COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS COASTAL RESILIENCE ASSESSMENT

2020

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Report cover images: Village of Songsong, Rota (top); coral reef in Saipan (bottom)

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GLOSSARY OF RELEVANT TERMS

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

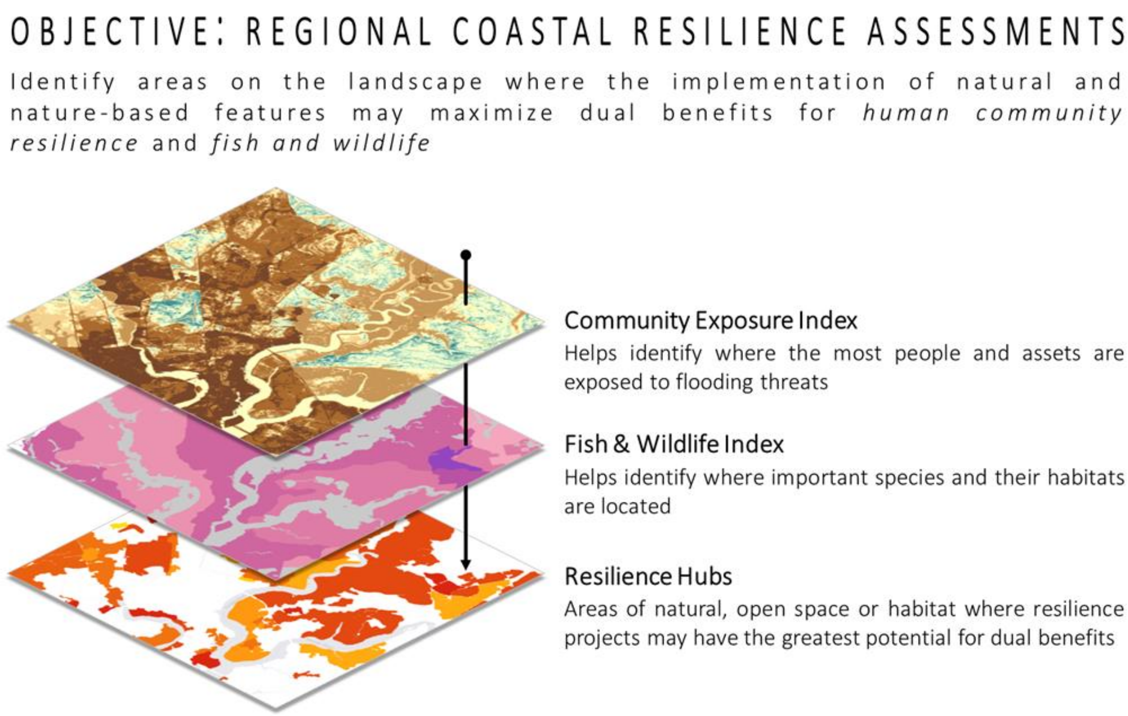
Term	Definition
Adaptive capacity	The ability of a person or system to adjust to a stressor, take advantage of new opportunities, or cope with change.
Ecosystem services	Benefits that humans receive from natural systems.
Exposure	The presence of people, assets, and ecosystems in places where they could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

EXECUTIVE SUMMARY

Coastal communities throughout the United States face serious current and future threats from natural events, and these events are predicted to intensify over the short and long term. Dynamic processes such as coastal erosion, storm surge flooding, and river runoff exacerbate the threat from sea level rise. Intense typhoons and extreme flooding have the potential to devastate both human communities and fish and wildlife habitat, as has been seen in recent years throughout the western Pacific region. Recently the Commonwealth of the Northern Mariana Islands (CNMI) has experienced numerous consecutive super typhoon events that caused loss of vegetation cover and left communities exposed to severe and devastating effects of coastal flooding. As communities rebuild, decision-makers need tools and resources that allow for data-driven decision support in an effort to maximize available funding opportunities and other planning needs.

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

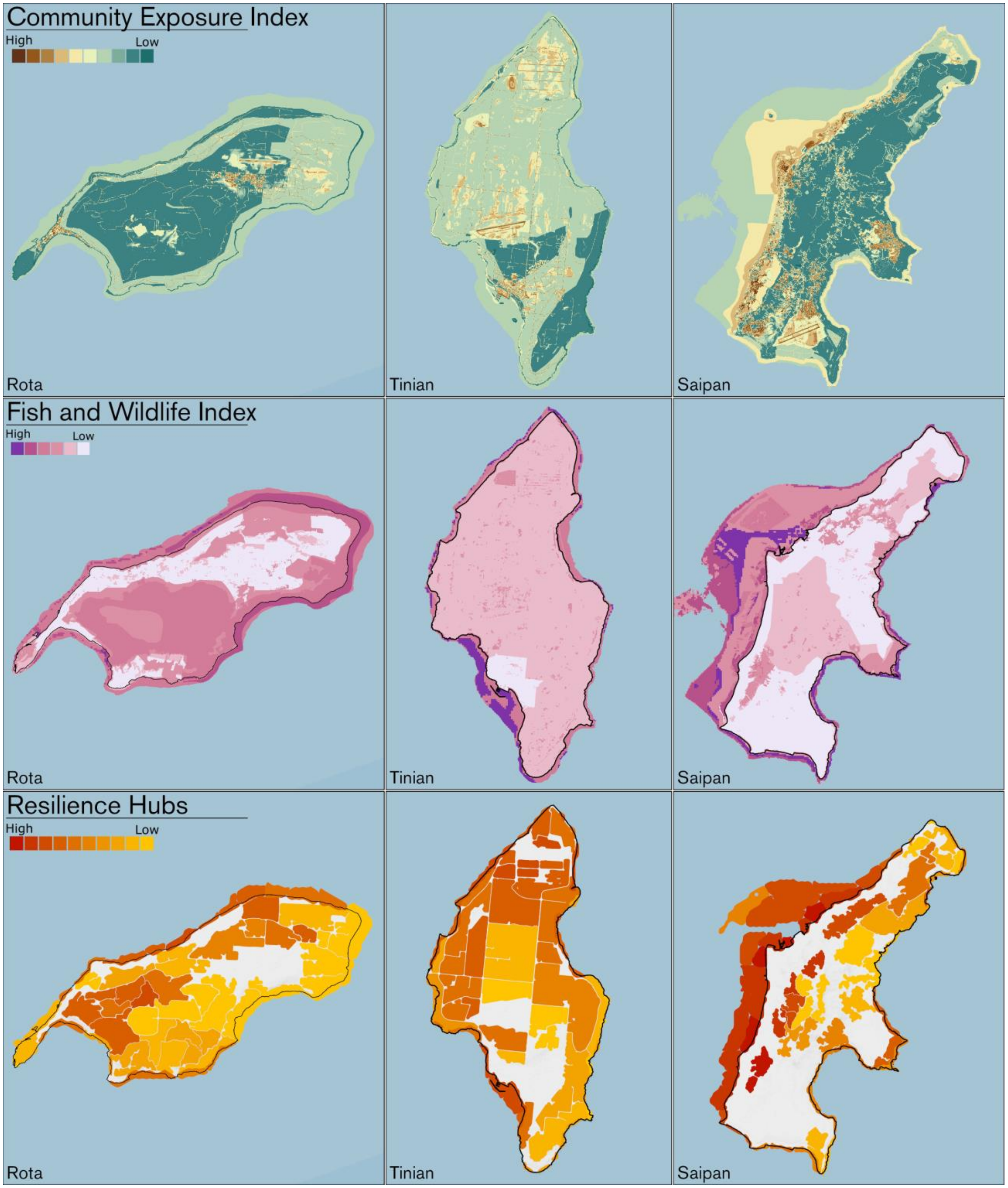
This Geographic Information System (GIS)-based Coastal Resilience Assessment combines spatial data related to land use, protected areas, human community assets, flooding threats, and natural resources (specifically fish and wildlife resources) in order to identify and prioritize Resilience Hubs (see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



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

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

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



Final Community Exposure Index (top), Fish and Wildlife Index (middle), and Resilience Hubs (bottom) for the CNMI Coastal Resilience Assessment (not shown to scale). Higher values represent areas where a higher concentration of assets are exposed to flooding threats (Community Exposure Index), areas where numerous important species and their habitats are located (Fish and Wildlife Index), or areas where resilience projects may have the greatest potential to benefit both human communities and wildlife (Resilience Hubs).

INTRODUCTION

1.1 Commonwealth of the Northern Mariana Islands

The Commonwealth of the Northern Mariana Islands (CNMI) is an archipelago consisting of 14 islands spanning over three hundred miles in the northwestern Pacific Ocean. The majority of CNMI's residents live on Tinian, Rota, and Saipan—the largest and most populous island. The islands are rich in biodiversity, endemic species, and cultural heritage. Positioned in Typhoon Alley, communities throughout the Northern Mariana Islands are highly exposed to a variety of coastal-flood related threats. In this tropical climate, flooding threats can have devastating effects, particularly in densely populated areas like Garapan on the capitol island of Saipan. Major typhoons have recently devastated the islands, including Super Typhoons Soudelor in 2015 and Yutu in 2018, as well as other significant typhoons that included Mangkut in 2018 and Hagibis in 2019. Local flooding threats range from coastal storm surge and typhoons to the long-term threat of rising sea level.

The Mariana Islands feature relatively healthy and extensive coral reef ecosystems. On Saipan for instance, the western side of the island is protected by a large fringing and barrier reef system. The resulting shallow-water lagoon contains a diversity of coral species, large seagrass beds, and CNMI's last remaining mangroves. Together, these habitats help to absorb wave energy and minimize the impacts of storm surge and flooding to the densely populated coastal communities of western Saipan. However, the effects of local stressors associated with nutrient and sediment pollution are compounded by large-scale, episodic stressors that degrade coral reef ecosystems, such as coral bleaching, invasive species, increasing drought and fire regimes, and physical damage from severe storm events. Degraded coral reefs, among other habitat types, provide limited coastal protection benefits, which increases CNMI's exposure—and potentially its vulnerability—to flooding threats.

In response to the increased frequency of severe storm events and the degradation of coral reefs and other important habitats, numerous efforts have worked to better understand the threats, needs, gaps, and nature-based approaches that can be applied to build resilience in the Northern Mariana Islands. Recent efforts include the Pacific Islands Regional Climate Assessments (Keener et al. 2012; Zena et al. 2020), Climate Change Vulnerability Assessment For the Island of Saipan (Greene and Skeele 2014), the Climate Vulnerability Assessment for the Islands of Rota and Tinian (DCRM 2015), efforts to understand the relative resilience of CNMI's coral reef ecosystems (Maynard et al. 2015), and the U.S. National Climate Assessment (USGCRP 2018), among others. Such studies are critical to help communities understand, respond to, and prepare for future storm events.

As the Northern Mariana Islands take steps to reduce exposure and plan for a more resilient future, resources such as this Coastal Resilience Assessment can equip decision-makers and stakeholders with valuable tools and information to help them better plan for future flood and storm events. The CNMI Coastal Resilience Assessment provides a framework for a holistic approach that considers both human community resilience and the natural environment.

1.2 Overview of the Regional Coastal Resilience Assessments

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

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

Figure 1. The geographic extent of the Regional Coastal Resilience Assessments in dark gray and the study area within the Northern Mariana Islands Assessment in orange. All Regional Assessments will be completed by 2021. Map not shown to scale.

Strategically implementing resilience projects can increase the ability of surrounding communities and habitats to withstand and recover from the impacts of coastal storms and flooding events (Narayan et al. 2017). Efforts to build resilience begin by determining the exposure of a community's assets to a hazard or threat. The Regional Assessments use a Geographic Information System (GIS)-based approach to model landscape characteristics and their potential impacts in order to identify places throughout the United States where assets are potentially exposed to flood threats. They combine human community assets, flooding threats, and fish and wildlife resource spatial data in order to identify and rank Resilience Hubs. Resilience Hubs are large areas of natural, open space or habitat where, if investments are made in conservation or restoration, there is potential for improved human community resilience and benefits to habitats and species.

From a modeling standpoint, the Regional Assessments consist of three separate but interrelated analyses: (1) the Community Exposure Index, (2) the Fish and Wildlife Index[1], and (3) the Resilience Hubs (Figure 2). These three components make these Assessments unique as they look at resilience potential through the lens of both human communities and the natural environment. Specifically, the Community Exposure Index can guide land use and hazard mitigation planners in identifying potential development constraints and improve the understanding of potential risks to critical infrastructure and human populations. The Fish and Wildlife Index identifies natural resources and can be used to inform where on the landscape important species and habitats occur. For the purposes of the CNMI Assessment, the index is referred to as the Fish and Wildlife Index throughout, but is synonymous to a natural resource index that considers species and habitat. The Resilience Hubs then identify open spaces and habitat where the implementation of restoration and conservation projects have potential to increase a community's resilience to flood events while also benefiting species and habitats.

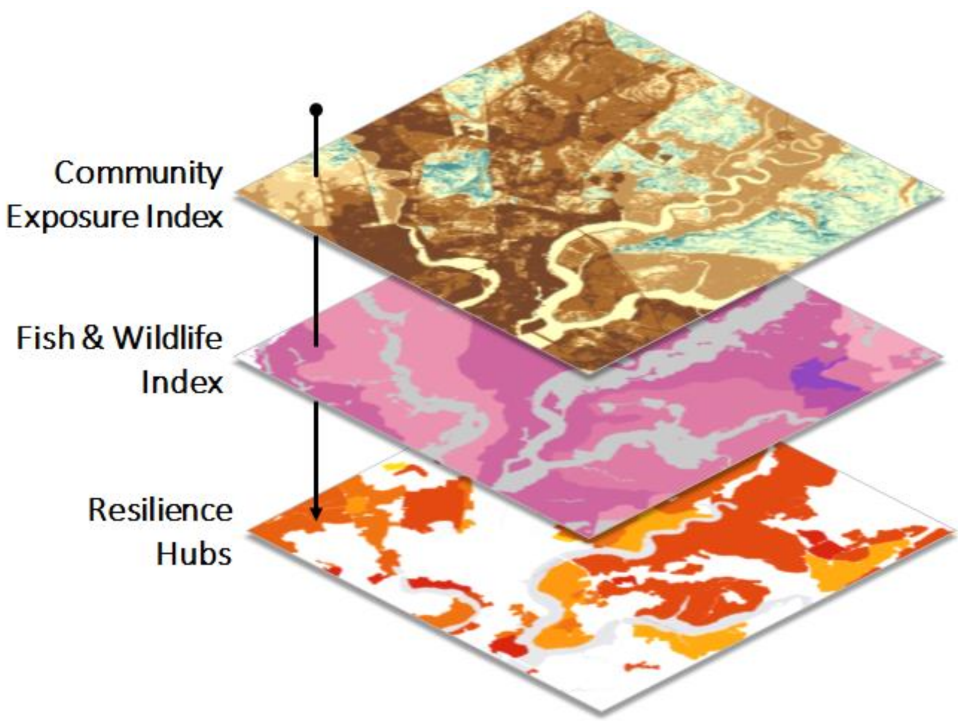


Figure 2. A conceptual model showing the separate, but interrelated components of the Regional Coastal Resilience Assessments.

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

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[1] The term "Fish and Wildlife Index" is used for consistency across all Regional Coastal Resilience Assessments, but can be considered as synonymous with a natural resource index.

METHODS

2.1 Introduction

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

The following sections provide a brief overview of the methods used in the CNMI Coastal Resilience Assessment (or CNMI Assessment). For more details about overarching methodology and data sources common across all Regional Coastal Resilience Assessments, please refer to Dobson et al. (2020). To the extent possible, the Regional Assessments aim to use the same methodology and data across all regions. However, given the unique geographic characteristics of each region and the fact that data availability varies, some regionally-specific modifications were required. Given the small geographic scale of CNMI, the Advisory Committee recommended that all GIS modeling be completed at a 3-meter resolution to best match the resolution common to the input data (with the exception of elevation data, which were only available at 10-meter resolution at the time of modeling, but are expected to be updated to a 3-meter resolution in the future). The following sections briefly discuss pertinent methodological changes to the Community Exposure Index, Fish and Wildlife Index, and Resilience Hubs for CNMI.

2.2 Study Area

The CNMI Assessment focuses on the three main inhabited islands of Saipan, Tinian, and Rota and does not include the many other smaller and sparsely populated or uninhabited islands of the Northern Marianas. The study area extends offshore as far as the 30-meter depth contour or boundary (Figure 3). As described below, the 30-meter depth boundary was used for the Fish and Wildlife Index to allow for the inclusion of marine habitats with potential to host significant biodiversity. Based on the recommendation of technical experts, however, the Resilience Hubs analysis only considered habitats less than 10 meters in depth since shallow water habitats are expected to provide greater coastal protection benefits through the implementation of nature-based solutions.

Saipan, Tinian, and Rota together encompass a total land area of 305 square kilometers and are part of the larger Mariana Islands Archipelago. Saipan is the largest of the three main islands, with a land area of 119 square kilometers and 97 kilometers of coastline, approximately 23 kilometers of which consist of natural beaches. Just to the south of Saipan is the island of Tinian, which contains a land area of 101 square kilometers and has 61 kilometers of coastline. Further south and west of Saipan and Tinian is the island of Rota, which contains a land area of 85 kilometers and has 62 kilometers of coastline. According to the 2010 Census, Saipan, Rota, and Tinian had a combined population of 53,883, with well over 50 percent of the population residing on Saipan, which is densely populated with approximately 453 people per square kilometer (Liske-Clark 2015).

This Assessment is unique in that it not only takes into account the immediate coastline, as many other studies have done, but it also focuses on inland areas that can often directly contribute to coastal flood-related issues. For instance, intense rain that can drain directly to the coast can exacerbate coastal flooding. In all regions, the boundary of the Assessments follow the U.S. Environmental Protection Agency's (EPA) designated coastal watersheds, which are watersheds that drain directly to the ocean and are represented at a hydrologic unit code eight scale (HUC-8)[2]. In the Northern Mariana Islands, the HUC-8 watersheds cover all of the islands and thus the study area also covers the entirety of each island (Figure 3).

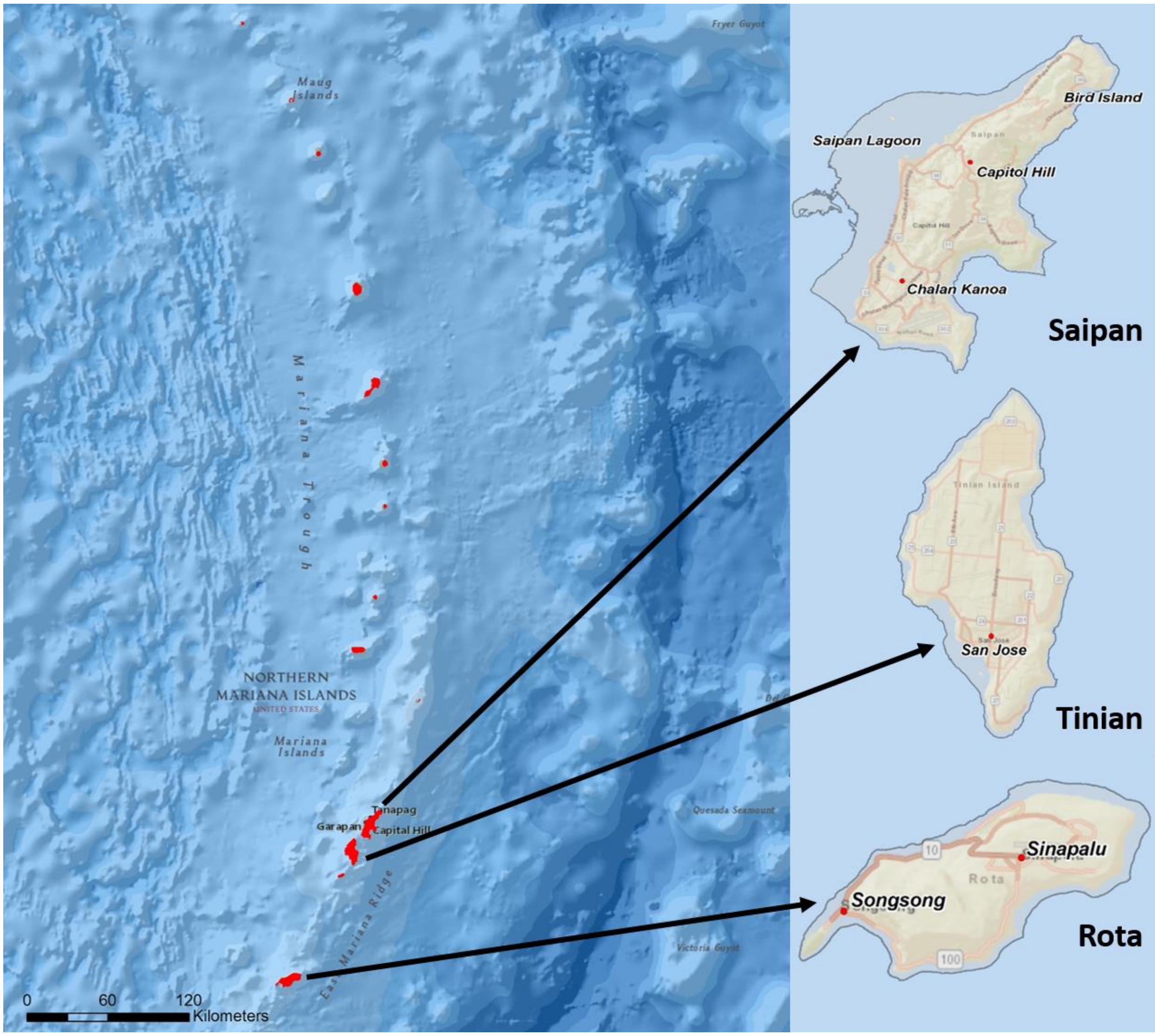

Figure 3. The Northern Mariana Islands (left) and the study areas for the CNMI Coastal Resilience Assessment, including all coastal and inland areas of Saipan, Tinian, and Rota (right). The 30-meter depth boundary is shown in black. Island maps on the right not shown to scale.

2.3 Data Collection and Stakeholder Engagement

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

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

To help guide the Assessment process, the Project Team established an Advisory Committee consisting of nine local and regional members representing NOAA, the U.S. Fish and Wildlife Service, the CNMI Department of Lands and Natural Resources, the CNMI Bureau of Environmental and Coastal Quality, the CNMI Division of Fish and Wildlife, the CNMI Office of Planning and Development, and the Pacific Islands Ocean Observing System. The Advisory Committee met regularly with the Project Team to:

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

With input from the Advisory Committee and building on initial data collection, the Project Team coordinated with the CNMI Office of Planning and Development (OPD) and the NOAA Office for Coastal Management to host a workshop in order to allow local stakeholders to review and provide input on preliminary CNMI Assessment products. The Stakeholder Workshop was held in Saipan on November 20, 2019 in conjunction with the third annual Marianas Terrestrial Conference and Workshop. Over 20 people attended the workshop, which was hosted and facilitated locally by OPD and NOAA; the Project Team attended the workshop virtually. The workshop attendees helped the Project Team:

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

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

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

2.4 Creating the Community Exposure Index

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

Threat Index × Community Asset Index = Community Exposure Index

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

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

2.4.1 Threat Index

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

At the time of this analysis, sea level rise scenarios were only available for Saipan and were only incorporated as such. Additionally, storm surge, which is typically a Threat Index input used in other Regional Assessments, was also unavailable for the Northern Mariana Islands at the time of modeling. An additional input—wave-driven flooding—was included to serve as a proxy for storm surge (see Appendix B.1 for details). For this input, the analysis utilized data from Storlazzi et al. (2019). These models used significant wave heights associated with the 10-, 50-, 100-, and 500-year storm return periods and inundation was modeled based on the presence or absence of coral reefs. For the purposes of this analysis, inundation models in the presence of coral reefs were used. Additional details on those data used to create the Threat Index for CNMI can be found in Appendix A.1 and Appendix B.

2.4.2 Community Asset Index

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

In CNMI, the Community Asset Index included population density, social vulnerability, and the full complement of critical facilities and infrastructure detailed in the Methodology and Data Report

(Dobson et al. 2020). It was of utmost importance to include locally available data whenever possible. Therefore, based on feedback from the stakeholder workshop and Advisory Committee, additional infrastructure types such as communication infrastructure and sources of potable water were included due to their importance in responding to storm and flood events on remote islands. In addition, the analysis included cultural heritage sensitivity areas and historic sites in the Northern Mariana Islands. Although these sites may not directly assist in responding to flood events, their importance to local communities, as well any economic value they may hold, were considered justification for including them as a type of Critical Infrastructure. The following types of critical infrastructure were included in the CNMI Assessment:

- Primary roads
- Airports
- Ports
- Wastewater Treatment Facilities, Potable Water Facilities and Sources
- Petroleum Terminals
- Hazardous Sites
- Power Plants & Substations
- Cultural, Historic, and Sensitive Sites
- Communication Infrastructure

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

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

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

2.5 Creating the Fish and Wildlife Index

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

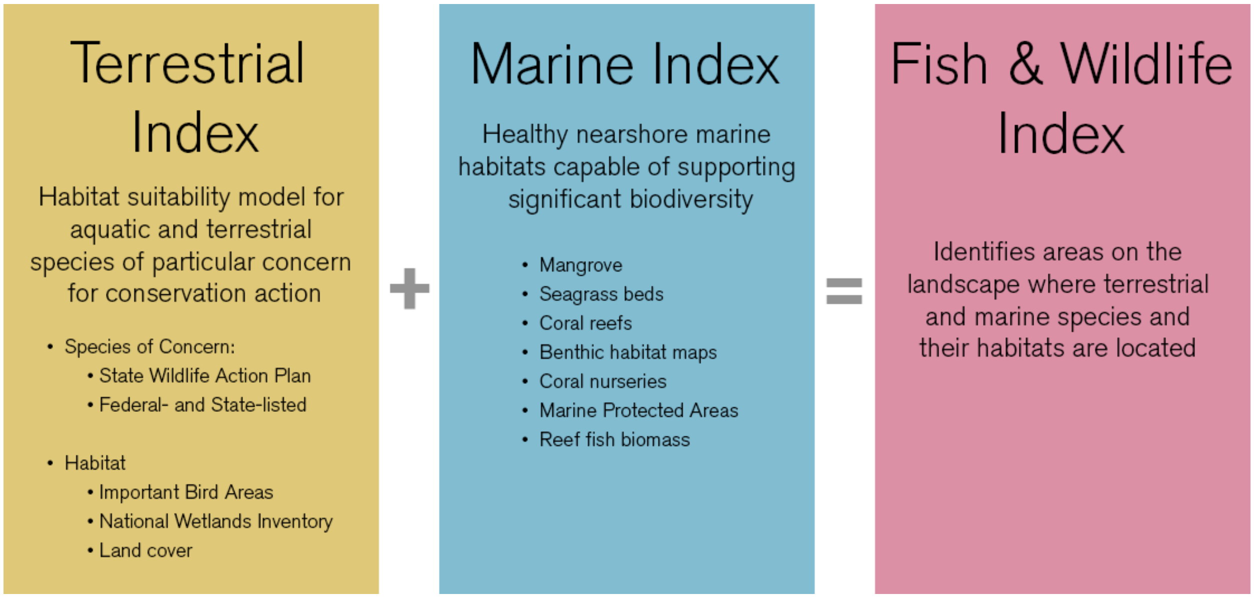

Figure 5. Elements of the Terrestrial and Marine Indices used to create the Fish and Wildlife Index.

2.5.1 Terrestrial Index

The Terrestrial Index aims to identify suitable habitats for major taxonomic groups using available land cover and habitat data. The Index is created relative to the habitat preferences and needs of the species of greatest conservation concern in the region, which were identified using the 2015-2025 State Wildlife Action Plan for the Commonwealth of the Northern Mariana Islands (Liske-Clark 2015) and species listed as threatened or endangered under the Endangered Species Act. Broad taxonomic groupings were used to model species' habitat preferences throughout the region including:

- Birds
- Reptiles
- Terrestrial Mammals

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

In addition to using NOAA Coastal Change Analysis Program land cover, U.S. Fish and Wildlife Service's National Wetlands Inventory, and USGS National Hydrography Dataset to identify habitat types, the analysis utilized the 2016 USFS Vegetation Dataset. BirdLife International Important Bird Areas (IBAs) were also included. A complete list of datasets and methods used to create the CNMI Terrestrial Index can be found in Appendix A.3 and Appendix E.1, respectively.

2.5.2 Marine Index

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

Benthic habitat maps, extending to a 30-meter depth bathymetry boundary around all islands, were used to define the spatial extent of coral reef and seagrass habitat. These data were also used to evaluate the percent cover of seagrass patches, where more species are assumed to occupy thicker patches (McCloskey & Unsworth 2015). To assess coral condition, estimates of live coral cover were obtained from NOAA's National Coral Reef Monitoring Program (NCRMP), which regularly implements stratified random sample surveys throughout the CNMI. Based on combined survey years 2011, 2014, and 2017, areas with higher coral cover—and thus more likely to support higher numbers of reef associated species (Komyakova et al. 2013)—were ranked higher. As a result of older mapped benthic habitat data, it was recommended that the survey data be used at the sector-level broken into three depth categories, known as the strata-level, using bathymetry (Tom Oliver, NOAA, personal communication). The coral cover data were pooled for each strata and then ranked across the islands. The three depth levels are as follows: shallow (0-6 meters), mid-depth (>6-18 meters), and deep (>18-30 meters). See Appendix E.2 for details about this data input. Data on mangrove extent were also incorporated using a presence/absence scoring to indicate their potential capability for supporting higher species richness (unlike other regions [see Dobson et al. 2020], data related to mangrove health were unavailable for the CNMI).

In addition to the spatial extent and condition of these habitat types, the Marine Index calls upon a number of additional datasets including the presence of coral nurseries and Marine Protected Areas. There are no designated Habitat Areas of Particular Concern in CNMI and the only designated Essential Fish Habitat is the Mariana Islands Coral Reef Ecosystem, the extent of which covers the entirety of the boundary set at the 30-meter depth. Therefore, these NOAA datasets were not incorporated into the CNMI Assessment. Instead, to incorporate some variability while still accounting for the presence of important reef fishes, NCRMP reef fish biomass surveys for the year of 2017 were incorporated at the sector-level. A complete list of datasets and methods used to create the CNMI Marine Index can be found in Appendix A.4 and Appendix E.2.

2.6 Creating the Resilience Hubs

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

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

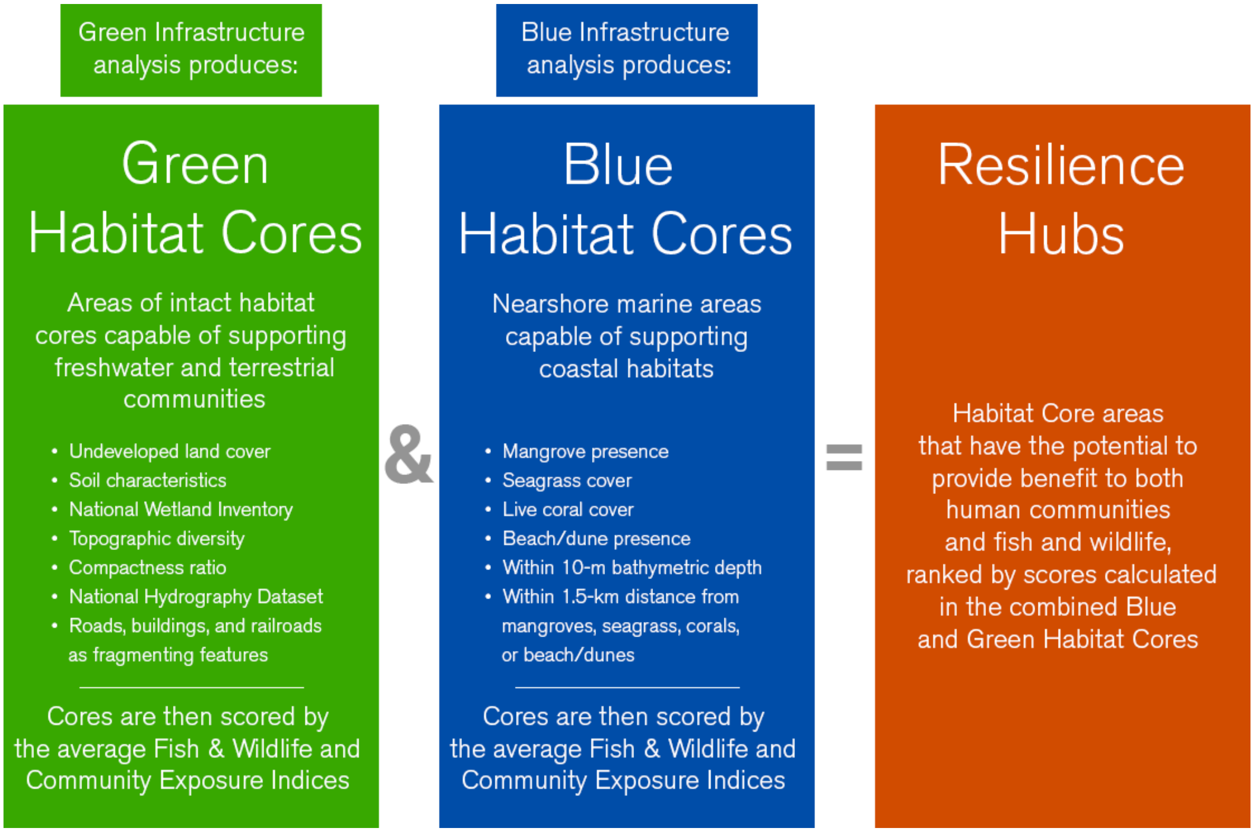

Figure 6. Elements of the Green and Blue Habitat Core outputs used to create the Resilience Hubs.

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

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

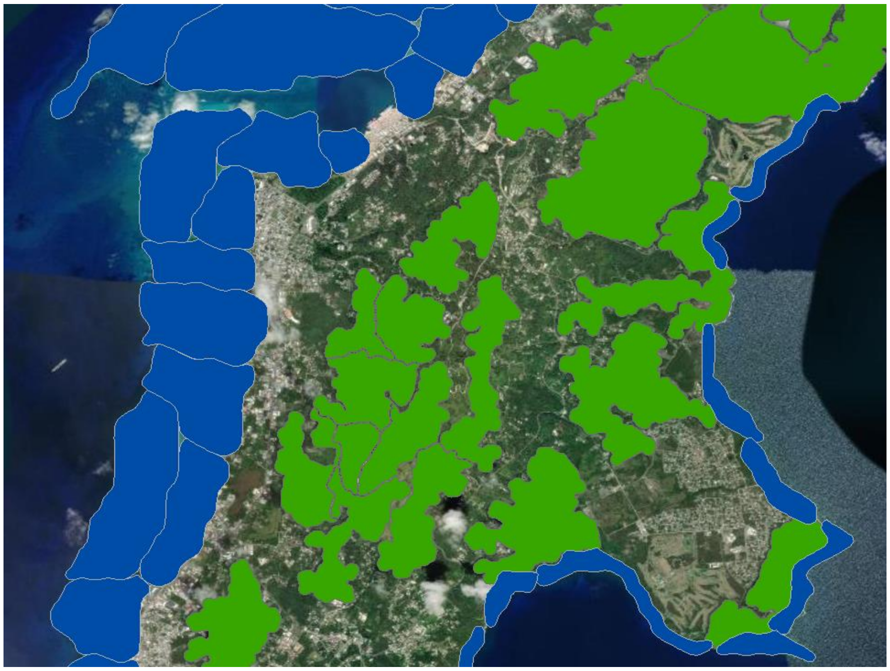

Figure 9. Final Green and Blue Habitat Cores. The Blue Habitat hexagons are grouped into Habitat Cores by bathymetric basin. The Green and Blue Cores are then ranked to become Resilience Hubs

2.6.1 Green Infrastructure

The Green Infrastructure[3] analysis used in the Regional Assessments builds upon methodology developed by the Green Infrastructure Center for the continental United States (Firehock & Walker 2019). Since these data were not available for CNMI, NEMAC replicated the analysis to create this important layer for the CNMI Assessment. The analysis identifies "intact habitat cores," or every natural area 40.5 hectares (100 acres) or greater, regardless of ownership or preservation status. The dataset is intended to guide local, regional, and urban planners in identifying important places to conserve prior to planning development projects. The dataset also helps to prioritize which landscapes to protect and connect—such as natural systems that mitigate flooding, provide recreational opportunities, and benefit air and water quality (Firehock & Walker 2019). Habitat cores also represent relatively intact habitat that is of a sufficient size to support more than one individual of a species and takes into account fragmenting features that may disrupt the movement of wildlife species.

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

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

2.6.2 Blue Infrastructure

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

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

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

when implemented in shallow water habitats. For full documentation on how the Blue Habitat Cores were created, please refer to Appendix F and Dobson et al. (2020).

2.6.3 Combining Habitat Cores and Ranking Resilience Hubs

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

RESULTS

The CNMI Coastal Resilience Assessment reveals abundant opportunities to use nature-based solutions to help build human community resilience while supporting important species and habitats. Nature-based solutions include actions that sustainably manage and utilize natural systems to address societal challenges such stormwater management, urban flooding, and heat islands while benefiting biodiversity and human well-being. Implementing nature-based solutions, such as coral reef or wetland restoration, can provide tremendous co-benefits to people and wildlife as described in the case study presented below (see Section 4).

The Community Exposure Index values show that areas of high exposure are distributed across both Saipan and Tinian, particularly in the immediate coastal areas and on the southern half of Saipan. In contrast, Rota revealed fewer areas with high exposure to flood threats due to the presence of fewer community assets. The CNMI Assessment also identified numerous areas with high Fish and Wildlife Index values, especially along the coastlines of all three islands. When the Community Exposure and Fish and Wildlife Indices were combined, the resulting Resilience Hubs demonstrated that there are high ranking Hubs throughout both coastal and inland areas of the Northern Mariana Islands.

3.1 Community Exposure Index

As expected, Community Exposure Index values varied substantially between the three islands analyzed. For the purposes of this report, the results for Saipan, Tinian, and Rota are described separately; however, a single model was used for all three islands, which allows results to be directly compared within and among islands.

Given that Saipan is the most populous of the three islands, it is unsurprising that it also features the highest exposure values in the CNMI Assessment. Areas of high exposure are found primarily along the immediate coastline and across the southern half of the island, which is primarily the result of the dense populations and considerable concentrations of critical facilities and infrastructure in these areas (Figure 10). In addition, these populated areas are also exposed to numerous flood related threats including impermeable soils and a concentration of flood-prone areas, which contribute to high Threat Index values (Figure 10).

Tinian is the second most populated island in the Northern Mariana Islands, the northern portion of which is under a military lease pursuant to the CNMI Covenant[5]. The majority of the medium to high exposure values on Tinian are found around the village of San Jose and Tinian Harbor, including the Tinian International Airport (Figure 10); however, several areas of high exposure are also evident on military-leased property to the north, which also contains the only lake on Tinian, Lake Hagoi. The higher values observed in the Threat Index are primarily the result of the low-lying areas, impermeable soils, and flood-prone area inputs.

As the least populated island analyzed in the CNMI Assessment, Rota also features some of the lowest exposure values. The highest exposure values are found around the towns of Sinapalo in east central Rota and Songsong on the far western portion of the island (Figure 10). Given the relatively low values observed in the Threat Index, concentrated areas of high exposure are primarily driven by the Community Asset Index.

[5] Article 8, section 802, http://cnmilaw.org/cov.php#gsc.tab=0

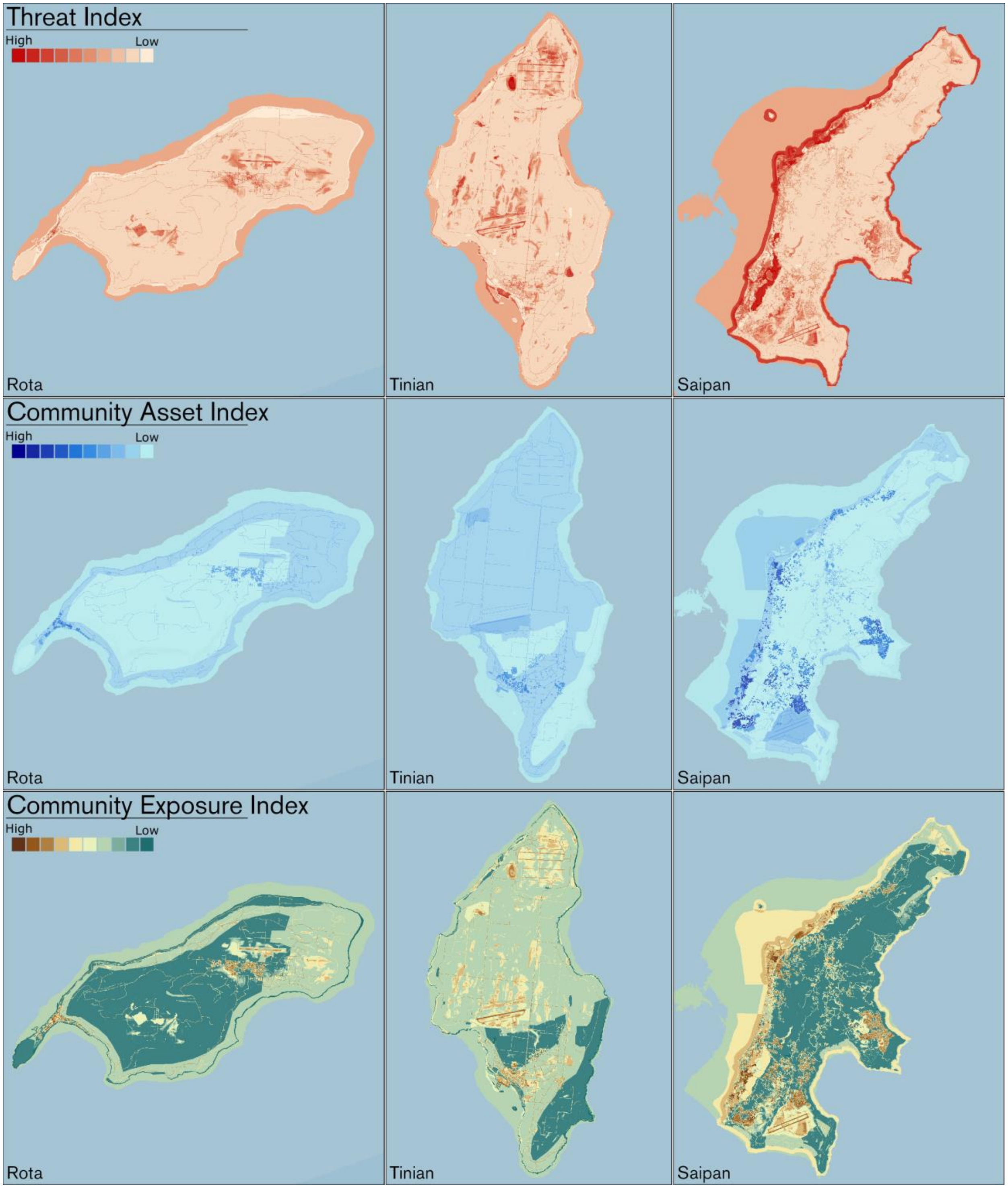

Figure 10. Threat, Community Asset, and Community Exposure Indices for the islands of Saipan (top panel), Tinian (middle panel), and Rota (bottom panel). The Threat and Community Asset Indices are multiplied to produce the Community Exposure Index, which shows areas where assets overlap flood threats.

While the whole-island results are helpful to identify areas with high exposure values, due to the resolution of the CNMI Assessment, results can also be viewed at a community scale to inform more localized decision-making. For instance, the villages around Chalan Kanoa on the southern end of Saipan scored highly in the Community Exposure Index (Figure 10). When zoomed into the areas surrounding Chalan Kanoa (Figure 11), the Assessment results reveal very high Threat Index scores on the western portion of the island, particularly around Lake Susupe and the surrounding marshes. This area features flood-prone and low-lying areas in addition to impermeable soils capable of retaining water. The presence of impervious surfaces in the communities surrounding Lake Susupe further contributes to the high Threat Index values. However, despite high Threat Index scores, since the lake and marsh do not contain any community assets, this area does not have a very high Community Exposure Index value (Figure 11). Instead, the towns and villages surrounding Lake Susupe show areas of high exposure due to the confluence of dense community assets and moderate to high flood threats. To explore the results of the analysis in more detail for any area of interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to [Section 3.4](#).

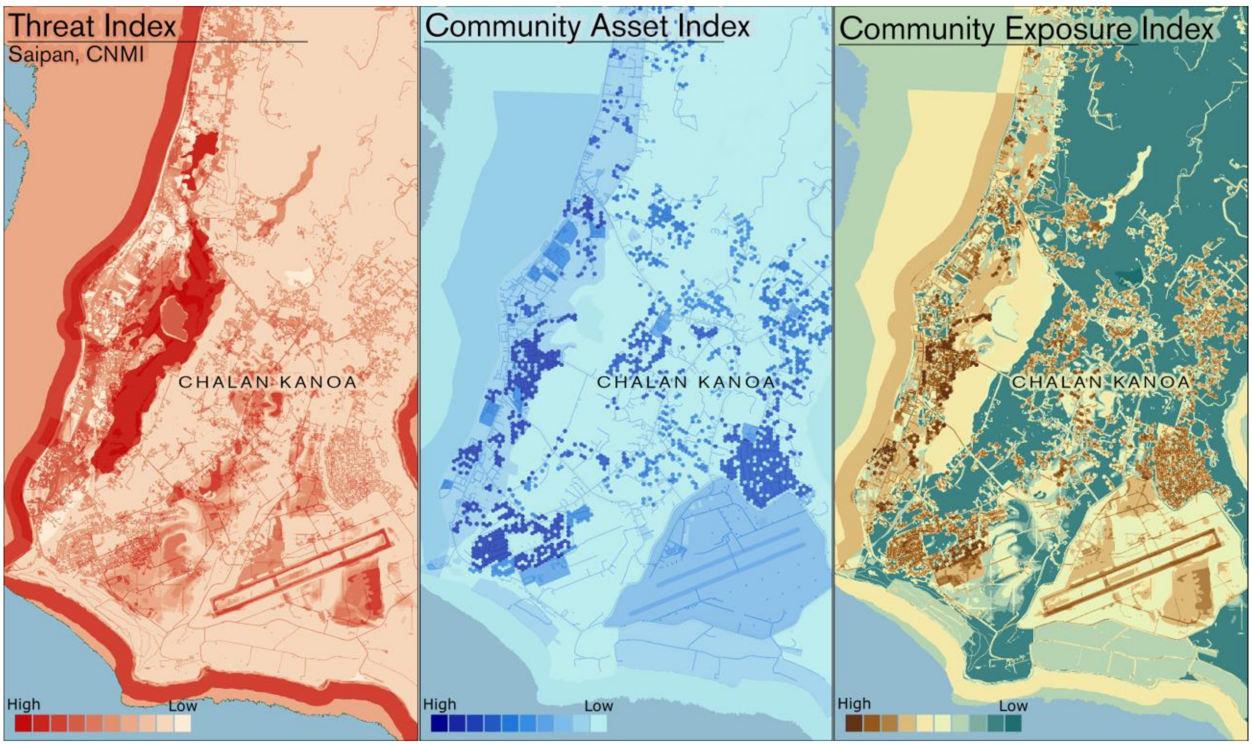

Figure 11. The area in and around Chalan Kanoa shows higher values of exposure, resulting from the combination of flood threats and community assets.

3.2 Fish and Wildlife Index

The combined Fish and Wildlife Index shows that areas expected to support numerous species and habitat types considered in the CNMI Assessment are fairly concentrated along the coastlines of all three islands, although there are also numerous inland areas that received high Fish and Wildlife Index values (Figures 12-15). The high values observed along the coastlines are partially driven by the prevalence of coral reef ecosystems on all three islands. While mangroves and seagrasses are present within the study area, they are not widely distributed, leaving live coral cover, reef fish biomass, and the presence of marine protected areas to significantly contribute to the Marine Index values.

As noted in the Methods section, the Terrestrial Index evaluated habitat suitability across taxonomic groups. Based on the species listed in the CNMI Wildlife Action Plan, birds and reptiles dominated the Terrestrial Index. The Terrestrial Index clearly shows higher concentrations of wildlife assets along the coastlines due to the importance of coastal habitats for reptiles (i.e., green and hawksbill sea turtles that nest on sandy beaches) and sea birds (i.e., great frigatebird which rely on coastal sandy, rocky, and other nearshore subtidal habitats)(Figures 12-15). Several areas in the interior of each island also received higher values in the Terrestrial Index, particularly in Rota where there are large areas of designated critical habitat, IBAs, and protected areas managed for biodiversity. For a complete list of species referenced for this analysis, see Appendix E.1.

When combined into the Fish and Wildlife Index, the patterns evident in the Marine and Terrestrial Indices remain prevalent. As may be expected, the Saipan Lagoon shows some of the highest Fish and Wildlife scores in the CNMI Assessment. However, there are significant fish and wildlife assets throughout the islands, indicating there are ample opportunities for habitat conservation and restoration projects to support enhanced resiliency outcomes.

On the island of Saipan, many of the highest Fish and Wildlife values are found along the coast, particularly within the shallow waters of the Saipan Lagoon along the west coast of the island (Figure 12). Due to the presence of several marine protected areas on the eastern coast coupled with high Terrestrial Index scores, there are also several high scoring areas on the eastern shore of the island, including Laolao Bay and Bird Island. Inland, medium to high Fish and Wildlife values are also observed in the marshes surrounding Lake Susupe near Chalan Kanoa and the forests north of the Capitol Hill area.

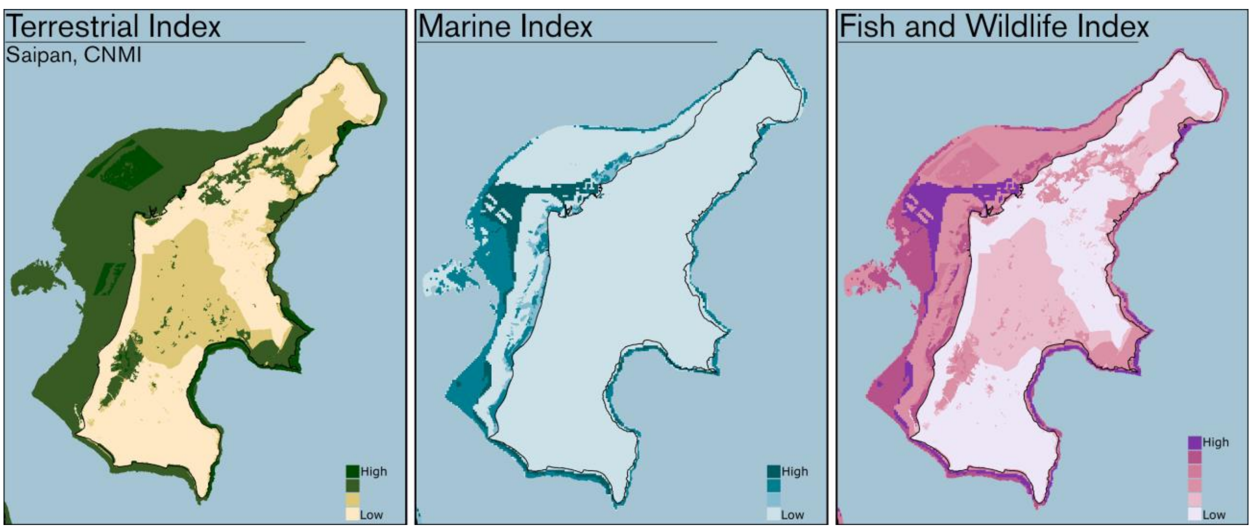

Figure 12. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for the island of Saipan.

On Tinian, the highest Fish and Wildlife values are all observed offshore, as a result of high Marine Index values associated with high coral cover and reef fish biomass (Figure 13). In addition, the high Terrestrial Index values along the coast are largely due to the presence of critical habitat for sea turtles, protected areas managed for biodiversity, and Important Bird Areas. The predominance of high values on the coastlines of Tinian is particularly evident in the waters offshore of San Jose, which includes some of the highest values on the island for both the Marine and Terrestrial Indices. By examining the San Jose area more closely (Figure 14), several factors contribute to the high values observed in this area. First, the CNMI Division of Fish and Wildlife manages a Marine Conservation Area that includes healthy coral reefs featuring high live coral cover and reef fish biomass. In addition, the sandy beaches along the coast provide important nesting habitat for green sea turtles and nearly the entire island is considered an

Important Bird Area by BirdLife International[6]. To explore the results of the analysis in more detail for any area of interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4.

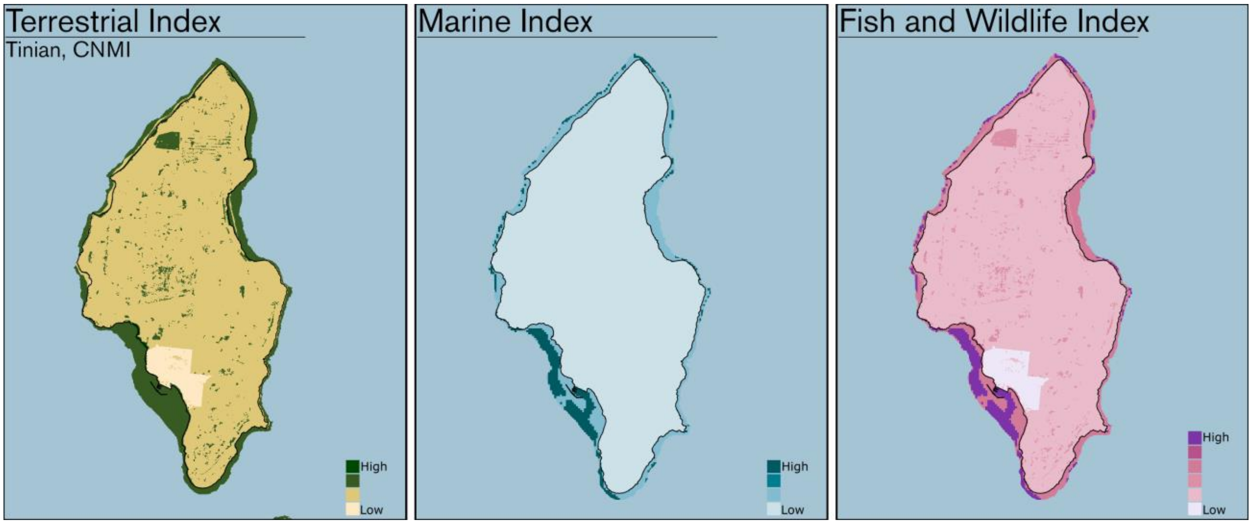

Figure 13. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for the island of Tinian.

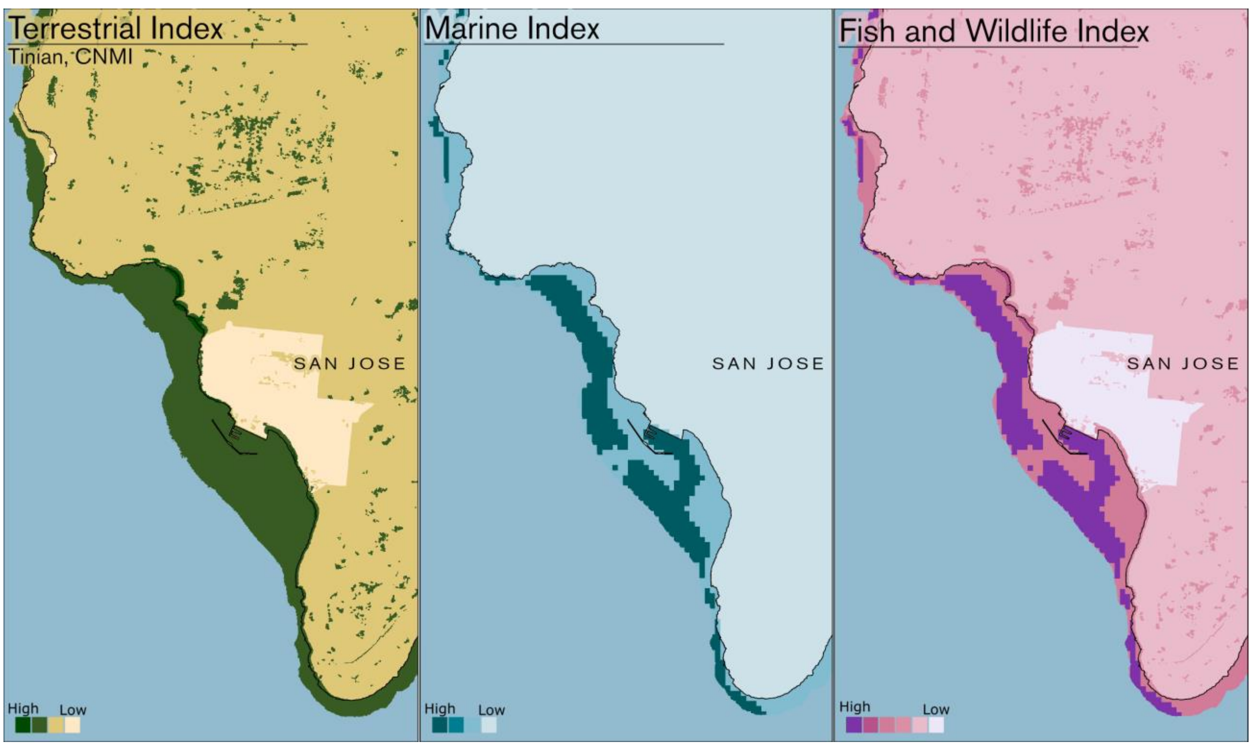

Figure 14. The southwestern portion of Tinian near San Jose is high in both the Terrestrial and Marine Indices, resulting in moderate to high values in the Fish and Wildlife Index. This is a result of a combination of the presence of several important marine and coastal habitats utilized by both marine and terrestrial species.

[6] For details about the Important Bird Area, see: http://datazone.birdlife.org/site/factsheet/tinian-island-iba-northern-mariana-islands-(to-usa).

Unlike the other islands, the Terrestrial Index scores on Rota strongly influence the resulting Fish and Wildlife Index values (Figure 15). While the presence of coral reefs and seagrass habitat reveal areas with higher scores offshore, much of the inland areas of Rota also received high values due to the presence of designated critical habitat for the Rota bridled white-eye and Mariana crow among other species. This is especially true in the rural areas between Sonsong and Sinapalu.

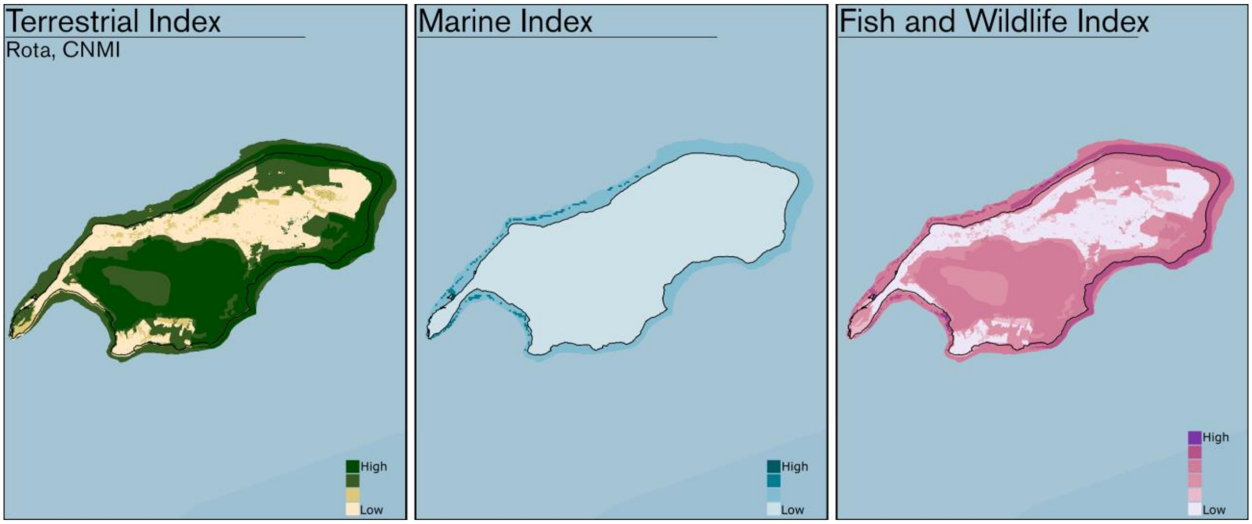

Figure 15. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for the island of Rota.

3.3 Resilience Hub Analysis

The analysis identified Resilience Hubs throughout each of the three main islands, as shown in Figures 16-18. Overall, Saipan appears to have more high-ranking Resilience Hubs as compared to Tinian and Rota. However, there are numerous high-ranking Hubs across all nearshore and inland areas indicating there are ample opportunities to implement nature-based solutions in CNMI to build human community resilience while benefiting fish and wildlife habitat and the species and ecosystem services they support.

The final Resilience Hub *rankings* are the product of the Community Exposure Index and Fish and Wildlife Index. As described in the Methods section above, the actual boundaries of the Resilience Hubs are formed through the Green and Blue Infrastructure analysis, which identifies Green and Blue Habitat Cores. The following maps show the ranked Blue and Green Habitat Cores and how they are combined to create the final Resilience Hub ranking for Saipan (Figure 16), Tinian (Figure 17), and Rota (Figure 18).

On Saipan, many of the higher-ranked Resilience Hubs are concentrated along the western coastline (Figure 16). This is in part due to the extensive presence of coral reef and seagrass habitat, which resulted in a large network of Blue Habitat Cores encompassing nearly the entire nearshore marine boundary (≤10 meter depth). Blue Habitat Cores found in nearshore areas also received a higher score if multiple habitat types are present in the same areas (within 1.5 kilometers). Since coral reefs and seagrass beds are frequently found in close proximity, this increased the Blue Habitat Core score due to the increased cumulative coastal protection benefits associated with the presence of multiple habitat types (Guannel et al. 2016). Areas with multiple habitat types in close proximity may offer opportunities to implement a suite of coordinated nature-based solutions to maximize the potential to protect surrounding coastal communities from storm and flood events (see the Case Study in Section 4). Numerous high ranking Resilience Hubs are also found inland, particularly near the Lake Susupe wetland complex, which not only scored highly in the Community Exposure and Fish and Wildlife Indices, but also features large tracts of continuous open space as demonstrated by the Green Habitat Cores.

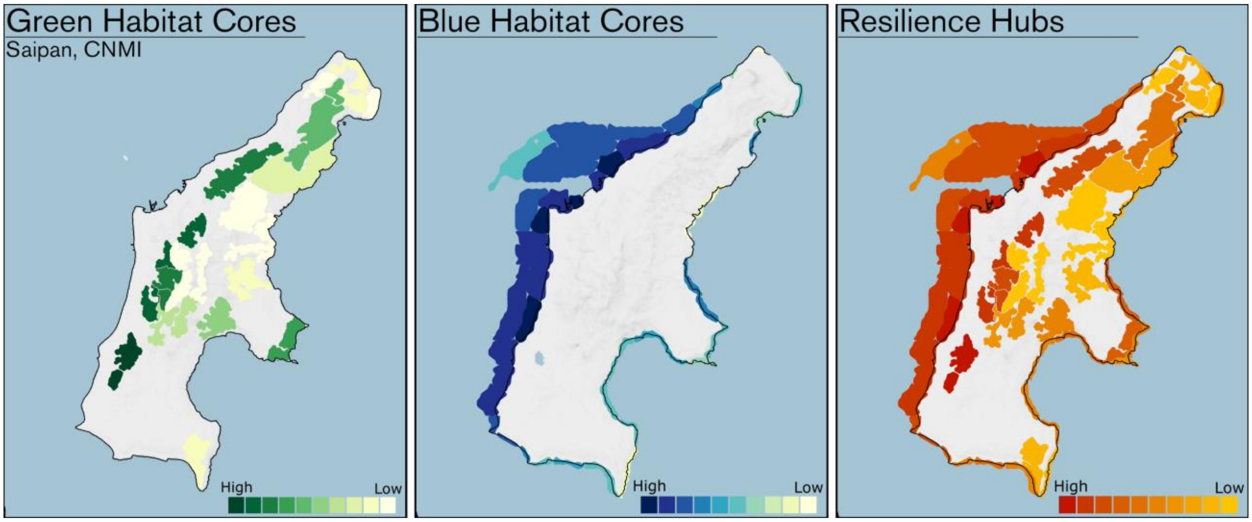

Figure 16. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for the island of Saipan. Darkest reds show areas with higher potential for resilience building efforts that offer dual benefits to both human and fish and wildlife communities.

On Tinian, the highest ranked Resilience Hubs are also found along the coastline (Figure 17); however, given the bathymetry of the nearshore areas and how quickly depths exceed 10 meters, the Blue Habitat Cores are relatively small in area compared to Saipan. There is a large concentration of inland Hubs on Tinian, although most Hubs received only moderate rankings. Overall, northern Tinian and the waters offshore of San Jose appear to have more opportunities to implement nature-based solutions. It is important to note, however, that the northern portion of Tinian is under a military lease, indicating that while there are large tracts of open space, siting and planning resilience projects in this area will require additional coordination.

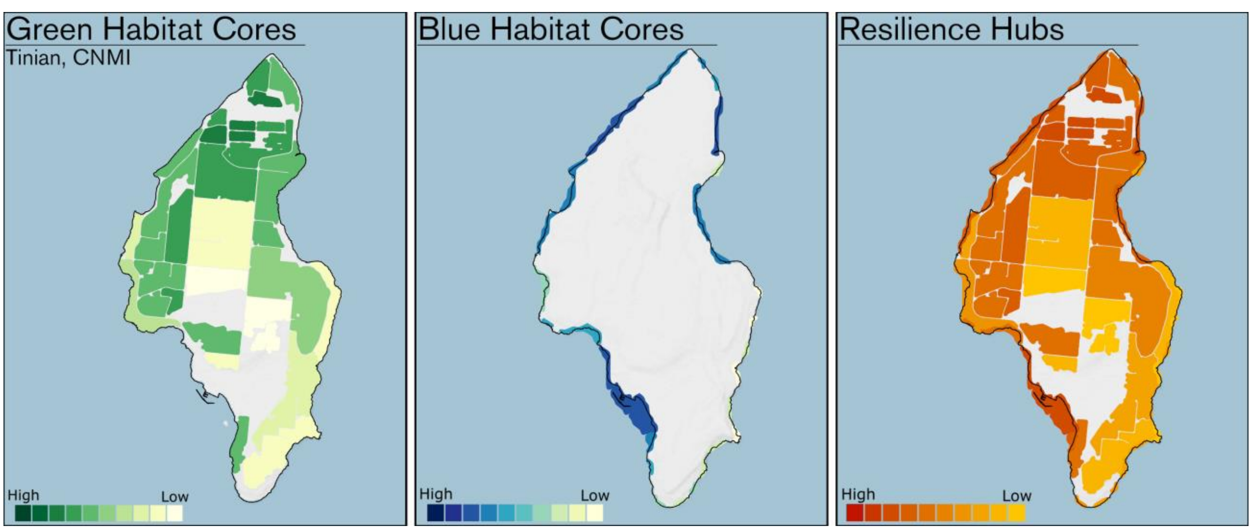

Figure 17. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for the island of Tinian. Darkest reds show areas with higher potential for resilience building efforts that offer dual benefits to both human and fish and wildlife communities.

Resilience Hubs cover nearly the entire island of Rota, with coastal areas along the north and inland areas to the southwest featuring some of the highest-ranked Hubs (Figure 18). Rota contains Green Habitat Cores with some of the highest Fish and Wildlife values among the three islands; however, due to the relatively small population, the Community Exposure Index values are generally low, resulting in relatively few high-ranking Hubs. While there are many natural and undeveloped areas on the island suggesting ample opportunities for wildlife conservation projects, due to the relatively low population, there are fewer high-ranking Hubs where dual human community and wildlife benefits can be achieved.

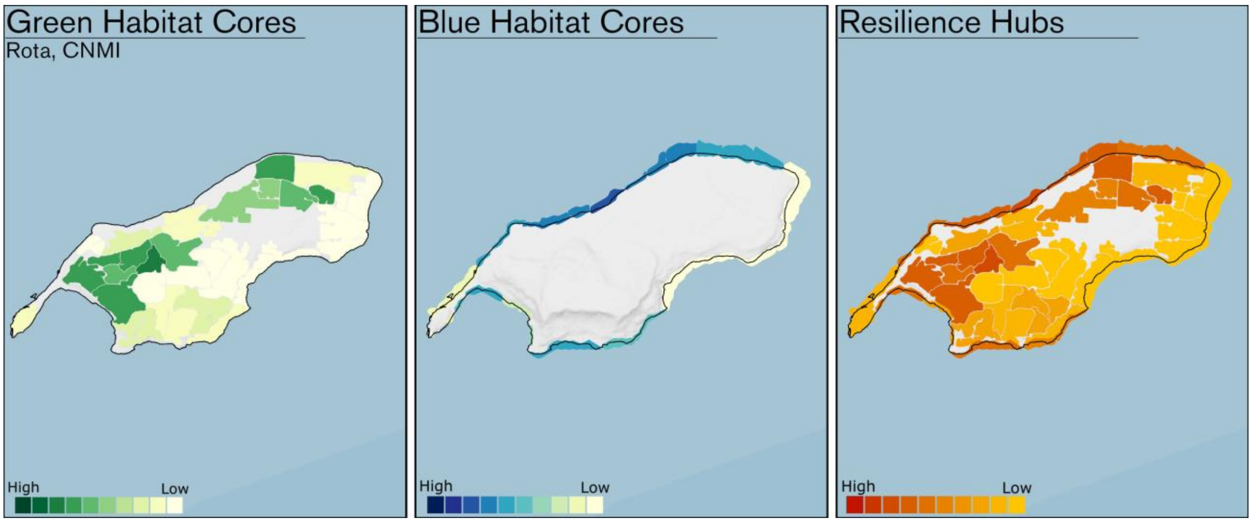

Figure 18. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for the island of Rota. Darkest reds show areas with higher potential for resilience building efforts that offer dual benefits to both human and fish and wildlife communities.

In and around the community of Songsong, there are a range of Resilience Hub scores (Figure 19). For instance, there are numerous nearshore marine and coastal sites that may be suitable for nature-based solutions, such as coral reef restoration. Further inland, there are additional sites that may be well suited for coastal forest conservation or restoration projects (darker shades of green or red in the Green Habitat Cores and Resilience Hubs maps, respectively). To explore the results of the analysis in more detail for any area of interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4.

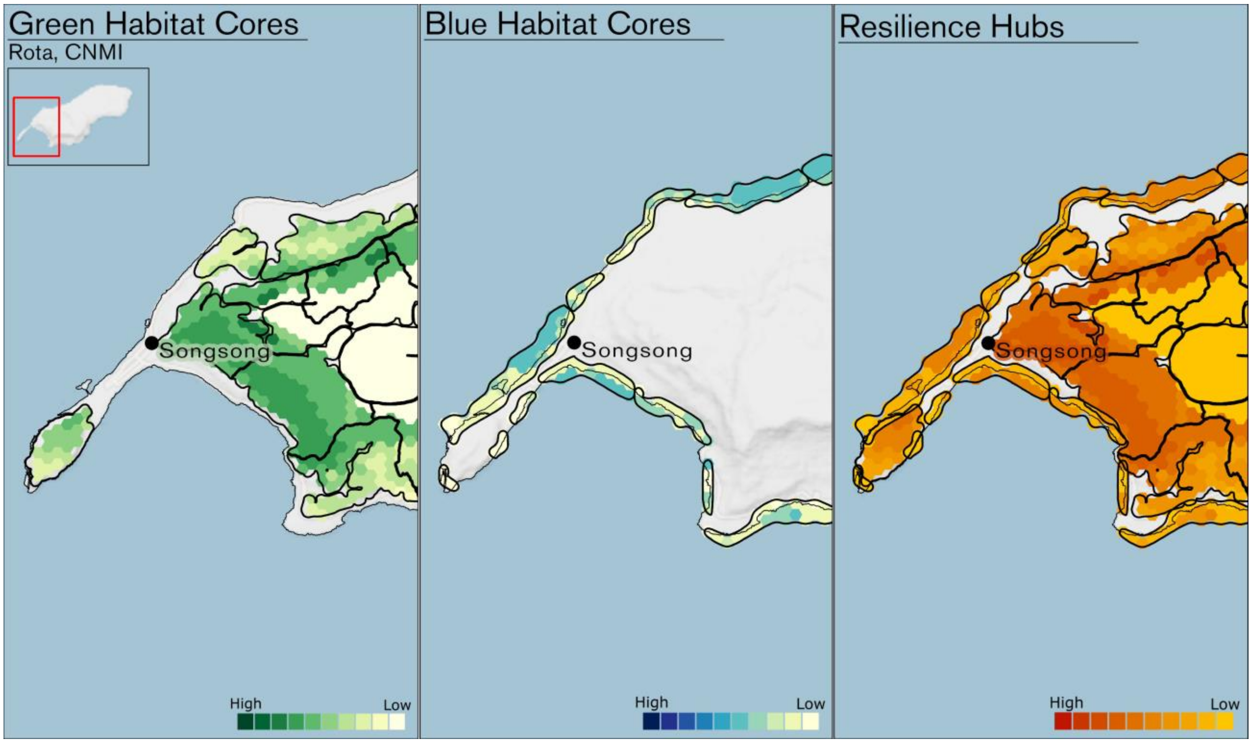

Figure 19. The area around Songsong in Rota shows a range of ranked Resilience Hub scores.

3.4 Coastal Resilience Evaluation and Siting Tool

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

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

CASE STUDY

4.1 Coastal Wetland and Coral Restoration to Build Local Resilience

Coastal wetland and coral reef ecosystems provide myriad benefits, from offering coastal protection to providing habitat for numerous endangered and economically important species. In the Northern Mariana Islands, coastal wetlands play a critical role in reducing the impacts of flooding and stormwater runoff. However, development has resulted in dramatic wetland habitat loss throughout CNMI, leaving just over 283 hectares of wetland habitat, most of which is impaired due to flow alterations and invasive species. Degraded wetland systems have a reduced ability to retain stormwater, which contributes to both flooding and poor water quality. In turn, poor water quality can compromise the health of nearshore coral reef ecosystems, reducing corals' ability to provide coastal protection and habitat benefits.

These interdependencies highlight the importance of considering a whole watershed approach that can utilize multiple natural ecosystems to maximize resilience outcomes. Ongoing efforts in the West Takpochao watershed in Saipan offer an excellent example of a multifaceted project designed to restore both wetlands and coral reefs to strengthen coastal resilience. With funding from the Emergency Coastal Resilience Fund[7] and other sources, the project will restore 1 hectare of coastal wetlands in the densely populated commercial and tourism hub of Garapan, and 0.4 hectare of coral reef habitat in the neighboring Saipan Lagoon (Figure 20). The project is being implemented through a coordinated effort among CNMI's natural resource agencies, including the Department of Lands and Natural Resources, Divisions of Fish and Wildlife and Forestry, the Bureau of Environmental and Coastal Quality's Divisions of Coastal Resources Management and Environmental Quality, and the Office of Planning and Development. The following description addresses ongoing restoration activities in the West Takpochao watershed, using the CNMI Assessment results to demonstrate the utility of various outputs to evaluate potential locations to site similar types of resilience efforts.

The West Takpochao watershed, including Garapan, is home to nearly 30 percent of Saipan's population. The area lacks sufficient infrastructure to convey runoff, leaving communities particularly susceptible to episodic flooding that degrades water quality and creates road hazards. In addition, the watershed was significantly impacted by recent typhoons, including Super Typhoon Yutu in 2018, which caused widespread flooding and significant damage. With much of the watershed less than 2.5 meters above mean sea level, communities are exposed to significant flooding threats. The results of the CNMI Assessment emphasize high exposure values around Garapan, including within the project location (Figure 21). These high exposure values are driven by significant concentrations of community assets coupled with flooding threats. For instance, Figure 22 shows the impact of sea level rise on the approximate project footprint and surrounding areas, highlighting one of the coastal flood-related threats impacting this region.

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[7] https://www.nfwf.org/programs/emergency-coastal-resilience-fund

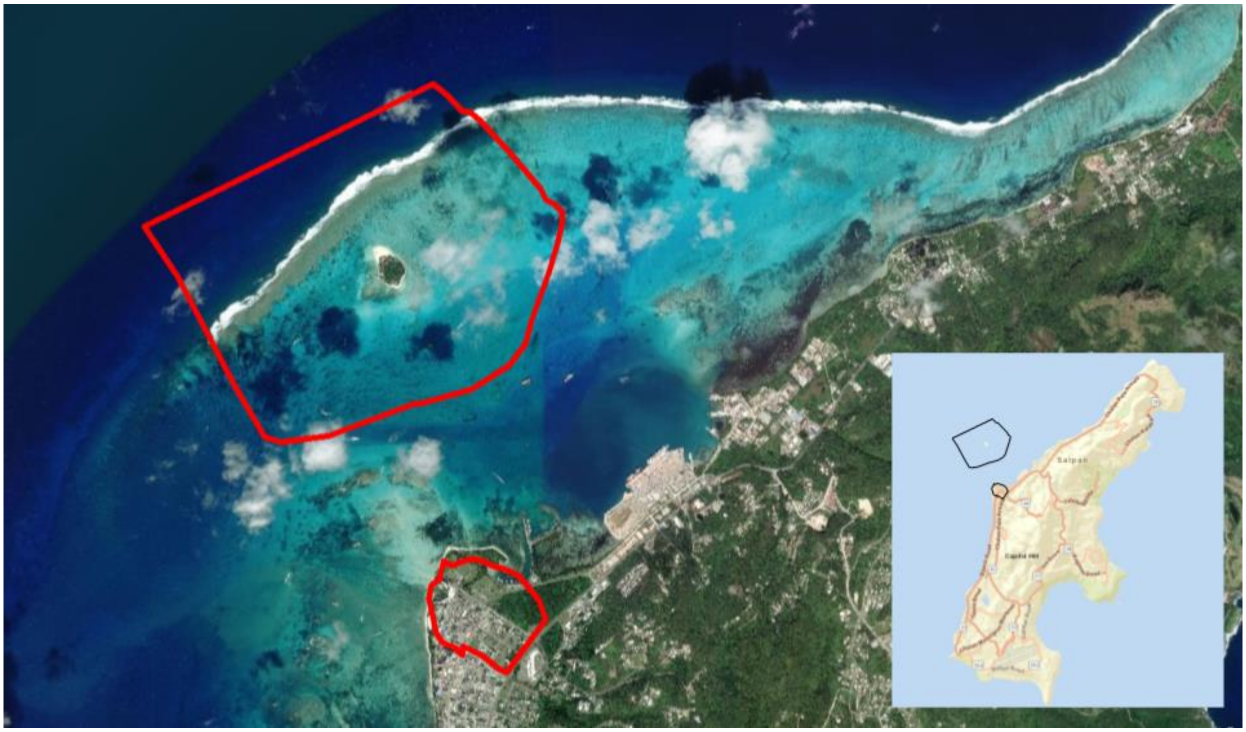

Figure 20. Map showing the general location of the wetland and coral reef restoration projects in the West Takpochao watershed and Saipan Lagoon on east-central Saipan.

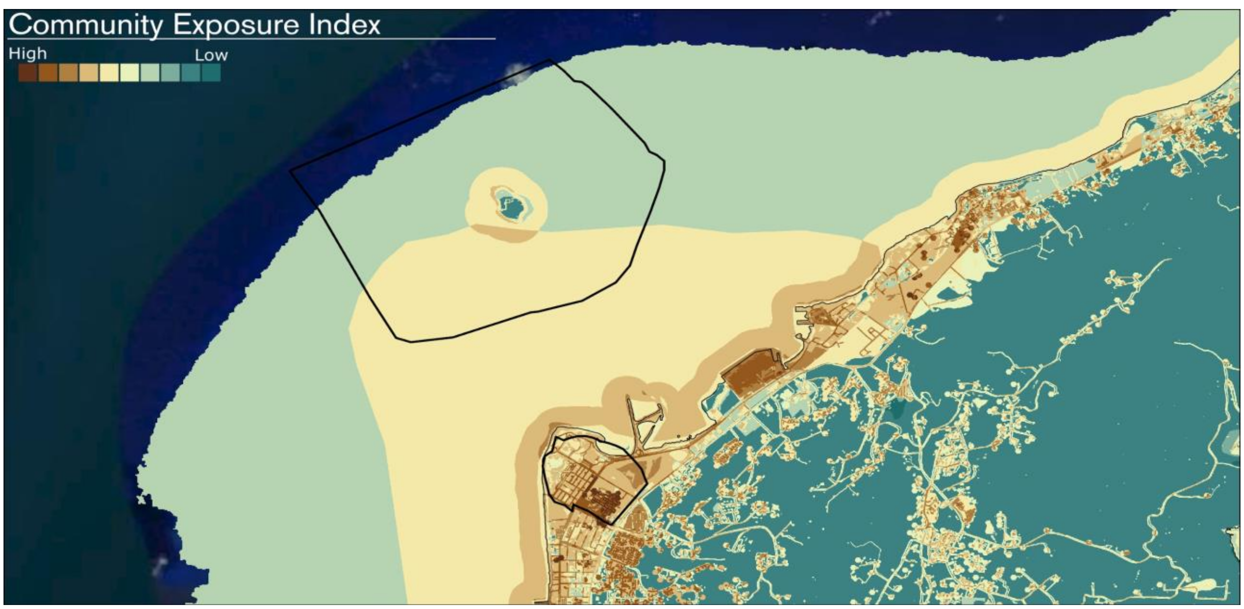

Figure 21. The Community Exposure Index results for the West Takpochao watershed, including Garapan. The black lines outline the wetland and coral restoration project locations. Many areas near the coast, including the wetland restoration sites in Garapan, exhibit higher amounts of exposure.

Figure 22. Wetland and coral reefs can help to minimize the impacts of flood threats such as sea level rise. Over time, sea level rise will exacerbate other flood-related threats.

The majority of the wetlands within the West Takpochao watershed are in poor condition. Altered hydrology and invasive species such as water hyacinth and pond apple reduce open water habitat and hinder the wetland's ability to store and convey water. As a result, during heavy rain events, the roads and properties adjacent to the wetlands frequently flood (Figure 23). In addition, as exotic plants reduce the amount of open water habitat (Figure 23), endangered species such as the Mariana common moorhen lose natural habitat. In response, the project will restore two wetlands in Garapan by removing invasive species and making important stormwater management improvements. Together, these efforts will provide flood control benefits to surrounding communities (Figure 24). Additionally, restoration will provide important wildlife habitat and contribute to improved water quality that can benefit nearshore coral reefs. In coordination with the Division of Forestry, the project will also establish a wetland plant nursery to grow native species and provide seed stock to restore both sites. By building the plant nursery, this project will provide capacity that can support future restoration efforts throughout Saipan.

Figure 23. Degraded wetlands in Garapan lead to flooding and open water habitat loss. Left: Flooding in the street behind the "MIHA" wetland after tropical storm Peipoh passes through Saipan in September 2019. Right: Invasive water hyacinth at the American Memorial Park wetland. Photos Credits: OPD (left), Erin Derrington (right).

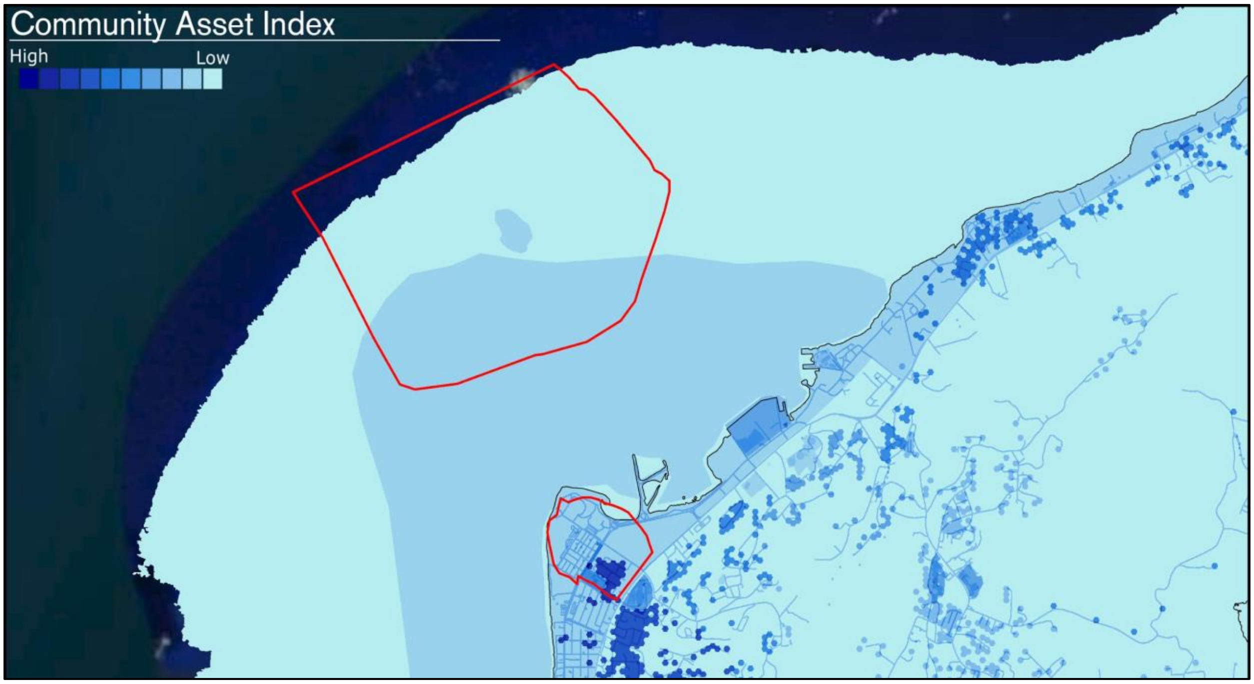

Figure 24. The Community Asset Index results for the West Takpochao watershed. The red lines outline the wetland and coral restoration project locations. Note the high density of community assets within and surrounding the wetland restoration site in Garapan.

Restoring the Garapan wetlands can provide important water quality benefits to adjacent coral reefs by reducing sediment and nutrient pollution. Poor water quality can reduce coral's ability to withstand and recover from bleaching events and other global stressors. Additionally, recent storm activity, including Typhoon Yutu, have caused widespread physical damage (Figure 25). Post-storm surveys showed physical impacts from storm debris and sediment on a large proportion of reef habitat sampled. Reef crests, flats, and lagoons, which play the most important role in storm protection for the coast, experienced impacts on over 70 percent of the areas sampled. The combination of poor water quality, storm damage, and global stressors impacting the reefs in the Saipan Lagoon suggest large-scale restoration efforts may be needed to catalyze coral recovery.

In response, an in-water coral nursery was established to facilitate restoration of key sites in the West Takpochao watershed (Figure 25). Through this project, DCRM will partner with NOAA to expand the nursery's capacity so they are able to generate up to 3,000 coral fragments from six different species, which can be out-planted to bolster coral populations throughout the watershed. Under the current project, the team will restore 0.4 hectare of coral reef habitat, representing the largest coral restoration effort in the CNMI to date. Restoration efforts are expected to increase coral cover and could potentially help connect areas of high Fish and Wildlife value identified in the CNMI Assessment (Figure 26). The project will also adopt a standard procedure to salvage coral fragments after storms to minimize future damage and maintain coral restoration efforts.

Figure 25. Left: Damage to coral in the West Takpochao watershed caused by debris associated with Super Typhoon Yutu. Debris such as trees and roofing tin can cause significant damage to coral reefs. Right: In-water coral nursery in the West Takpochao watershed used to out-plant corals to adjacent target sites for restoration. Photo Credits: Provided by DCRM (left), XinMei Tang (right).

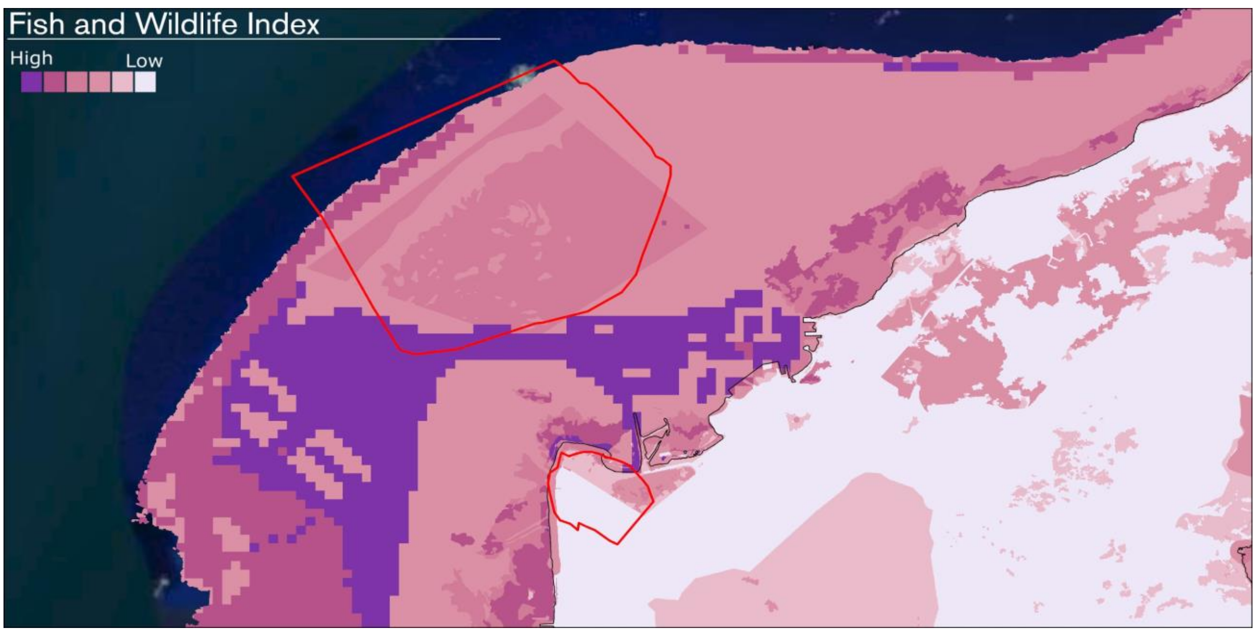

Figure 26. The Fish and Wildlife Index results for the West Takpochao watershed. The red lines outline the wetland and coral restoration project areas. Note the high fish and wildlife values within and adjacent to the nearshore coral restoration site. Efforts to restore corals in this location may help to expand areas of high fish and wildlife value.

The increased capacity afforded by both the wetland plant nursery and the coral nursery will together provide opportunities for future restoration efforts in Saipan. With the presence of considerable flooding threats, concentrations of coastal community assets, and wildlife habitat, the West Takpochao watershed wetland and coral restoration projects demonstrate the importance of placing resilience projects in areas that can achieve dual benefits for communities and fish and wildlife. The Assessment reveals how Resilience Hubs are a useful tool to identify areas suitable for nature-based, resilience-building interventions. In the areas surrounding Garapan, a range of high-ranking Hubs are visible

(Figure 27). Additionally, by visualizing the 4-hectare (10-acre) hexagonal grid, the user can access finer-resolution information to understand the variation in scores within Resilience Hubs. The Resilience Hubs in West Takpochao, and throughout CNMI, can help support the prioritization of habitats for other similar types of projects in Saipan and elsewhere.

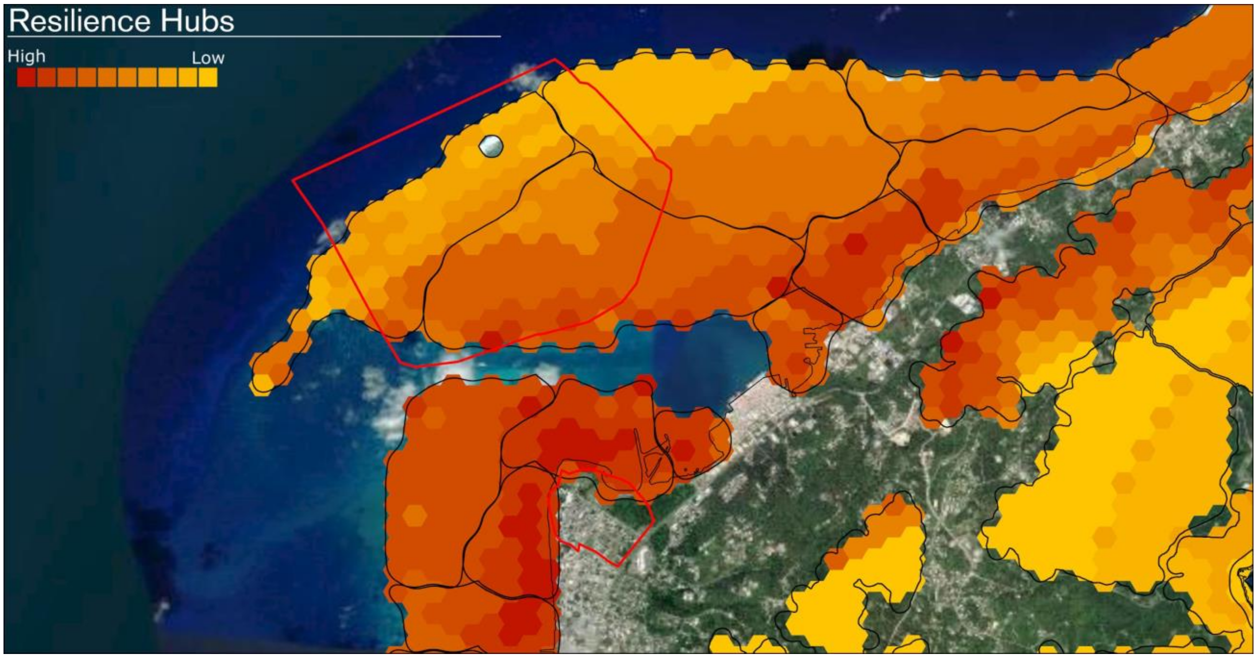

Figure 27. Resilience Hubs (black lines) in the West Takpochao watershed indicate that there are multiple areas potentially well suited for restoration projects. Note the 4-hectare (10-acre) hexagons show variation in scores within Resilience Hubs.

CONCLUSION

5.1 Summary and Key Takeaways

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

With a combined total of 219 kilometers of coastline across all three islands, the Northern Mariana Islands remain highly exposed to a variety of coastal flood related hazards in many areas. This is compounded in areas with higher populations and community assets, such as on the west and southern portions of Saipan. Inland communities are not immune from flood-related threats either, especially as it relates to heavy precipitation events and flash flooding. Furthermore, the effects of coastal flooding are exacerbated when combined with increasing droughts and fires, as well as heavy precipitation inland, suggesting efforts to build resilience should consider the benefits of a holistic, island-wide approach.

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

5.2 Future Work

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

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APPENDIX

The following sections describe the data used for the Commonwealth of the Northern Mariana Islands (CNMI) Coastal Resilience Assessment in detail, as well as any regional deviations from the methodologies outlined in the Methodology and Data Report (Dobson et al. 2020).

The CNMI Assessment was completed at a 3-meter resolution, using the projection *NAD 1983 UTM Zone 55N* (WKID 32655).

A. Data Summary

A.1 Threat Index

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

Layer Name	Dataset and Source
Flood-prone Areas	FEMA National Flood Hazard Layers, USDA-NRCS SSURGO (2.2 or later)
Sea Level Rise	NOAA Office for Coastal Management Sea Level Rise Inundation Database (2015 or later - Saipan coverage only)
Wave Driven Flooding	Floodmasks; USGS/Curt Storlazzi (Storlazzi et al. 2019)
Areas of Low Slope	USGS National Elevation Dataset, 10-meter resolution (most recent available)
Soil Erodibility	USDA-NRCS SSURGO (2.2 or later)
Impervious Surfaces	USDA-NRCS SSURGO (2.2 or later), NOAA Coastal Change Analysis Program Landcover (2014, Rota & Tinian; 2016, Saipan)

A.2 Community Asset Index

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

Layer Name	Dataset and Source
Population Density	U.S. Census Bureau, 2010 Decennial Census - place geography (demographic summary profile)
Social Vulnerability	U.S. Census Bureau, 2010 Decennial Census - place geography (demographic summary profile)
Critical Facilities	Schools: USGS National Structures Dataset; Law Enforcement, Fire Stations, and Medical Facilities: CNMI Dept. of Public Lands
Parcels	CNMI Dept. of Public Lands
Building Footprints	Open Street Maps
Critical Infrastructure *(Various Inputs, see below)*	
Primary roads	*Open Street Maps*
Airport runways	*National Transportation Atlas Database: Airport Runways (2015 or later)*
Ports	*Locations identified using information from the Commonwealth Ports Authority, digitized by NEMAC*
Power Plants	*CNMI Dept. of Public Lands*
Wastewater treatment facilities, potable water	*CNMI Dept. of Public Lands*
Petroleum terminals	*U.S. Energy Information Administration: EIA-815, Monthly Bulk Terminal and Blender Report*
Hazardous Sites/Landfill	*CNMI Dept. of Public Lands*
Cultural, Historic, and Sensitive Sites	*CNMI Historic Preservation Office*
Communication Infrastructure	*CNMI Dept. of Public Lands*

A.3 Terrestrial Index

The following table lists those datasets that were used to create the Terrestrial Index for the Northern Mariana Islands.

Dataset Name	Source and Year
C-CAP Land cover	NOAA Office for Coastal Management (2014, Rota & Tinian; 2016, Saipan)
National Wetlands Inventory	U.S. Fish & Wildlife (most recent available)
National Hydrography Dataset	USGS (most recent available)
Vegetation Data	USFS (2017)[8]
Important Bird Areas	BirdLife International (2020)
Environmental Sensitivity Index Species Habitat	NOAA Office of Response and Restoration (2000)
Critical Habitat Designations	NOAA & U.S. FWS (most recent available)
State Wildlife Action Plan species list	State Wildlife Action Plan for the Commonwealth of the Northern Mariana Islands, 2015-2025
Habitat Classification Scheme	IUCN Red List of Threatened Species (Version 3.1)
Protected Areas Database of the U.S. (PADUS)	USGS (Version 2.0)[9]

[8] Amidon, F., M. Metevier, and S.E. Miller. 2017. Vegetation mapping of the Mariana Islands: Commonwealth of the Northern Mariana Islands and Territory of Guam. U.S. Fish and Wildlife Service, Pacific Islands Fish and Wildlife Office, Honolulu, Hawaii. Technical Report and Data Layers.

[9] At the time of modeling, the Project Team was unaware that this dataset has a data gap. Local protected area Susupe and Nightingale Reed-warbler Conservation Area in Marpi were not included in the analysis.

A.4 Marine Index

The following table lists those datasets used to create the Marine Index for the Northern Mariana Islands.

Dataset Name	Source and Year
Critical Habitat Designations	NOAA & U.S. FWS (most recent available)
Reef Fish Biomass	NOAA National Coral Reef Monitoring Program: Reef Fish Monitoring sector-level data (2017, used in lieu of Marianas Coral Reef Ecosystem EFH)
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2015)
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program, strata-level data (combined observation years 2011, 2014, 2017)
Mangrove Presence	NOAA Coastal Change Analysis Program Landcover (2016, Saipan)
Protected Areas Database of the U.S. (PADUS) - Marine Protected Areas	USGS (Version 2.0)
Coral Nurseries	NOAA and DOI

A.5 Resilience Hubs

The following table lists those datasets used to create the Resilience Hubs for the Northern Mariana Islands.

Dataset Name	Source and Year
C-CAP Land Cover Atlas	NOAA Office for Coastal Management (2014, Rota & Tinian; 2016, Saipan)
National Wetlands Inventory	U.S. Fish & Wildlife (most recent data available)
National Hydrography Dataset	U.S. Geological Survey (USGS) 1:24,000
Bathymetry	NOAA Coral Reef Ecosystem Division, Pacific Islands Benthic Habitat Mapping Center (2007)
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program, strata-level data (combined observation years 2011, 2014, 2017)
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2015)
Mangrove Presence	NOAA Coastal Change Analysis Program Landcover (2016, Saipan)
National Elevation Dataset	U.S. Geological Survey (USGS), EROS Data Center
SSURGO Soils Survey	USDA, NRCS
Roads polyline	OpenStreetMap (latest data available)
Railroads polyline	OpenStreetMap (latest data available)

B. Detailed Methodology: Threat Index

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

B.1 Wave Driven Flooding

Wave driven flooding was ranked according to probability of occurrence, where a 10-year return period is given a higher rank than a 500-year return period. The following rank value was applied to each return period:

Wave Driven Flooding	Rank Value
0	0
500-year return period	1
100-year return period	2
50-year return period	3
10-year return period	4

A. Import each floodmask vector and add a rank field according to the table above
    a. Right click layer in Table of Contents > Attribute Table > Add Field: “Rank”, Field Type: Short Integer.
    b. For each, right click rank field > Field Calculator > Rank = *see above*
B. Merge floodmask with regional boundary
    a. Geoprocessing > Merge
C. Rasterize the merged vectors
    a. Conversion Tools > To Raster > Polygon to Raster
        i. Input Feature: merged boundary and floodmask vectors
        ii. Value field: Rank
        iii. Cell assignment type: Maximum Area
        iv. Priority field: Rank
        v. Cell size: 3

B.2 Calculating the Threat Index

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

CNMI Threat Index Distribution

Threat Index Break Value	0 - 1	2 - 3	4	5	6	7	8 - 9	10 - 12	13 - 17	18 - 23
Final Rank Value	1	2	3	4	5	6	7	8	9	10

C. Detailed Methodology: Community Asset Index

C.1 Population Density

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

Population Density Distribution for CNMI	Rank Value
0	0
<= 343.2	1
<= 637.8	2
<= 813	3
<= 1340.6	4
<= 7858.8	5

C.2 Social Vulnerability

Following the guidance outlined in *Climate Change Vulnerability Assessment for the Island of Saipan, CNMI* (Greene & Skeele 2014), data from the U.S. Census Bureau 2010 decennial census "place" geography was used to identify 22 socio-economic variables. According to the report, "data values for each variable were grouped into five classes using a natural breaks method, and re-classified to reflect a value of 1-5. The variables were weighted according to relative contribution to vulnerability, and overlaid to reflect cumulative vulnerability" (Greene & Skeele 2014). The variables used in this index are listed below:

- Average household size
- Median household income
- Median rent
- Percentage of population 25 and older with Bachelor's degree
- Percentage of population 25 and older with high school education
- Percentage of population disabled
- Percentage of population below poverty line
- Percentage of houses with metal roof
- Percentage of houses with metal wall
- Median rent as a percentage of median household income
- Percent non-U.S. citizen
- Per capita income
- Percent of houses mobile or non-permanent
- Percentage of households without a computer
- Percentage of population with no health insurance
- Percentage of households with no radio
- Percentage of households receiving social security income
- Percentage of population over 16 relying solely on subsistence activities
- Percentage of population over 16 unemployed
- Percentage of houses with wood roof
- Percentage of houses with wood wall
- Percentage of houses built on wood pilings

As outlined above, the variables were reclassified using variables 1-5 and a natural breaks distribution and then combined. The final distribution of values to rank the input for the Northern Mariana Islands is below:

Social Vulnerability Distribution for CNMI	Rank Value
0	0
<= 32.1	1
<= 34.75	2
<= 37	3
<= 38.35	4
<= 42	5

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

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

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

C.4 Calculating the Community Asset Index

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

CNMI Community Asset Index Distribution

Asset Index Break Value	0	1	2	3	4 - 5	6	7 - 8	9 - 10	11 - 13	14 - 17
Final Rank Value	1	2	3	4	5	6	7	8	9	10

D. Detailed Methodology: Community Exposure Index

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

CNMI Community Exposure Index Distribution

Exposure Index Break Value	0 - 1	2	3	4	5 - 7	8 - 11	12 - 18	19 - 31	32 - 52	53 - 90
Final Rank Value	1	2	3	4	5	6	7	8	9	10

E. Detailed Methodology: Fish and Wildlife Index

E.1 Calculating the Terrestrial Index

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

Birds

Micronesian Megapode	White-throated Ground Dove	Rufous Fantail
Wedge-tailed Shearwater	Mariana Fruit Dove	Tinian Monarch
Masked Booby	Mariana Swiftlet	Mariana Crow
Great Frigatebird	Mariana Kingfisher	Nightingale Reed-warbler
Mariana Common Moorhen	Micronesian Honeyeater	Bridled White-eye
Golden White-eye	Rota White-eye	

Reptiles

Mariana Skink	Hawksbill Turtle
Micronesian Gecko	Green Sea Turtle

Terrestrial Mammals

Pacific Sheath-tailed Bat
Mariana Fruit Bat

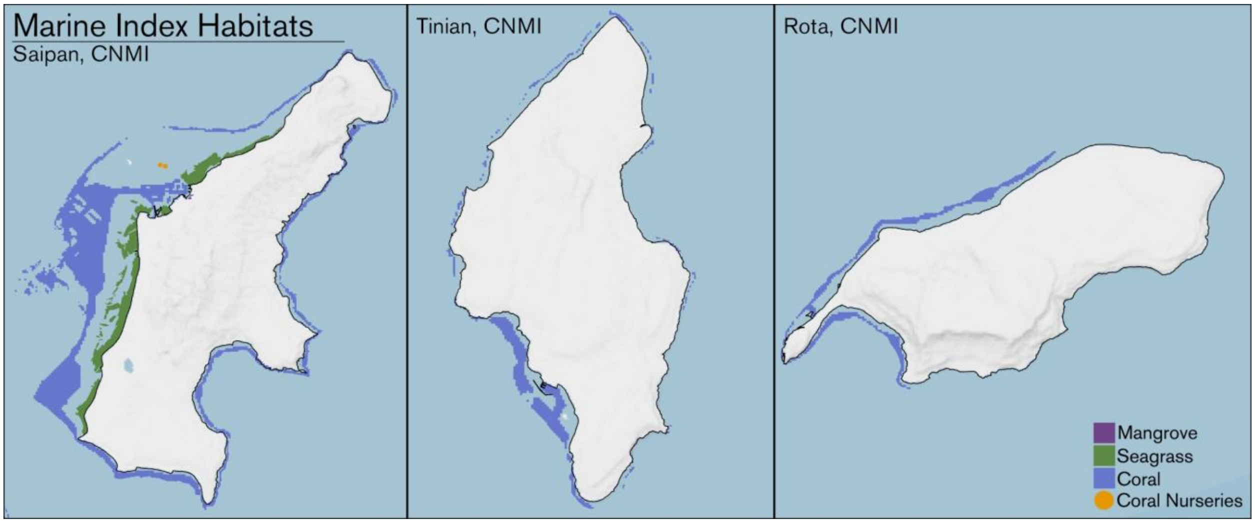
The distribution for the Northern Mariana Islands Terrestrial Index is displayed below. The final rank value for the Index is determined using a quantile distribution and was then combined with the Marine Index to create the Fish and Wildlife Index.

CNMI Terrestrial Index Distribution

Terrestrial Index Break Values	0	1	3 - 4	5 - 9
Final Rank Value	1	2	3	4

E.2 Calculating the Marine Index

In general, the same overarching methods were applied to CNMI as outlined in the Methodology and Data Report (Dobson et al. 2020). However, due to differences in data availability, some modifications to the datasets and methods used for CNMI were necessary. These are discussed in the following sections. See Appendix A.4 for details on datasets used in this analysis. The spatial extent and distribution of coral reefs and nurseries, seagrasses, and mangroves are shown in the map below and described in the following text.



Coral Cover

The benthic habitat maps available for CNMI are relatively old and potentially unreliable. Therefore, to incorporate coral cover data from NOAA's National Coral Reef Monitoring Program, each strata-level (depth bin) surveyed was ranked according to the percent coral cover and then rasterized to be included in the Marine Index (Tom Oliver, NOAA, personal communication). The strata-level depth bins were created according to guidance from NOAA using bathymetry as follows:

Strata	Depth
Shallow	0 - 6m
Mid-depth	>6 - 18m
Deep	>18 - 30m

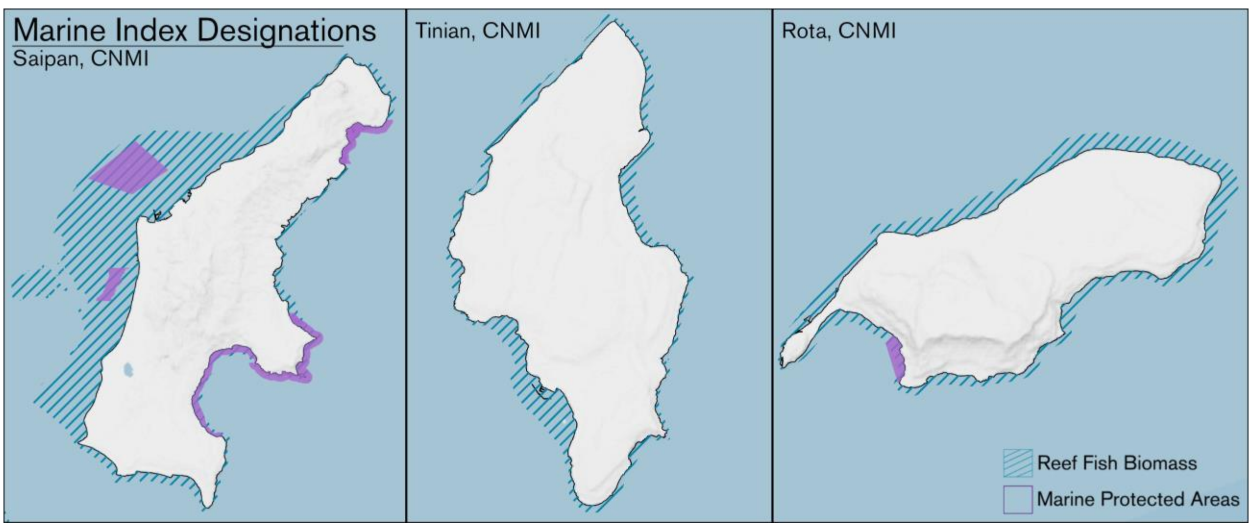
The percent coral cover was ranked across the three islands using a geometric interval distribution and five classes. The following ranking scheme was used to rank the coral cover by strata-level in CNMI. The rank value of '0' shown below is the land area of each island.

Percent Coral Cover in CNMI	Rank Value
0	0
<= 5.8	1
<= 8.8	2
<= 13.6	3
<= 21.7	4
<= 34.8	5

Seagrass Cover
Despite the potential unreliability of the benthic habitat maps, seagrass cover was still incorporated into the analysis since no other options were available during the time of modeling. The following ranking scheme was used to rank seagrass cover in CNMI.

Seagrass Cover in CNMI	Rank Value
0	0
Patchy, 10 - <50%	1
Patchy, 50 - <90%	2
Continuous, 90 - 100%	3

Reef Fish Biomass
Reef fish biomass was used in place of the Mariana Islands Coral Reef Ecosystem Essential Fish Habitat. Biomass was ranked at the sector (island) level in ascending order of the mean total fish biomass and then rasterized to be included in the Index. The ranking scheme for CNMI is shown below. The rank value of '0' shown below is the land area of each island.



Fish Biomass in CNMI	Island	Rank Value
0	---	0
14.5	Saipan	1
16.4	Rota	2
16.6	Tinian	3

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

CNMI Marine Index Distribution

Marine Index Break Values	0 - 1	2	3 - 4	5 - 9
Final Rank Value	1	2	3	4

E.3 Calculating the Fish and Wildlife Index

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

CNMI Fish and Wildlife Index Distribution

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

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

F. Detailed Methodology: Resilience Hubs

The methodology outlined in the Methodology and Data Report (Dobson et al. 2020) in the creation of Resilience Hubs were followed for the Northern Mariana Islands.