.

The ESLM framework is just one of several approaches to planning, for example the National Fish and Wildlife Foundation recently completed a Coastal Resilience Assessment for the USVI, and created a USVI module for the Coastal Resilience Evaluation and Siting Tool (CREST) that project managers can use to make informed decisions about the siting of coastal restoration and resilience projects. Similarly, the BlueValue (Harte Research Institute, 2020) database is a searchable database of simplified and useful ecosystem valuation information, and the Economic Decision Guide Software and Online Tool (EDGe$) was designed by the National Institute of Standards and Technology (NIST) to support community-level resilience planning.

Regardless of the planning tools of choice, it is evident through the feedback collected from both subject matter experts and professional community workshops that island communities must be engaged as leads (or co-leads with technical experts) from the beginning of project or program planning and continue as leads throughout the planning, implementation, and evaluation process. When asked to share local examples of successful community engagement within the context of environmental decisions and resilience planning, participants were able to point to some evidence of positive engagement (Table 12). For instance, native plant/vegetation restoration emerged as a top choice for mitigation activities in all workshops, and one participant mentioned that Cub Scouts and other volunteers were successful in planting plant over 100 endangered *Agave eggersiana* to enhance the habitat of Buck Island in St. Croix. These types of community events can enhance engagement and community sense of agency, which was noted as one of the many community engagement issues (Table 10). These experiences are opportunities for learning what did or did not work for each local case and can serve as a foundation upon which to build for improved adaptive planning. Planning is a community- or place-based process that provides a future vision for communities and translates social values into government policies and programs to protect human and ecological wellbeing (Daniels & Daniels, 2003). Adaptation planning considers approaches for managing a changing environment and community conditions (Figure 16; Del Angel, 2021).

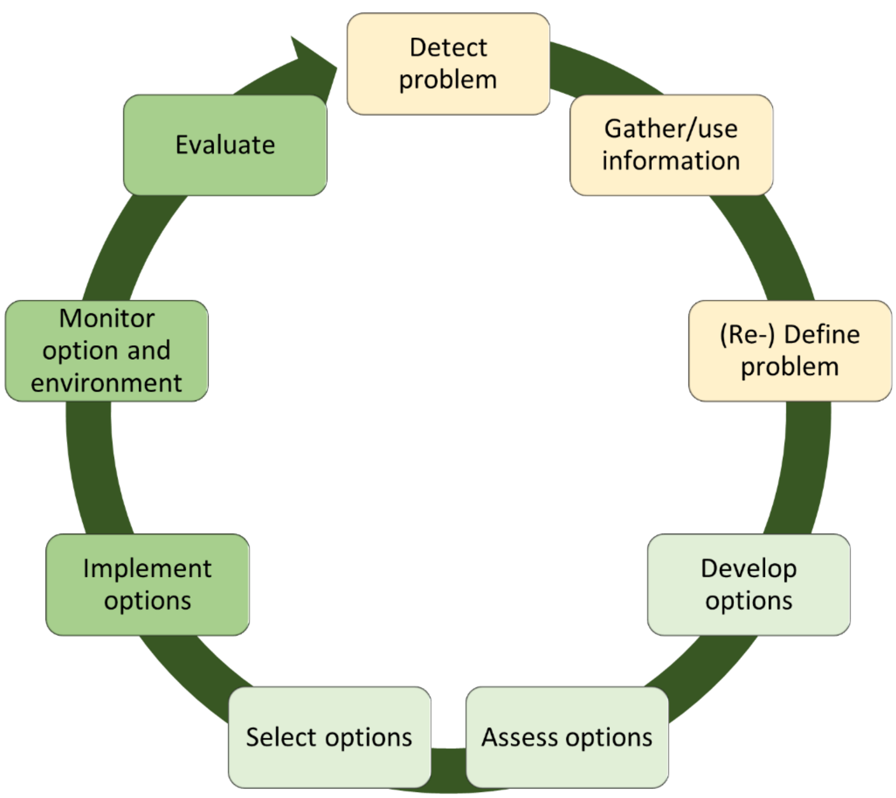

Figure 16. The three phases and process stages of adaptation planning. Figure adapted by Del Angel, (2021) from Moser and Ekstrom (2010).

It is recognized that like many small island jurisdictions, the USVI is limited in capacity and resources in terms of research, monitoring, and implementation of hazard mitigation activities and resilience projects and programs. However, there are methods of community capacity building which draws from positive experiences like those discussed in the workshop (Table 12) and that could be adapted for the USVI, such as Asset Based Community Development (ABCD). The ABCD approach mobilizes individuals, local associations, and institutions for capacity-driven development. It focuses on community assets and strengths rather than problems and needs, and identifies and mobilizes individual and community assets, skills, and passions. It is community driven – 'building communities from the inside out' – and is relationship driven (Kretzmann & McKnight, 1993).

4. Conclusion

In summary, this ecosystem services assessment is an evaluation of the general condition of the USVI ridge to reef ecosystem, with particular focus on habitats and land use that contribute to hazard mitigation and resilience. Importantly, this assessment *process*, as well as its results, helped improve understanding of the connections between environmental and human wellbeing specific to the USVI, factors to consider in decisions surrounding the natural and built environments, and offered a framework for moving toward a more resilient and sustainable future. This process has informed the following suggestions for ways in which the Territory can strengthen the underlying positive factors and enhance the resilience of the VI's ecosystem services for the Territory's benefit:

1. Island communities, or community liaisons, must be engaged as leads or co-leads from the beginning of hazard mitigation and resilience project or program planning and continue leading throughout the planning, implementation, and evaluation process.

2. Decision-makers should use the local community's feedback to identify wellbeing outcomes that are important to the community, as well as in identifying priority ecosystem components and mitigation activities.

3. Decision-makers can intentionally target human health outcomes as a starting point in hazard mitigation and resilience planning.

4. Decision-makers should invest in hazard mitigation activities that will likely benefit multiple habitats and that influence outcomes important to many people (e.g. human health). Focusing hazard mitigation efforts on upland habitats (e.g. forests, ghut-associated forests, native vegetation, farms), will not only benefit upland areas and the people living there, but will also have cascading benefits to other habitats that provide

ecosystem services crucial to hazard mitigation and resilience (e.g. mangroves and coral reefs).

5. Consistent, well-planned long-term monitoring of paired terrestrial and marine ecosystems is necessary to gain a clear picture of how the whole ridge to reef ecosystem changes over time.

6. More local socio-ecological systems research is needed to connect ridge to reef ecosystem changes to human wellbeing outcomes.

7. Developing a human wellbeing monitoring protocol that captures physical, mental, economic, and other health metrics in tandem with natural resource metrics would allow for a more holistic assessment of resilience, consistently over time.

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Appendix 1. Ecosystem services organized by Use Value and Non Use Value. (Harte Research Institute, 2020)

USE VALUES		
Ecosystem Service	**Description of service**	**Example**
Supportive Functions and Structure	**Ecological structures and functions that are essential to the delivery of ecosystem services**	
Nutrient processing	The cycling of nutrients, including acquisition and storage, within the biosphere.	Nitrogen cycle; phosphorus cycle; maintenance of soil fertility
Primary production	The conversion of sunlight into biomass.	Plant growth
Pollination and seed dispersal	Movement of plant genes.	Insect pollination; seed dispersal by animals
Habitat	The physical place where organisms reside.	Refugium for resident and migratory species; spawning and nursery grounds
Hydrological Cycle	Movement and storage of water through the biosphere.	Evapotranspiration; stream runoff; groundwater retention
Regulating Services	**Maintenance of essential ecological processes and life support systems for human wellbeing**	
Gas sequestration, storage, and production	Regulation of the chemical composition of the atmosphere and oceans.	Sequestration of carbon dioxide and release of oxygen; vegetative absorption of volatile organic compounds
Climate processes	Processes related to regulation of climate from a local to global scale.	Direct influence of land cover on temperature, precipitation, wind, and humidity
Storm surge protection	Dampening or reducing environmental impacts from storm surge.	Marshes and other coastal habitats absorbing waters from surge
Biological control	Species interactions.	Control of pests and diseases; reduction of herbivory (crop damage)
Water flow	Flow of water across the planet’s surface.	Modulation of the drought-flood cycle; purification of water
Soil retention	Erosion control and sediment retention.	Prevention of soil loss by wind and runoff; avoiding buildup of silt in lakes and wetlands
Pollution abatement	Removal or breakdown of non-nutrient compounds and materials, or other forms of potentially harmful pollution.	Pollution detoxification; absorption of noise pollution
Provisioning Services	**Provisioning of natural resources and raw materials**	

Freshwater provision	Filtering, retention, and storage of freshwater.	Provision of freshwater for drinking; medium for transportation; irrigation
Food	Provisioning of edible plants and animals for human consumption.	Hunting and gathering of fish, game, fruits, and other edible animals and plants; small-scale subsistence farming and aquaculture
Raw materials	Products harvested from natural resources for human use such as building, manufacturing, energy, fertilizer.	Lumber, skins, plant fibers, oils and dyes; fuel wood, organic matter (ex: peat); topsoil, leaves, litter, excrement
Genetic resources	Genetic resources.	Genes to improve crop resistance to pathogens and pests and other commercial applications
Medicinal resources	Biological and chemical substances for use in drugs and Pharmaceuticals.	Quinine; Pacific yew; Echinacea
Ornamental resources	Resources for fashion, handicraft, jewelry, pets, worship, decoration and souvenirs.	Feathers used in decorative costumes; shells used as jewelry
Cultural Services	**Enhancing emotional, psychological, and cognitive wellbeing**	
Recreation	Opportunities for rest, refreshment, and recreation.	Ecotourism; bird-watching; outdoor sports
Aesthetic	Sensory equipment of functioning ecological systems.	Proximity of houses to scenery; open space
Science and education	Use of natural areas for scientific and educational enhancement.	A natural field laboratory and reference area
Cultural, spiritual and historic	Use of nature for symbolism or representation; natural landscapes/seascapes with significant spiritual, religious, or cultural value.	Oyster middens; burial sites; ancestral lands
NON-USE VALUES		
Bequest	Value people place on knowing that future generations will have the option of using an ecosystem good or service.	
Existence	Value people place on knowing that a certain ecosystem good or service exists.	
Option	Value people place on knowing that they have the option of using/benefiting from a certain service or good.	
Total Economic Value (TEV)	Value of all Use and Non-Use Ecosystem Services.	

Appendix 2. Questions for Subject Matter Experts

1. In what ways do people benefit from the "ridge to reef" ecosystems (or natural habitats; terrestrial, coastal, marine) of the USVI? *For example, clean ocean water is important for our health – it sustains fish that we eat or sell, attracts tourism to our islands, and is a place to swim and relax.*

2. Thinking about all the diverse habitats and species that make up the "ridge to reef" ecosystem of the USVI, what aspects reduce risks to communities? *For example, are forests important for protecting us from hazards like mud slides?*

3. How have these ecosystems (or natural habitats) changed due to natural hazards? *For example, how have droughts impacted the landscape?*

4. As ecosystems have changed, and the services they provide changed, have islanders changed their methods for dealing with this change, how have they adapted? *For example, as trees and bush are removed, soil becomes loose, and over time we build bigger retaining walls to keep the soil in place.*

5. How have these ecosystems (or natural habitats) changed due to human activity? *For example, how have building developments impacted the land or sea?*

6. How do we know when the island ecosystems (or natural habitats) have changed? What are the indicators (signs)? *For example, when a fisherman is out at sea and sees too many lionfish – an invasive species – that could signal a problem. What examples can you think of on land or in the sea?*

7. Are communities involved in decisions concerning the USVI ecosystem (or natural habitats)? How so? If not, how can they be? *Are they at the table, do they care to be? Do they know that decisions are being made?*

8. Are there any specific places within the Territory that have come to your mind during our conversation today? Would any of these places be good for a case study? *We will be hosting a workshop this spring and will focus on a place currently facing a management challenge or decision related to ecosystems and resilience.*

9. Is there anyone else that you recommend we talk to?

Appendix 3. Workshop agendas