HAWAI‘I COASTAL RESILIENCE ASSESSMENT

2020

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Report cover images: Diamond Head (Lēʻahi) State Monument, Oʻahu (top); Hawaiian monk seal (bottom)

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** Contractor with Lynker Technologies*

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

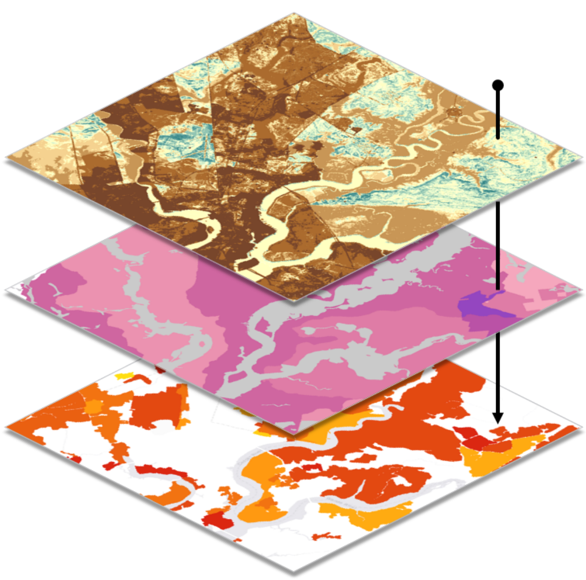
Coastal communities throughout the United States face serious current and future threats from natural events, and these events are predicted to intensify over the short and long term. Dynamic processes such as coastal erosion, storm surge flooding, and river runoff exacerbate the threat from sea level rise. Tropical systems and heavy precipitation events have the potential to devastate both human communities and fish and wildlife habitats, as has been seen in recent years. As communities prepare, decision-makers need tools and resources that allow for data-driven decision support to maximize available funding opportunities and other planning needs.

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

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

OBJECTIVE: REGIONAL COASTAL RESILIENCE ASSESSMENTS

Identify areas on the landscape where the implementation of natural and nature-based features may maximize dual benefits for *human community resilience* and *fish and wildlife*



Community Exposure Index
Helps identify where the most people and assets are exposed to flooding threats

Fish & Wildlife Index
Helps identify where important species and their habitats are located

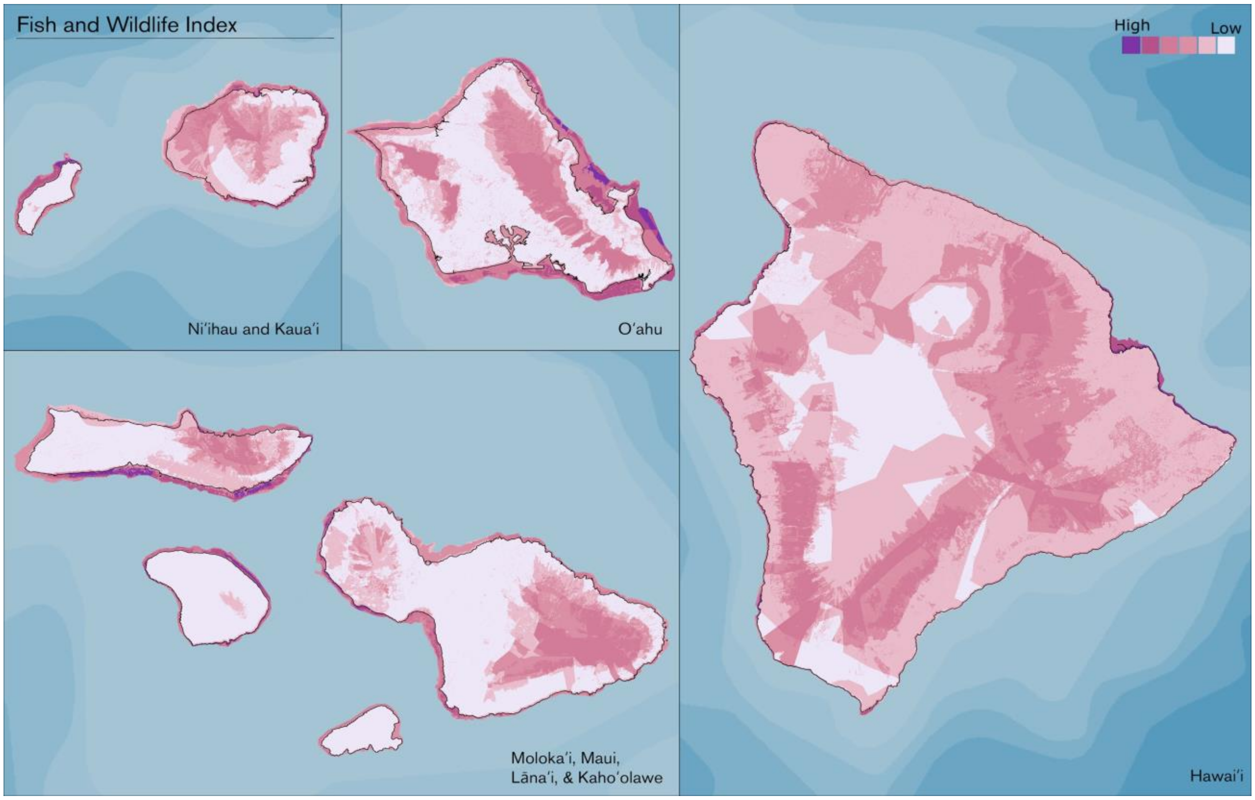
Resilience Hubs
Areas of natural, open space or habitat where resilience projects may have the greatest potential for dual benefits

The Assessment identified areas throughout Hawaiʻi 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 abundant fish and wildlife resources. Together, the Assessment 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 Hawaiʻi. The primary mapping products from the Hawaiʻi Assessment are shown below.

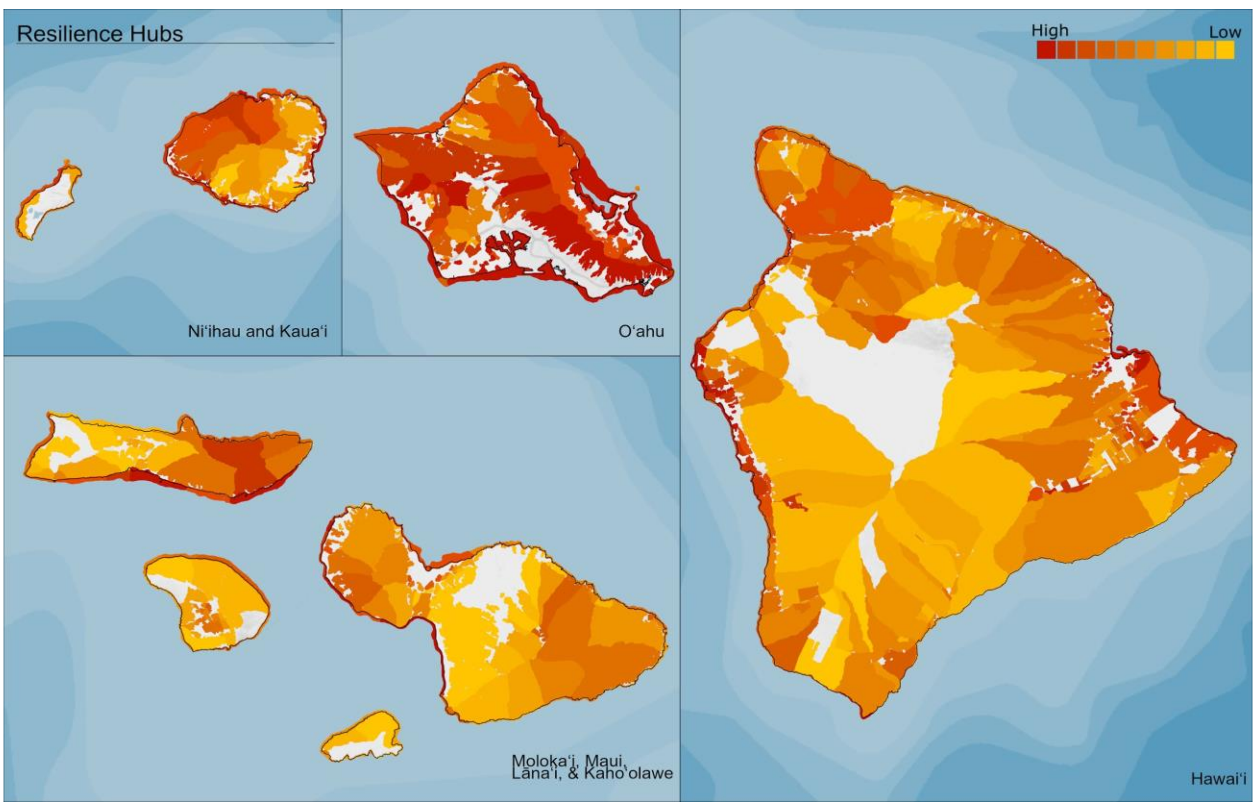
Local community planners, conservation specialists, and others can use the outputs of the Hawaiʻi Assessment to help make informed decisions about the potential of restoration, conservation, or resilience projects to achieve dual benefits for both human and fish and wildlife communities.

This Hawaiʻi 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 case studies. 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 Hawaiʻi Assessment (available at resilientcoasts.org).

Community Exposure Index for the Hawaiʻi Coastal Resilience Assessment. Higher values represent areas where a higher concentration of assets are exposed to flooding threats.



Fish and Wildlife Index for the Hawai'i Coastal Resilience Assessment. Higher values represent areas where numerous important species and their habitats are located.



Resilience Hubs for the Hawai'i Coastal Resilience Assessment. Higher values represent areas where resilience projects may have the greatest potential to benefit both human communities and wildlife.

INTRODUCTION

1.1 Hawaiʻi

The Hawaiian Islands are an archipelago in the north Pacific Ocean consisting of eight main islands as well as over one hundred atolls, islets, and seamounts. They are rich in endemic biodiversity, natural resources, and cultural heritage. However, communities throughout Hawaiʻi are highly exposed to a variety of coastal-flood related threats. Hawaiʻi's dynamic landscape faces numerous natural hazards ranging from volcanoes, tsunamis, and seismic activity to floods, drought, wildfire, and extreme heat (Fletcher et al 2002, Hwang & Okimoto 2019).

Local flooding threats range from heavy rains, sea level rise, increased storm activity, and compound flooding. Compound flooding associated with multiple, simultaneous or sequential heavy rain events and coastal storms can significantly impact both coastal and inland communities. Hurricane Iniki in 1992 was the last major hurricane to devastate the islands, with particular impacts to Kauaʻi. While only two hurricanes have made landfall in Hawaiʻi, heavy rain, strong wind, and resulting flooding and erosion pose considerable threats. For example, in 2018, Hurricane Lane brought record breaking rainfall to the islands despite never making landfall. One station on the island of Hawaiʻi recorded 58 inches of rain from Lane (Beven & Wroe 2019). The storm caused one death and approximately $250 million in damages due to landslides, flooding, and wildfires sparked by downed power lines spread by strong winds.

The State of Hawaiʻi prioritizes nature-based policy approaches that build resilience. Such efforts include, but are not limited to, the setback policies, no-hardening regulations, and sea level rise exposure zones to prevent building in the hazardous coastal zone. Unique to Hawaiʻi, traditional watershed boundaries from mountains to sea, or mauka to makai, permeate the management documents for the region, and combine indigenous knowledge within the regulatory framework for a holistic approach. Hawaiʻi was one of the first states in the nation to adopt a climate adaptation policy in 2012, and has proactively established progressive coastal building setbacks to manage retreat, including a 2020 law that prohibits shoreline hardening.[1] Erosion rates in Hawaiʻi typically average 0.5-1 foot per year, with some areas experiencing shoreline loss as high as two feet per year (Fletcher et al. 2002). With 70 percent of Hawaiʻi's beaches undergoing chronic sand loss and shoreline retreat, and many miles of beach loss due to hardened structures, this measure reflects Hawaiʻi's efforts to effectively address coastal threats.

In addition to climate forward policy actions, numerous efforts have worked to better understand the threats, needs, gaps, and nature-based approaches that can be applied to help build resilience in Hawaiʻi. Recent efforts include, but are not limited to Sea Level Rise Vulnerability and Adaptation report (Hawaiʻi Climate Commission 2017), Guidance for Disaster Recovery Preparedness in Hawaiʻi (Courtney et al. 2019), Assessing the Feasibility and Implications of Managed Retreat Strategies for Vulnerable Coastal Areas in Hawaiʻi (Hawaiʻi CZM 2019), Hawaiian Islands Climate Vulnerability and Adaptation Synthesis (Gregg 2018), the Pacific Islands Regional Climate Assessments (Keener et al. 2012), the State of Hawaiʻi Hazard Mitigation Plan (Tetra Tech 2018) and the Hawaiʻi Ocean Resources Management Plan (Hawaiʻi CZM 2020). Such studies are critical to help communities understand, respond to, and prepare for future storm events. Additional county-level plans and policies govern management of each island.

[1] https://mauinow.com/2020/09/17/coastal-zone-management-bill-becomes-law-mitigating-erosion-and-rising-sea-level-threats/

These forward-thinking plans, combined with the local governance, hold promise for responding and implementing effective measures to prepare for future storm events and sea level rise.

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

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 Hawaiʻi 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, the U.S. Virgin Islands, and the Commonwealth of the Northern Mariana Islands. Additional Assessments are underway for American Samoa, Guam, Alaska, and the U.S. Great Lakes (Figure 1).

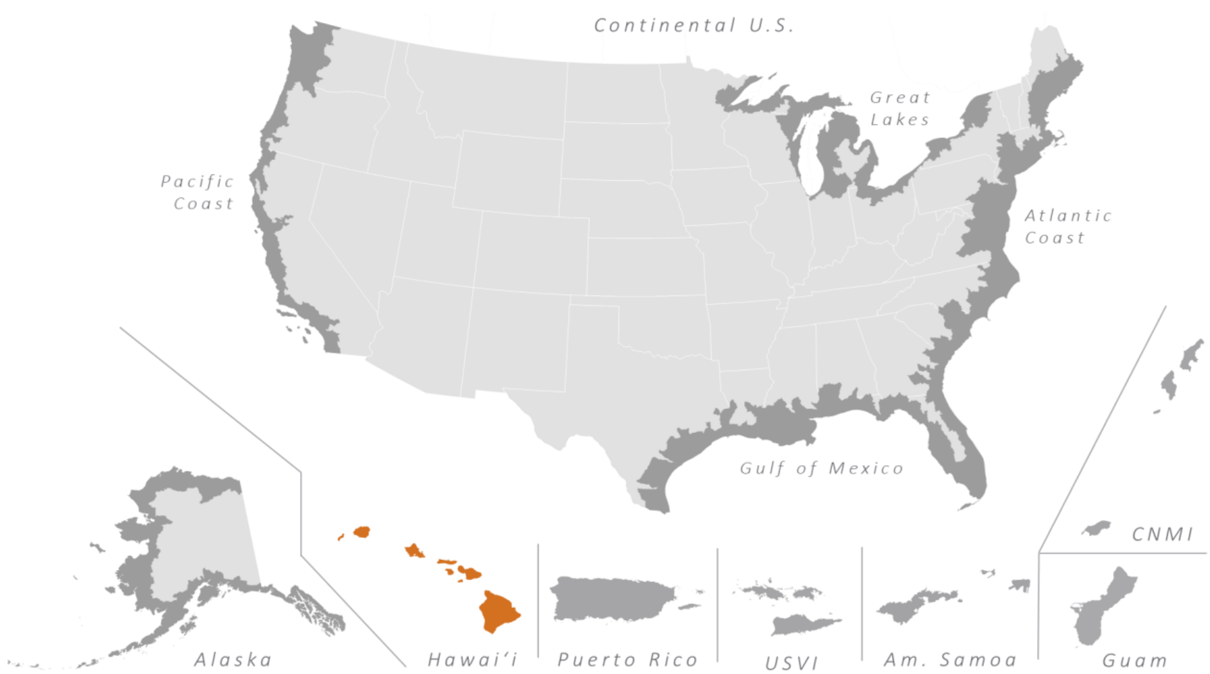


Figure 1. The geographic extent of the Regional Coastal Resilience Assessments in dark gray and the Hawaiʻi Assessment in orange. All Regional Assessments will be completed by 2021. Map not shown to scale.

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 GIS-based approach to model landscape characteristics and their potential impacts 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 to identify and rank Resilience Hubs. Resilience Hubs are large areas of natural, open space or habitat where, if investments are made in conservation or restoration, there is potential for improved human community resilience and benefits to fish and wildlife habitats and species.

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

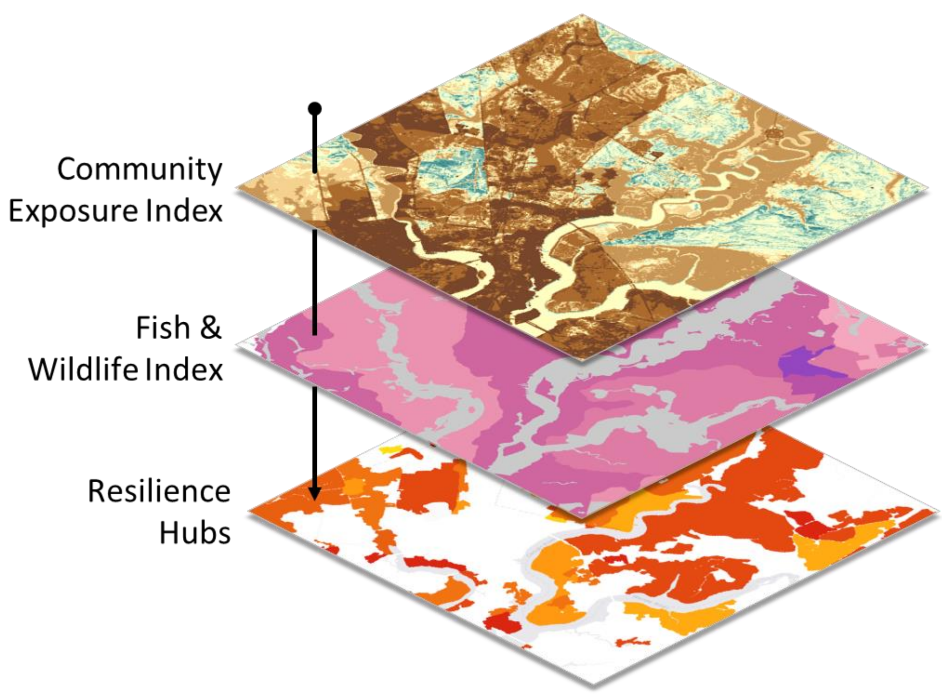


Figure 2. A conceptual model showing the separate, but interrelated components of the Regional Coastal Resilience Assessments.

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

METHODS

2.1 Introduction

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

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

2.2 Study Area

The Hawaiʻi Assessment focuses on the main islands of Hawaiʻi, Maui, Kahoʻolawe, Lānaʻi, Molokaʻi, Oʻahu, Kauaʻi, and Niʻihau, and does not include the Northwest Hawaiian Islands. Hawaiʻi has a total population of nearly 1.4 million people, though the population of each of the main Hawaiian Islands varies widely, from the most populous island of Oʻahu with over 950,000 people to Niʻihau with just 170 residents. The island of Kahoʻolawe is uninhabited. With just under 1,300 kilometers of coastline, the main islands possess a startling diversity of ecosystems, climates, terrain, and habitats ranging from volcanic craters to coral reefs.

The Assessment covers the entire watershed, from mauka to makai, or from the mountains to sea, extending into the ocean to the 30-meter depth contour (Figure 3). As described below, the 30-meter depth boundary was used for the Fish and Wildlife Index to allow for the inclusion of the marine habitats with potential to host significant biodiversity. Based on the recommendation of technical experts, however, the Resilience Hub analysis only considered habitats less than 10 meters in depth since shallow water habitats are expected to provide greater coastal protection benefits through the implementation of nature-based solutions.

This Assessment is unique in that it not only considers the immediate coastline, as many other studies have done, but it also focuses on inland areas that can often directly contribute to coastal flood-related issues. For instance, intense rain and riverine flooding that then drains directly to the coast can exacerbate coastal flooding. In all regions, the boundary of the Assessments follow the coastal watersheds designated by the U.S. Environmental Protection Agency (EPA), which are watersheds that drain directly to the ocean and are represented at a hydrologic unit code eight scale (HUC-8)[2]. For

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

Hawaiʻi, the HUC-8 watersheds cover all the islands, and thus the study area also covers the entirety of each island (Figure 3).

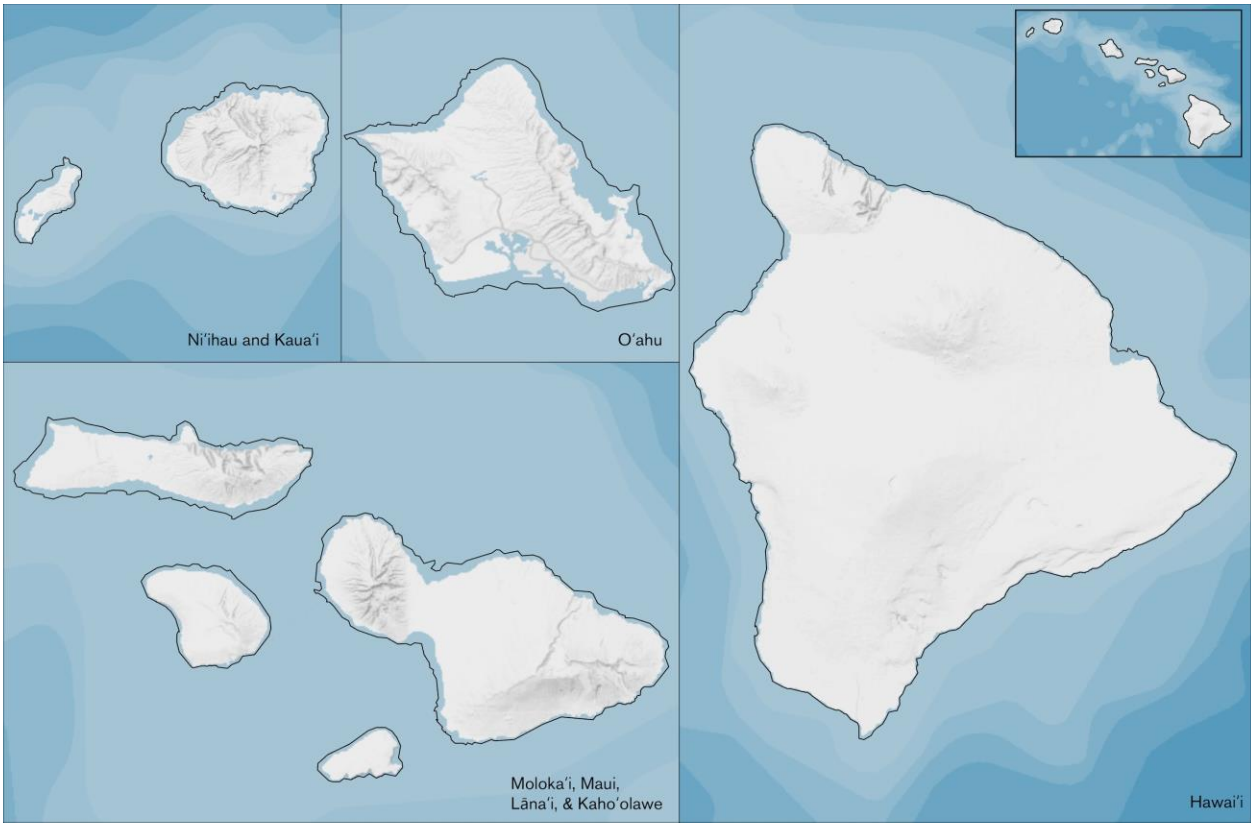


Figure 3. The Hawaiʻi Coastal Resilience Assessment study area. The 30-meter depth contour is shown in black.

2.3 Data Collection and Stakeholder Engagement

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

To help guide the Assessment process, the Project Team established an Advisory Committee consisting of six members representing NOAA, the Hawaiʻi Department of Land and Natural Resources, the Pacific Regional Integrated Sciences and Assessment, the State Hawaiʻi Office of Planning, University of Hawaiʻi at Mānoa, and the U.S. Fish and Wildlife Service. 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 Hawaiʻi Assessment; and
3. Advise on final products and tools, including the effective dissemination of results.

From the Advisory Committee and building on initial data collection, the Project Team hosted a workshop to allow local stakeholders to review and provide input on preliminary Assessment products. The Stakeholder Workshop was held on March 10, 2020 in Honolulu as part of an open training session held in conjunction with the 2020 Pacific Risk Management ʻOhana (PRiMO) Conference.

Over 40 people attended the workshop, representing state, federal, municipal, non-government, and academic organizations from Oʻahu, Maui, Kauaʻi and Hawaiʻi islands. Workshop participants 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 Hawaiʻi.

Participants reviewed draft maps and data sources, providing important feedback and recommendations to improve the analyses. In addition, participants considered measures that local communities can take to enhance resilience, including management strategies, activities, and projects that restore habitats and install natural and nature-based features that reduce flood-related threats.

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. Results of the Hawaiʻi 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 Hawaiʻi 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.

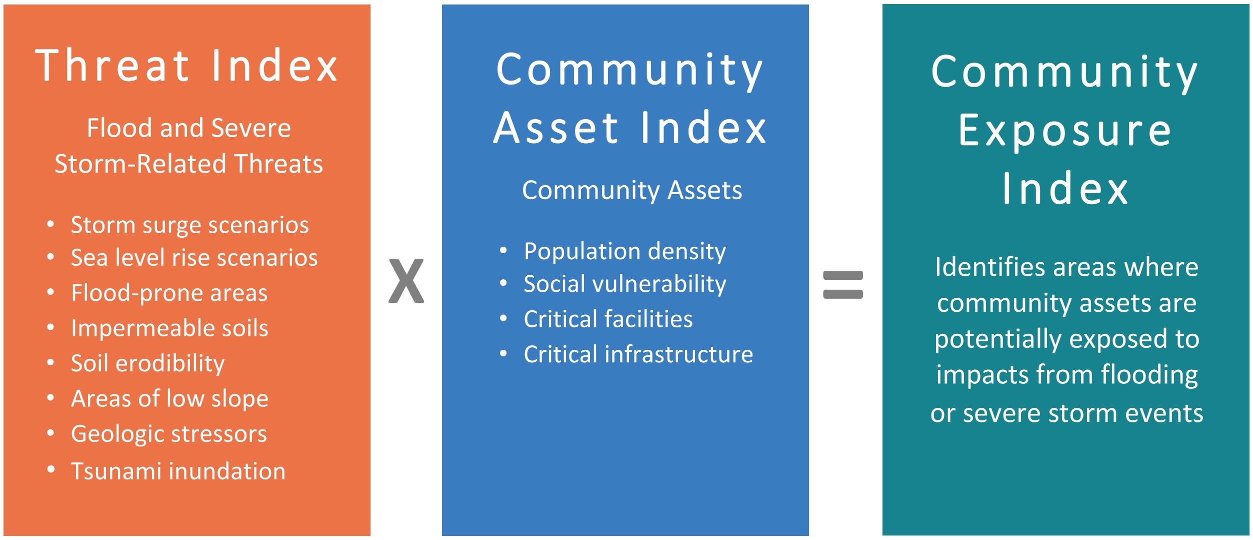


Figure 4. Elements of the Threat and Community Asset Indices used to create the Community Exposure Index.

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 Hawaiʻi 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 Hawaiʻi analysis included data related to storm surge, sea level rise, flood-prone areas, soil erodibility, impermeable soils, areas of low slope, landslide susceptibility, and tsunami evacuation areas, each of which are described in detail in the Methodology and Data Report (Dobson et al. 2020). Additional details on those data used to create the Threat Index for Hawaiʻi 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 Hawaiʻi, 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, many local datasets found on the Hawaiʻi Statewide GIS Program Geospatial Data Portal[3] were incorporated. In addition, the analysis included cultural heritage sensitivity areas and historic sites within the study area. Although these sites may not directly assist in responding to flood events, their importance to local communities, as well as 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 Hawaiʻi Assessment:

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[3] To view data available through the Hawaiʻi State Office of Planning's Hawaiʻi Statewide GIS Program, visit https://geoportal.hawaii.gov/

- Primary roads
- Bridges
- Airports
- Ports
- Power Plants & Substations
- Petroleum Terminals & Refineries
- Hazardous Sites
- Wastewater Treatment Facilities
- Railroads/Urban Train
- Dams
- Cultural & Historic Resources

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

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

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

2.5 Creating the Fish and Wildlife Index

The Fish and Wildlife Index, which consists of Marine and Terrestrial components, allows for a greater understanding of important habitats and fish and wildlife resources to aid in the identification of areas where implementing nature-based solutions may support coastal resilience and ecosystem benefits (Figure 5). The Index attempts to identify areas on the landscape where terrestrial, aquatic, and marine species and their habitats are located. For the Hawaiʻi 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 Hawaiʻi 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.

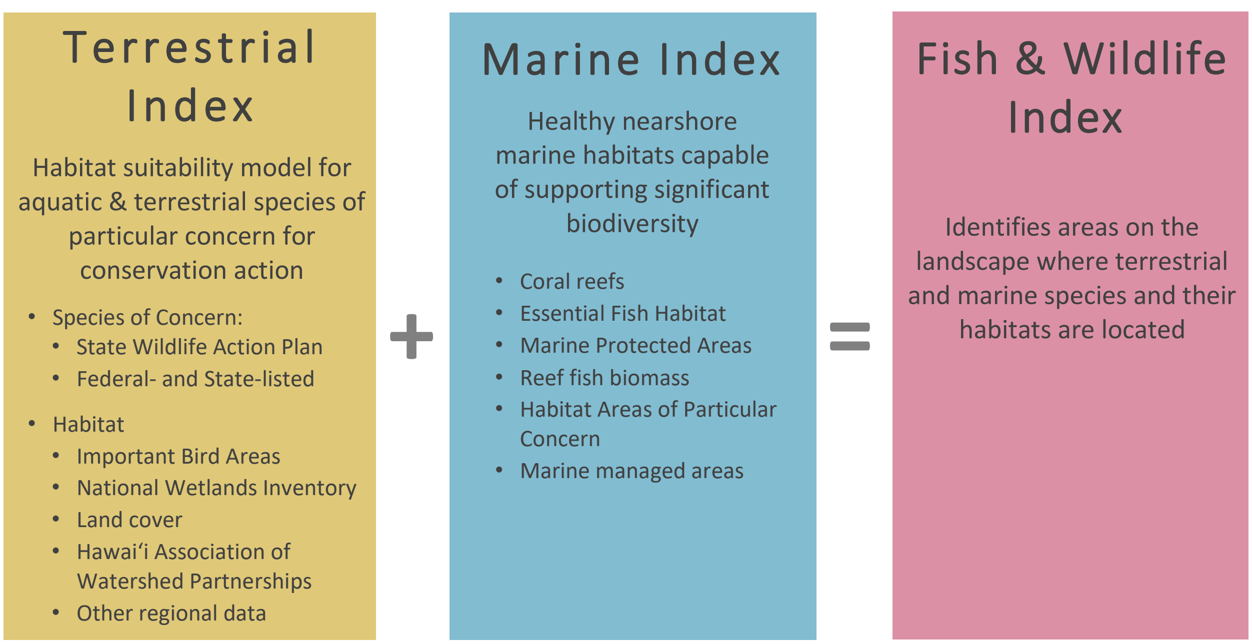

Figure 5. Elements of the Terrestrial and Marine Indices used to create the Fish and Wildlife Index.

2.5.1 Terrestrial Index

The Terrestrial Index aims to identify suitable habitats for major species 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 State of Hawaiʻi State Wildlife Action Plan (Hawaiʻi DLNR 2015) and species listed as threatened or endangered under the Endangered Species Act. Broad taxonomic and species groupings were used to model habitat preferences throughout the region, including:

- Forest Birds
- Seabirds
- Waterbirds
- Migratory Birds
- Raptors
- Freshwater Fishes
- Reptiles
- Terrestrial Mammals[4]
- Invertebrates

Based on habitat preferences associated with each species 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 and species group) included in the Hawaiʻi Assessment is available in Appendix E.1.

In addition to using the 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 Carbon Assessment of Hawaiʻi - Land Cover/Biome Unit available through the Hawaiʻi Statewide GIS Program. BirdLife International Important Bird Areas (IBAs) were also included, as well as other areas prioritized by local agencies for protection or management such as the Hawaiʻi Association of Watershed Partnerships and State watershed priority areas. A complete list of datasets and methods used to create the Hawaiʻi 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 can support significant biodiversity, such as coral reefs. While other marine habitat types may support significant biodiversity, the Hawaiʻi Assessment focused on those habitat types where restoration and resilience projects may offer the multiple benefits of species richness, ecosystem enhancement, and coastal protection.

Benthic habitat maps, extending to a 30-meter depth bathymetry contour around all islands, were used to define the spatial extent of coral reef habitat. To assess coral condition, estimates of live coral cover were obtained from NOAA's National Coral Reef Monitoring Program, which regularly implements stratified random sample surveys throughout the islands. Based on surveys from 2019, areas with higher coral cover—and thus more likely to support higher numbers of reef associated species (Komyakova et al. 2013)—were ranked higher. Due to ecosystem changes since the benthic habitats were mapped in 2007, 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).

In addition to the spatial extent and condition of these habitat types, the Marine Index calls upon a number of additional datasets including managed areas such as NOAA Habitat Areas of Particular

[4] The Hawaiian hoary bat (*Lasiurus cinereus semotus*) is the only native terrestrial mammal in Hawaiʻi.

Concern (HAPC), Essential Fish Habitat (EFH), the Hawaiian Islands Humpback Whale National Marine Sanctuary, Marine Protected Areas, designated critical habitat for the Hawaiian monk seal, and marine managed areas. Several Fisheries Management Plans designate EFH in Hawaiʻi, including pink snapper, sea bass, and giant trevally. A complete list of datasets and methods used to create the Hawaiʻi Marine Index can be found in Appendix A.4 and Appendix E.2.

2.6 Creating the Resilience Hubs

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

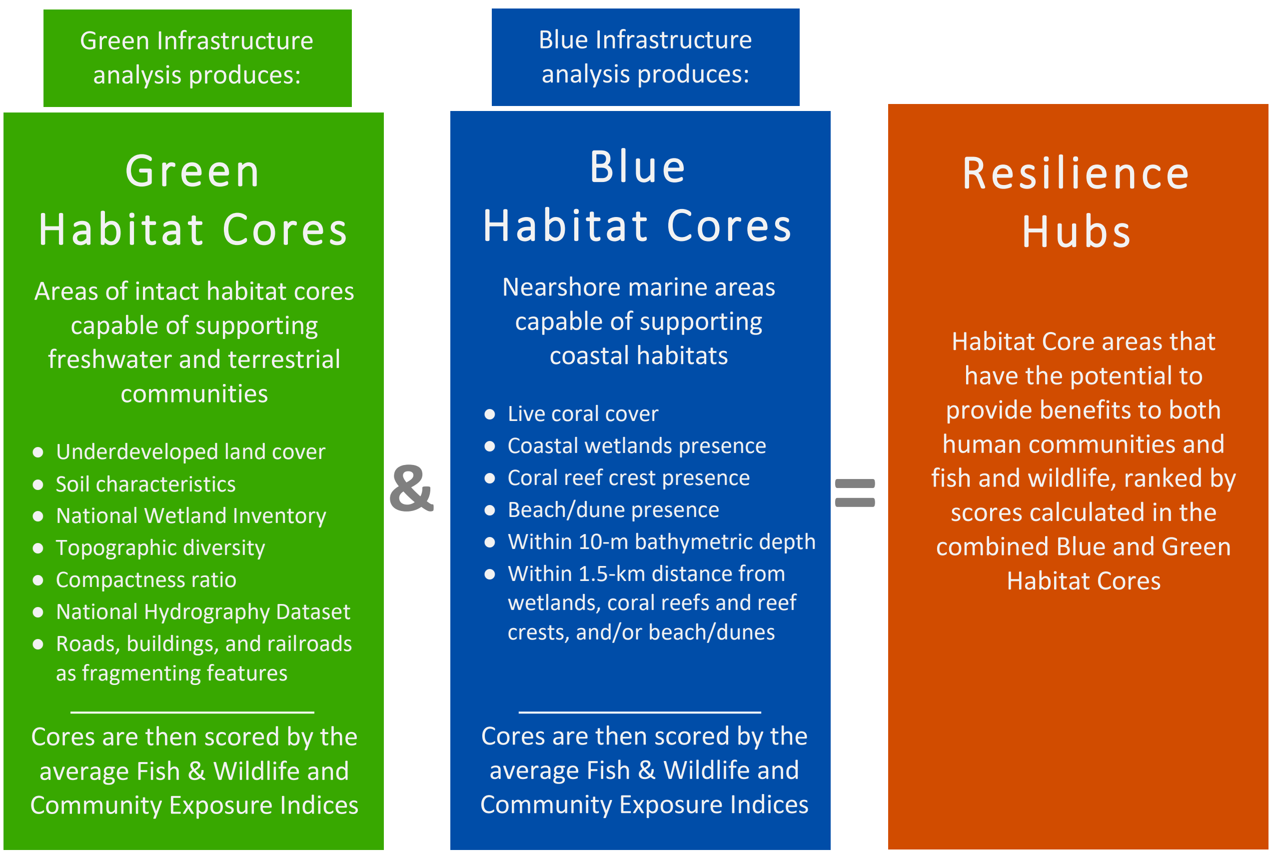

Figure 6. Elements of the Green and Blue Habitat Core outputs used to create the Resilience Hubs.

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

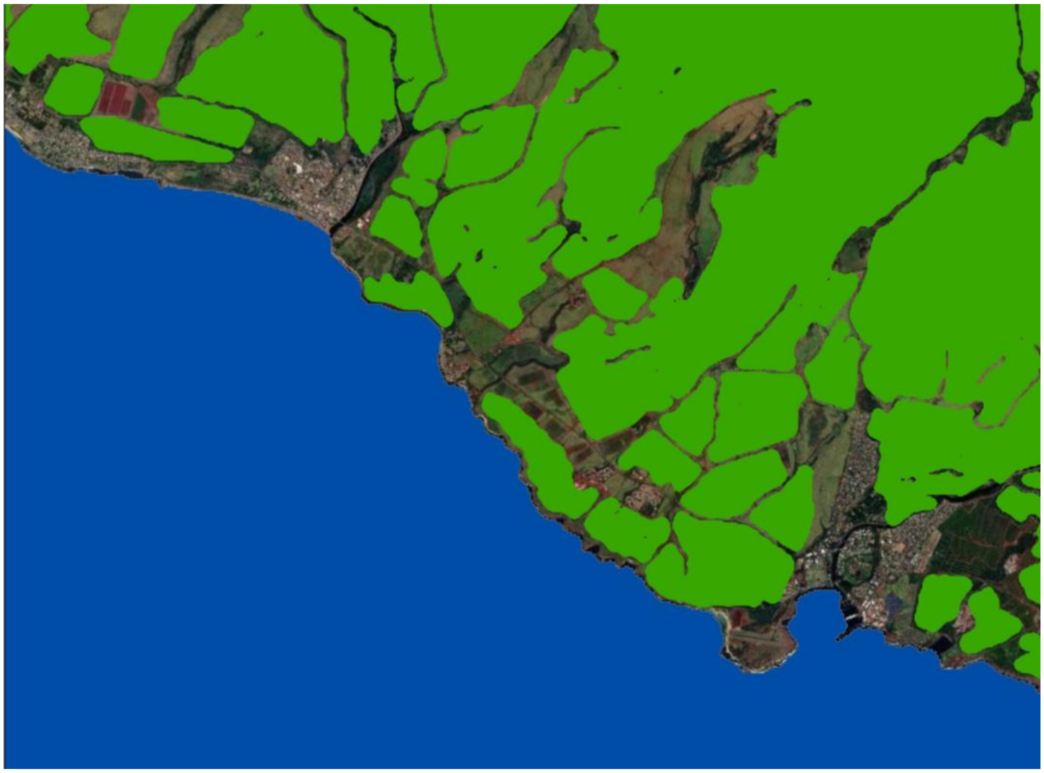

Figure 7. An initial step in creating the Green and Blue Habitat Cores. Note the Green Habitat Cores include both terrestrial and freshwater aquatic areas. The Blue Habitat data include coral cover, beach and dune, tidally influenced wetlands, coral reef crests, and nearshore marine areas less than 10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

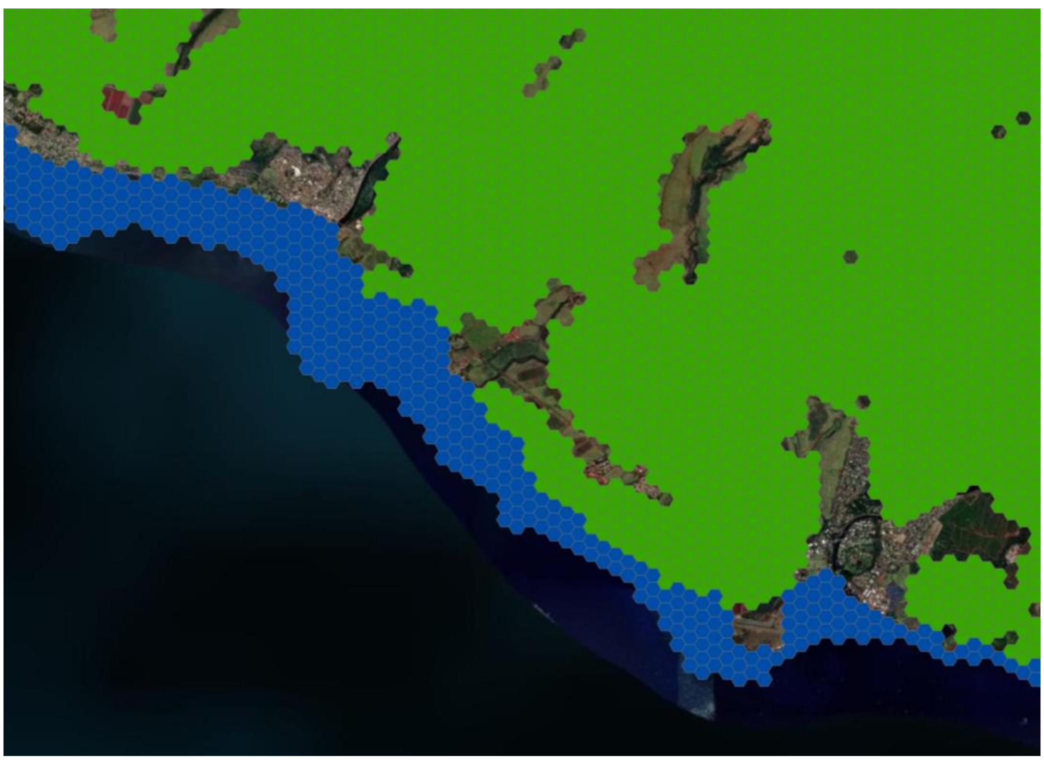

Figure 8. Green and Blue Habitat Cores converted to 4-hectare (10-acre) hexagons. As with each Habitat Core, each hexagon is later ranked to show variation within Resilience Hubs.

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

2.6.1 Green Infrastructure

The Green Infrastructure[5] 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 Hawaiʻi, NEMAC replicated the analysis to create this important layer for the Hawaiʻi 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 considers fragmenting features that may disrupt the movement of wildlife species.

Applying these methods to Hawaiʻi, 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).

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

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

2.6.2 Blue Infrastructure

Recognizing the prominence of valuable coastal marine habitats in Hawaiʻi, the Assessment developed a Blue Infrastructure[6] analysis. Marine and coastal habitats, such as coral reefs, wetlands, and beach and dune systems not only support significant biodiversity but are also important natural features that can protect human communities and infrastructure from flooding-related threats. 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 to identify Blue Habitat Cores, or marine and coastal areas represented by habitats that may be suitable for the implementation of conservation or nature-based resilience projects. The Blue Habitat Cores were delineated by creating a 4-hectare (10-acre) hexagonal grid of all coastal and marine habitats less than 10 meter in depth and then by grouping hexagons according to the Hawaiʻi bathymetric basins and the marine habitats they contain. Unlike the Fish and Wildlife Index, only habitats less than or equal to 10 meters in depth were considered in the Blue Infrastructure analysis since nature-based solutions are more likely to provide coastal protection when implemented in shallow water habitats. For full documentation on how the Blue Habitat Cores were created, please refer to Appendix F and Dobson et al. (2020).

2.6.3 Combining Habitat Cores and Ranking Resilience Hubs

To capture the potential impact the Green and Blue Habitat Cores may have on reducing the effects of coastal flooding on nearby community assets while also benefiting fish and wildlife, the Habitat Cores were scored using the average values of the Community Exposure and Fish and Wildlife Indices to determine the rankings of Resilience Hubs. After ranking, the lowest 10 percent of ranked cores were removed. 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.

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

RESULTS

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

The Community Exposure Index shows that areas of high exposure are concentrated around dense urban areas. Along the coastlines of each island, the Fish and Wildlife Index reveals a concentration of habitat types expected to support wildlife species. As expected, inland areas outside of urban centers show moderate values that support high concentrations of important habitat for species of concern. Finally, the Resilience Hubs show that there are numerous Hubs across all islands, both along the coastline and inland. For the purposes of this report, the results for all islands are described separately; however, a single model was used for all eight islands, which allows results to be directly compared within and among islands.

3.1 Community Exposure Index

The Community Exposure Index for the State of Hawaiʻi shows that exposure is mainly concentrated around the densely populated urban areas along the coast. With an average population density of 220.5 people per square mile and with the vast majority of residents living along the shoreline, it is unsurprising that low-lying, populated areas are most exposed to flooding threats. Throughout the state, the highest exposure values were associated with the most populous cities, including Hilo, Kahului, and Honolulu, whereas the lowest exposure values are found on the sparsely populated (or uninhabited) islands of Niʻihau, Molokaʻi, Lānaʻi, and Kahoʻolawe (Figures 10 and 11). When compared to other coastal regions of the United States, Hawaiʻi does not contain vast stretches of highly exposed coastline. In fact, outside of the urban centers, coastal areas around each island exhibit consistently low exposure values. This is likely due to the topography of the coastline, which not only prevents high concentrations of community assets from being located directly near the water in many places, but also results in relatively low values for several flood-related threats.

The Threat Index reveals that flood-related threats affect nearly all coastlines throughout the island chain. However, cumulatively across all inputs, there are relatively few areas that are highly threatened by the coastal flood threats. The highest Threat values are seen along the west coast of Kauaʻi, the southeastern coast of Oʻahu, central Maui, and the northeastern coast of Hawaiʻi Island (Figures 10 and 11). The topography of the islands strongly influences the presence of flood-related threats and their impacts on the landscape. For example, apart from bays and inlets, the islands feature relatively few low-lying areas capable of pooling water. In addition, inputs such as sea level rise, storm surge, and tsunami inundation are all limited to the immediate coastline. Except for impervious surfaces around densely populated areas, most of the landscape features well- to moderately well-drained soils that help to minimize flooding risks. Relatively high Threat Index values within the interior portions of the islands are largely driven by landslide susceptibility and soil erodibility.

While the topography of the region may result in fewer areas of high flooding threat, portions of Hawaiʻi are densely populated, leaving important community assets exposed to the impacts of flooding. The

Community Asset Index identifies concentrations of developed, populated areas (Figures 10 and 11); however, important community assets can be seen throughout the islands, including roads, communication infrastructure, ports, and airports, all of which are critical for effective emergency response in the event of major flooding.

At the island-scale, Oʻahu clearly features the highest Community Exposure Values. By focusing on the city of Honolulu, finer-resolution patterns in exposure become evident (Figure 12). The Threat Index is mostly driven by storm surge, low lying areas, and the prevalence of impervious surfaces. As expected for a city of this size, the Community Asset Index is influenced by population density and social vulnerability, with high concentrations of both critical infrastructure and facilities throughout. Together, patterns of high exposure are evident throughout southern Oʻahu. Even within the central portions of the island, near the Schofield Barracks (Figure 11), there are areas of very high exposure due to the presence of numerous critical facilities and a relatively high population. When combined with low slope, erodible and impermeable soils, and landslide susceptibility, the Barracks are highly exposed to flooding 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 below.

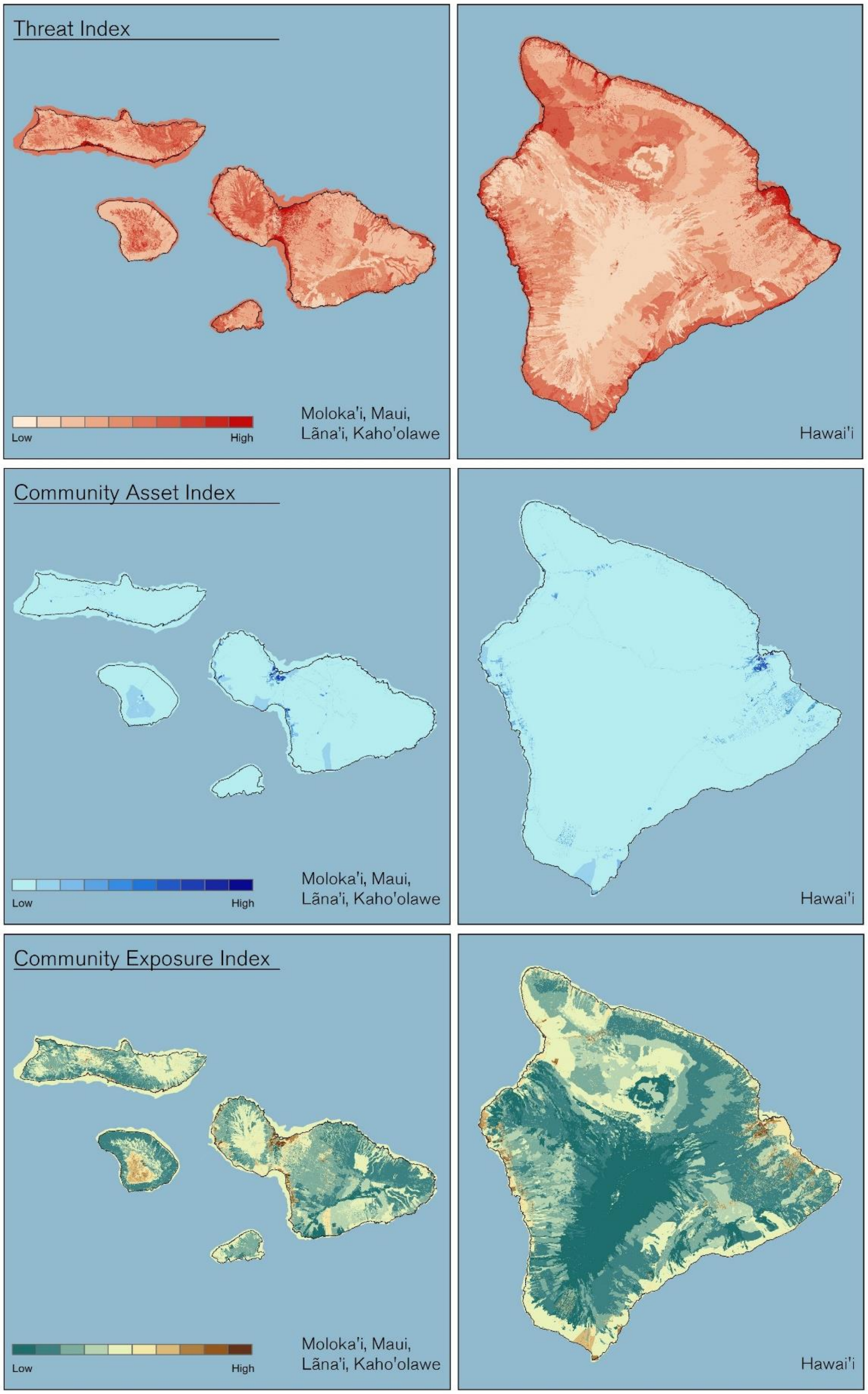

Figure 10. Threat, Community Asset, and Community Exposure Indices for the islands of Molokaʻi, Lānaʻi, Maui, Kahoʻolawe, and Hawaiʻi. The Threat and Community Asset Indices are multiplied to produce the Community Exposure Index, which shows areas where assets overlap flood threats. To view results in detail, see Appendix G or view results in CREST.

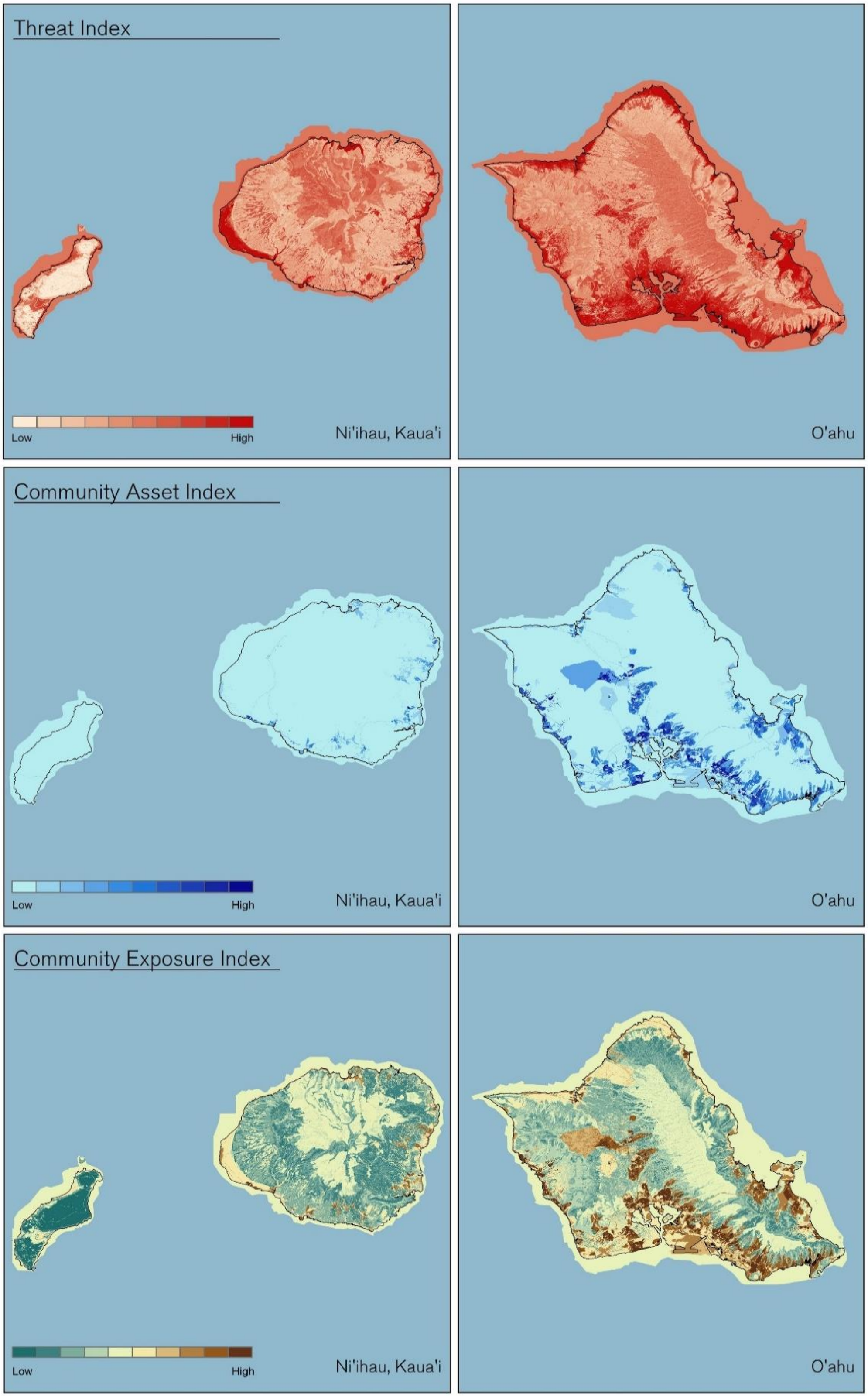

Figure 11. Threat, Community Asset, and Community Exposure Indices for the islands of Niʻihau, Kauaʻi, and Oʻahu. The Threat and Community Asset Indices are multiplied to produce the Community Exposure Index, which shows areas where assets overlap flood threats. To view results in detail, see Appendix G or view results in CREST.

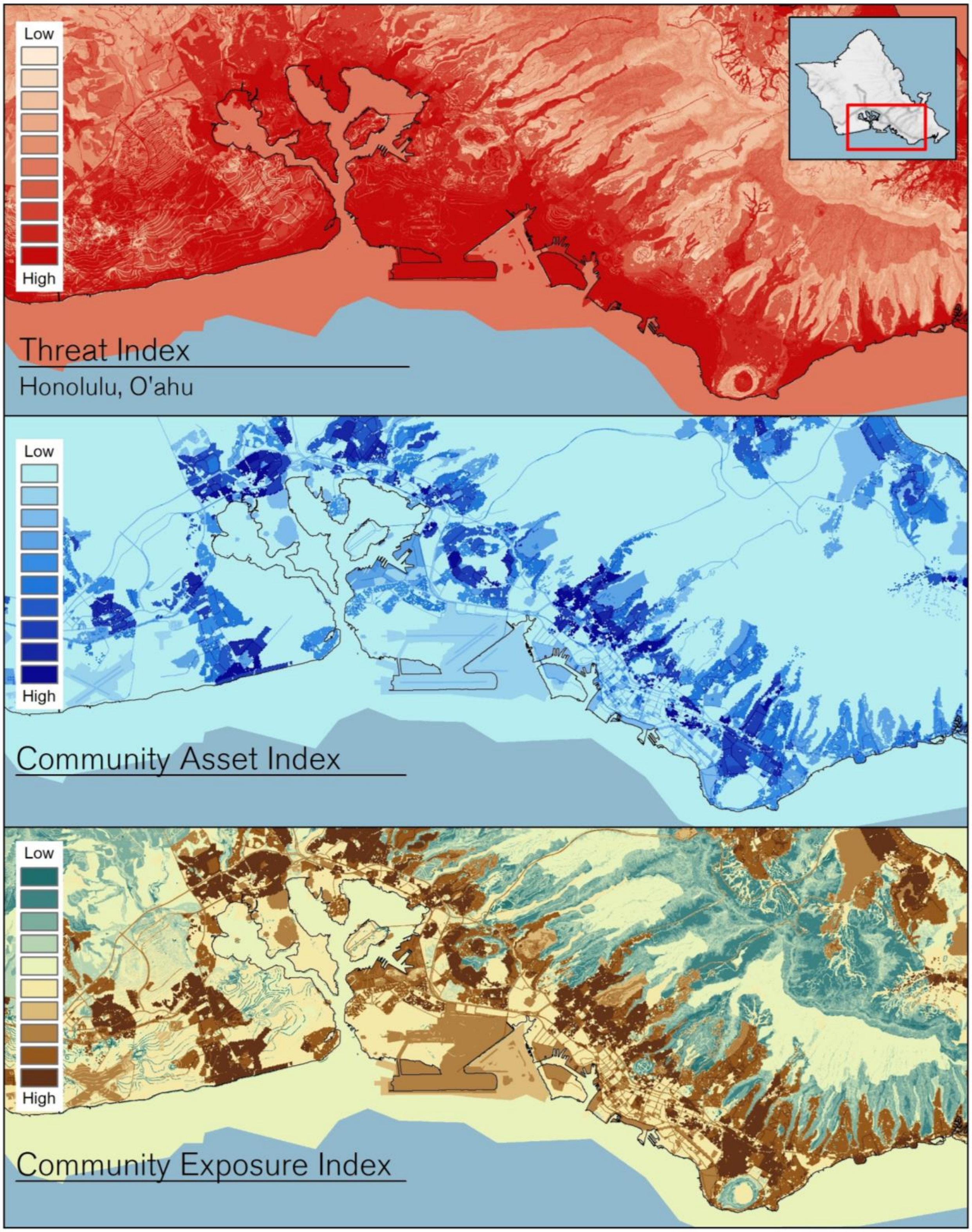

Figure 12. Honolulu, O'ahu and surrounding communities show higher values of exposure, resulting from the combination of flood threats and community assets.

3.2 Fish and Wildlife Index

The combined Fish and Wildlife Index shows the highest values within productive nearshore marine waters and biodiverse forests along the islands' mountain ranges (Figures 13 and 14). Due to the additive nature of the Fish and Wildlife Index, the highest values are all observed in coastal waters where healthy marine habitats coincide with terrestrial resources such as seabirds and sea turtles. This is evident in Hanalei Bay in northern Kauaʻi where there is primary habitat for dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*) and green sea turtle (Honu)*(Chelonia mydas)*. In other instances, high values are driven by overlapping features, such as areas that are designated for protection or conservation by multiple agencies. This is particularly apparent in the Marine Index. For instance, and perhaps counterintuitively due to the heavy development in this area, the southeastern shore of Oʻahu between Māmala Bay and Maunalua Bay receives a moderate-high value in both the Terrestrial and Marine Indices. The presence of several protected and managed areas, such as designated critical habitat for the Hawaiian monk seal (*Neomonachus schauinslandi*), the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS), Essential Fish Habitat (EFH), and Marine Managed Areas by the Hawaiʻi Division of Aquatic Resources contributes to this high score. While the highest scoring areas are evident, there are significant fish and wildlife assets throughout all eight islands, indicating there are ample opportunities for habitat conservation and restoration projects to sustain Hawaiʻi's incredible biodiversity.

As noted in the Methods section, the Terrestrial Index evaluated habitat suitability across species groups. Due to the proportionally low number of native terrestrial mammals, freshwater fishes, invertebrates, and reptiles listed in the Hawaiʻi State Wildlife Action Plan (Hawaiʻi DLNR 2015), birds dominated the Terrestrial Index. Higher concentrations of wildlife assets in the Terrestrial Index along the coastlines highlight the importance of coastal habitats for migratory birds, sea birds, waterbirds, and sea turtles (Figures 13 and 14). Forest birds and raptors dominate the interior areas of each island, in addition to numerous overlapping protected or managed areas. For a complete list of species referenced for this analysis, see Appendix E.1.

The Marine Index reveals many very high values around each island, highlighting the importance of marine habitat and species throughout the region (Figures 13 and 14). This is largely driven by the prevalence of coral reefs and marine managed areas throughout the state. Despite recent bleaching events, live coral cover was relatively high along large reef tracts in southwestern Maui, eastern Lānaʻi, and western Hawaiʻi Island. In addition to the presence of corals, these areas also feature EFH for resource fishes, designated critical habitat for the Hawaiian monk seal, and are located within the HIHWNMS. Together, these features all indicate these regions harbor significant marine biodiversity.

Some of the highest Marine, Terrestrial, and combined Fish and Wildlife values identified in the Hawaiʻi Assessment are found along the southern coast of Molokaʻi (Figure 15). Here, high values result from a combination of marine and coastal habitat used by *both* marine and terrestrial species. Over 20 miles in length, the fringing reef off the Southern Molokaʻi shore is the longest and among the healthiest coral reefs in Hawaiʻi. In addition to very high coral cover, Marine Index values are driven by moderate reef fish biomass and the presence of EFH, Hawaiian monk seal critical habitat, and the HIHWNMS. This area also features habitat important to reptiles, sea birds, and migratory birds, contributing to an increased combined Fish and Wildlife Index score for this region. While many of southern Molokaʻi's wetlands are highly degraded by invasive mangroves, they were once home to threatened waterbirds populations that would likely benefit from habitat restoration efforts in this area. To explore the results of the analysis in more detail for any area of interest, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4 below.

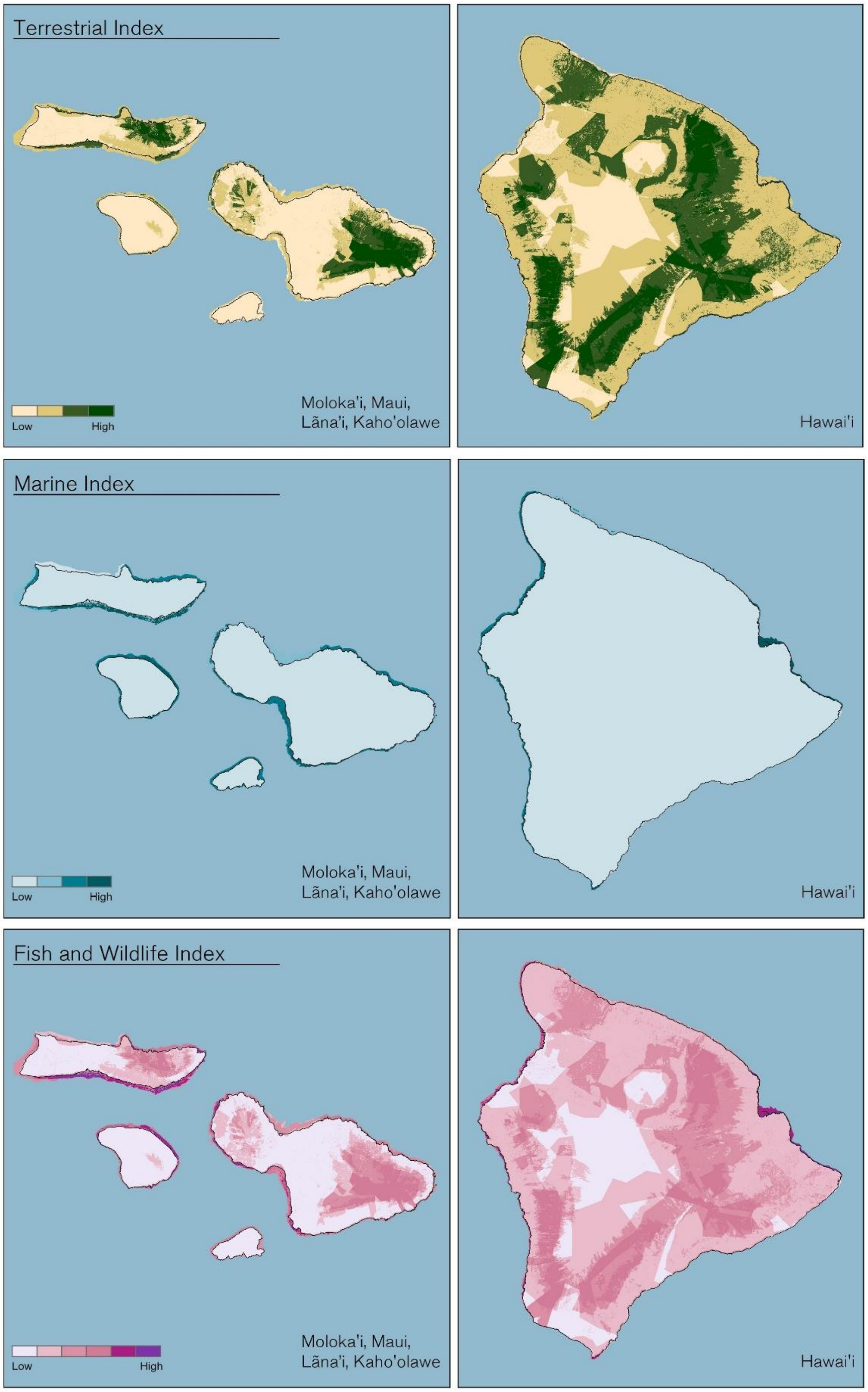

Figure 13. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for the islands of Molokaʻi, Lānaʻi, Maui, Kahoʻolawe, and Hawaiʻi. Terrestrial and Marine Indices are added to produce the Fish and Wildlife Index, which shows concentrations of fish and wildlife species and their habitats. To view results in detail, see Appendix G or view results in CREST.

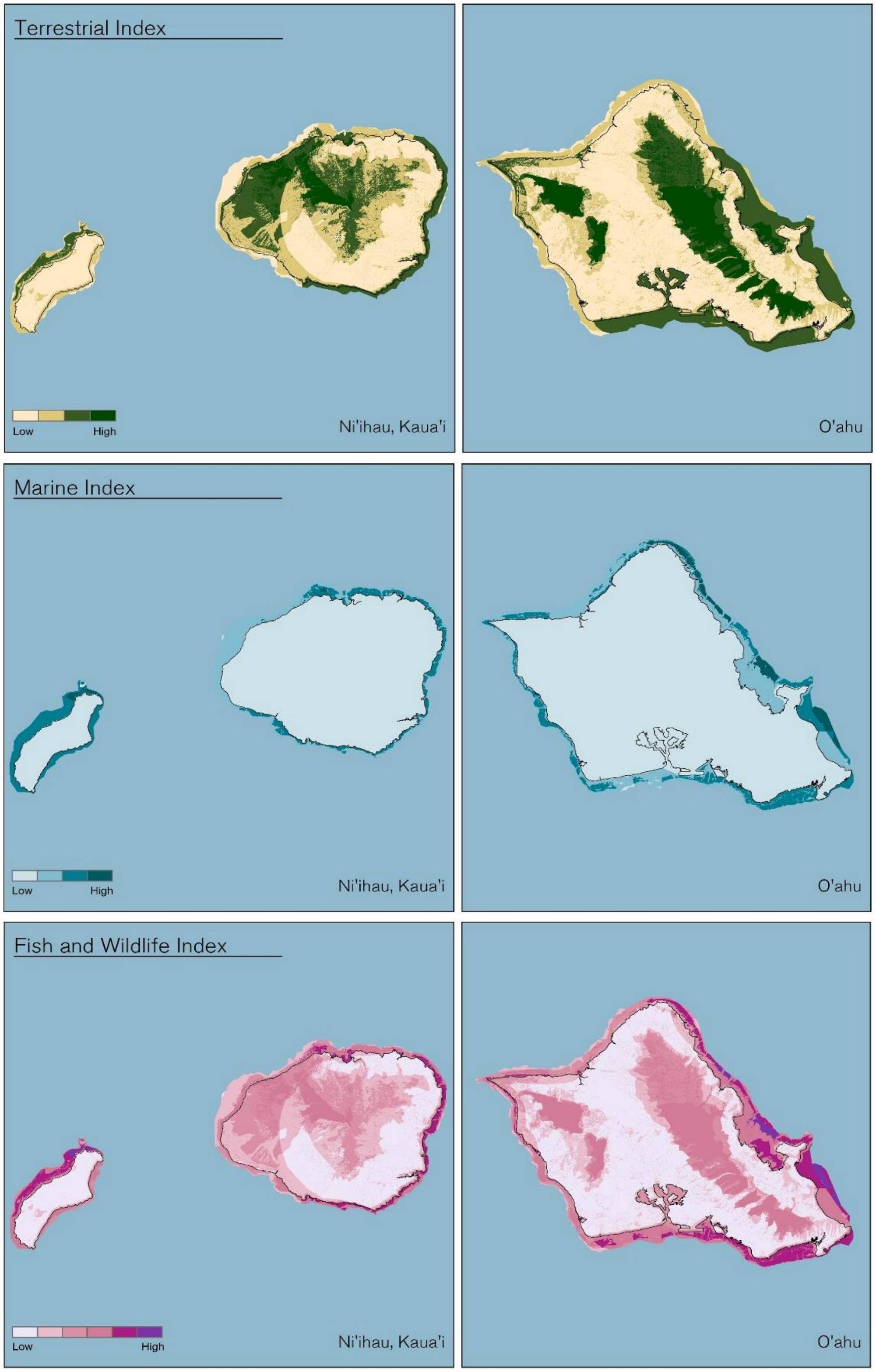

Figure 14. Terrestrial Index, Marine Index, and the resulting Fish and Wildlife Index for the islands of Niʻihau, Kauaʻi, and Oʻahu. The Terrestrial and Marine Indices are added to produce the Fish and Wildlife Index, which shows concentrations of fish and wildlife species and their habitats. To view results in detail, see Appendix G or view results in CREST.

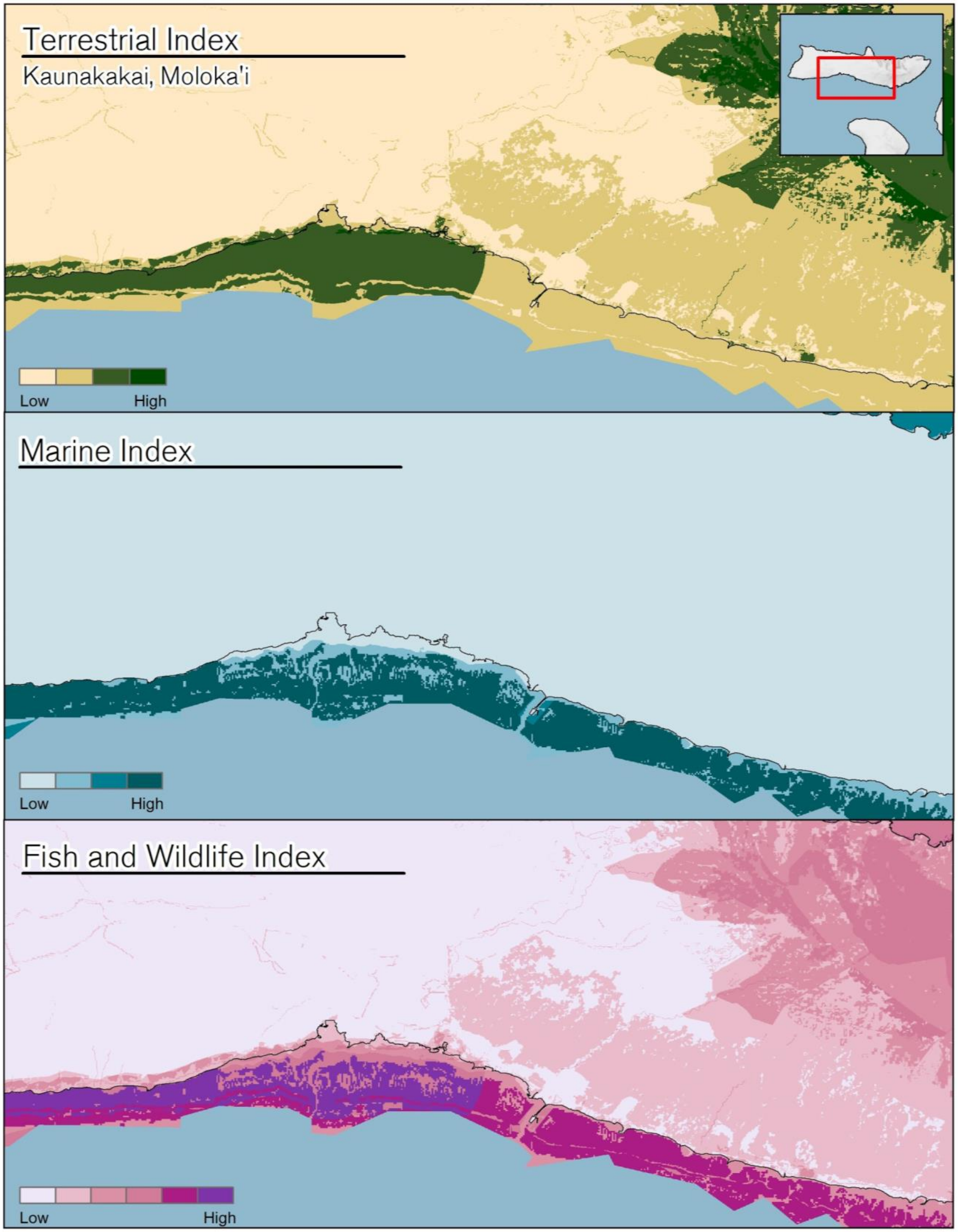

Figure 15. The southern coast of Moloka'i, near Kaunakakai, shows higher values in both the Terrestrial and Marine indices, resulting in medium to high values in the Fish and Wildlife Index. This is a result of a combination of the presence of several important marine and coastal habitats utilized by marine and terrestrial species.

3.3 Resilience Hub Analysis

The Hawaiʻi Assessment identified many Resilience Hubs covering much of the state (Figures 16 and 17). While Oʻahu features many of the highest ranking Resilience Hubs, the assessment revealed ample opportunities throughout the main Hawaiian islands to implement nature-based solutions 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. Figures 16 and 17 show the ranked Blue and Green Habitat Cores and how they are combined to create the final Resilience Hub rankings. Due to the extensive presence of coral reefs and vast tracts of natural land cover with few fragmenting features, the analysis identified many, large Resilience Hubs. However, only high-ranking Hubs represent areas with significant potential for nature-based solutions to achieve benefits for fish and wildlife while also reducing flooding risk to important human community assets. Therefore, high-ranking hubs in portions of Kauaʻi, Molokaʻi, Maui, Hawaiʻi Island, and throughout Oʻahu, show the greatest potential for dual benefits and may be best suited for the implementation of nature-based solutions. In contrast, the less populated (or uninhabited) islands of Niʻihau, Lānaʻi, and Kahoʻolawe feature few high-ranking Hubs.

On Oʻahu, higher-ranked Resilience Hubs can be found across most of the island, particularly in Kāneʻohe Bay and within the Koʻolau and Waiʻanae mountain ranges (Figure 16). This is due in part to the extensive presence of coral reef and wetland habitats, and the analysis revealed 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). 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). High ranking Green Habitat Cores are also found along the relatively undeveloped mountain ranges, where highly endangered native forest birds and invertebrates remain. While the Community Exposure Index revealed relatively low exposure along the mountain ridges, high ranking Hubs are still visible. This is in part driven by high Fish and Wildlife values but is also the result of large tracts of contiguous open space where at least a portion of nearly any given Resilience Hub is in close proximity to community assets threatened by flooding.

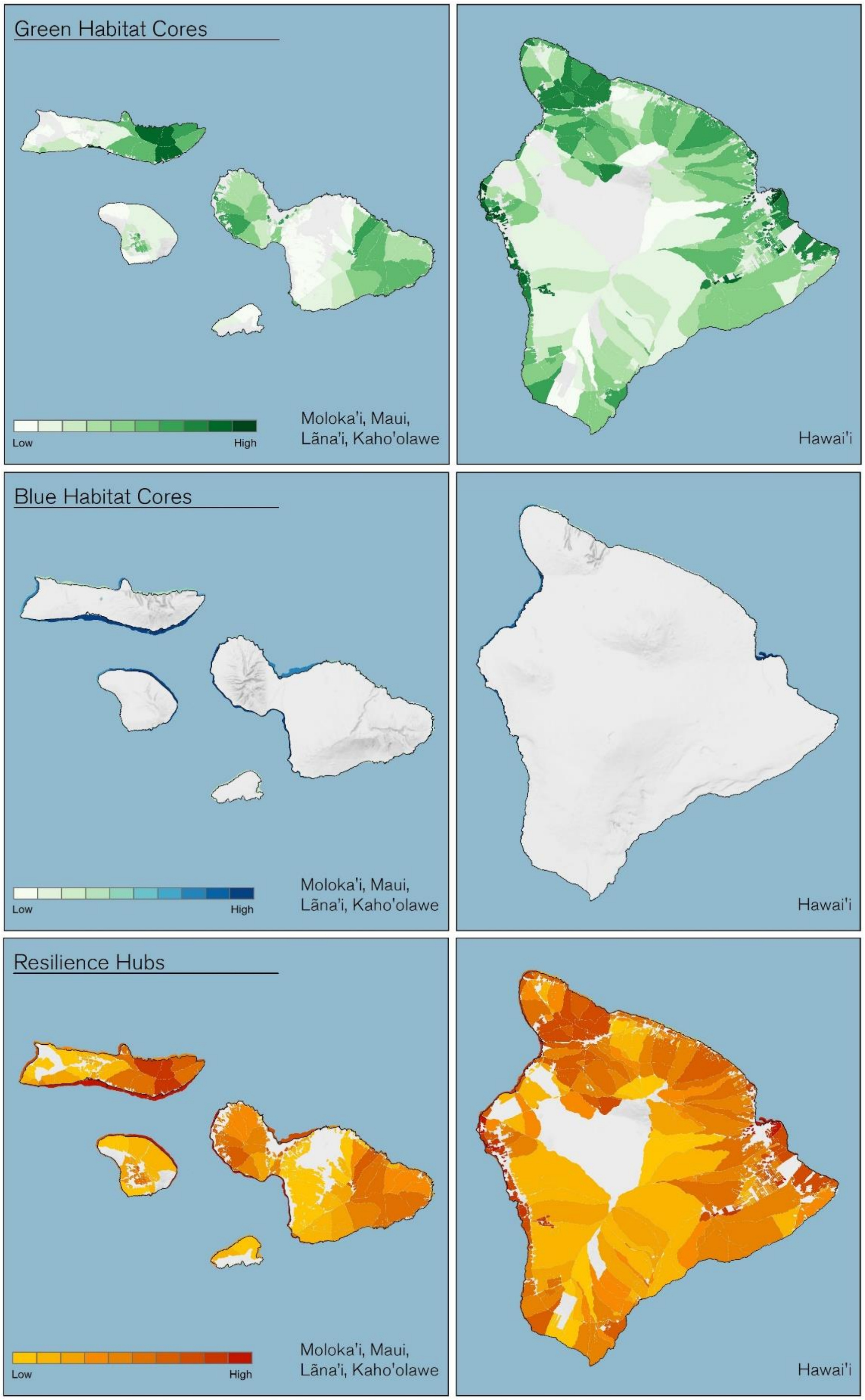

Figure 16. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for the islands of Moloka'i, Lāna'i, Maui, Kaho'olawe, and Hawai'i. To view results in detail, see [Appendix G](#) or view results in [CREST](#).

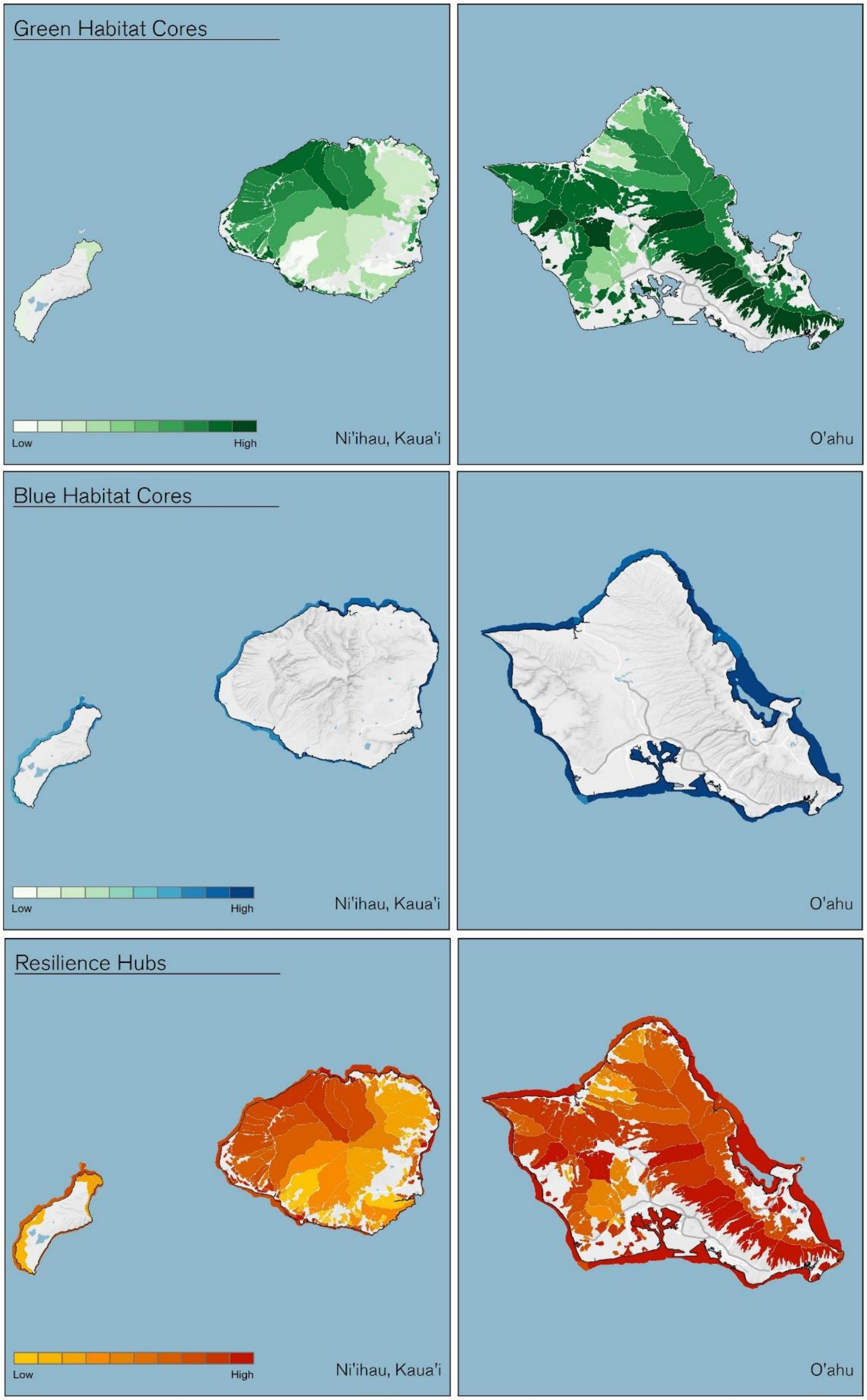

Figure 17. Green Habitat Cores, Blue Habitat Cores, and Resilience Hubs for the islands of Niʻihau, Kauaʻi, and Oʻahu. To view results in detail, see Appendix G or view results in CREST.

Resilience Hub size also varied considerably between islands, due in part to the large amount of open and natural land cover found in the interior of most islands (Figures 16 and 17). This is particularly evident along the coast between Kailua-Kona and Captain Cook on the western coast of Hawaiʻi Island, where numerous small habitat cores line the shore in contrast to very large, contiguous Green Habitat Cores further inland (Figure 18). As the waters on the Big Island quickly exceed 10 meters in depth, the Blue Habitat Cores in this area are relatively small with highly variable ranks. Similarly, small and highly ranked Green Habitat Cores are concentrated along the coast due to their proximity to community assets and presence of terrestrial habitat. When the two are combined, the Resilience Hubs highlight many areas of opportunity for restoration projects. To explore the results of the analysis in more detail for any area of interest throughout Hawaiʻi, visit the Coastal Resilience Evaluation and Siting Tool (CREST) at resilientcoasts.org. For more details about CREST, please refer to Section 3.4 below.

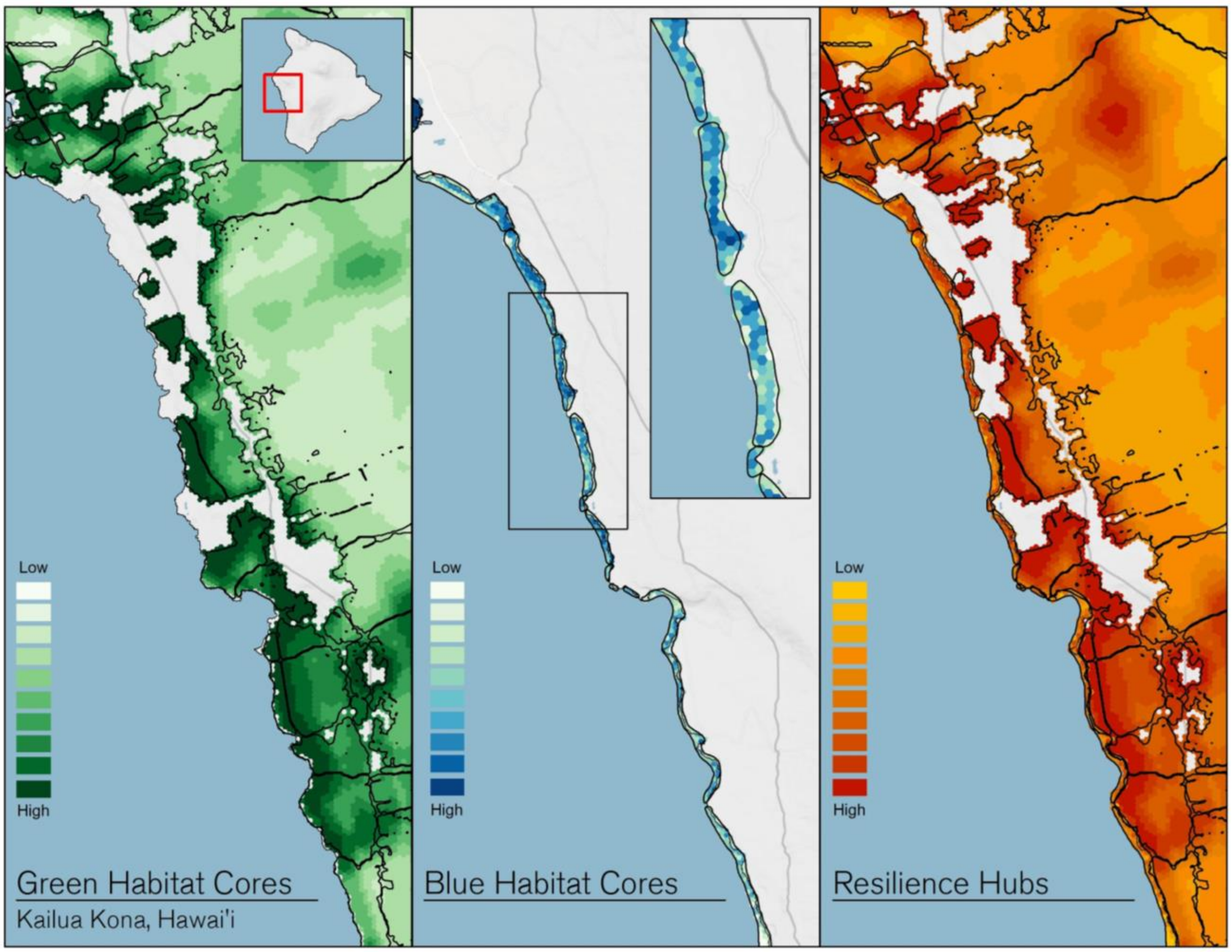

Figure 18. The area around Kailua Kona on the western coasts of Hawaiʻi Island shows a range of ranked Resilience Hub scores. Variability within Resilience Hubs is visible within the 4-hectare (10-acre) hexagons. The inset map for Blue Habitat Cores further highlights the variability in this area.

3.4 Coastal Resilience Evaluation and Siting Tool

To provide an online interface to allow users to interact with key Assessment data, including input data and final models for the Community Exposure Index, Fish and Wildlife Index, and the Resilience Hubs, the Coastal Resilience Evaluation and Siting Tool (CREST) was developed as an accompanying GIS-based web tool (available at resilientcoasts.org). CREST helps users make informed decisions about proposed project sites and address other key questions about how to build resilience within their community. It also allows users full access to the Hawaiʻi Assessment data so they may incorporate them into their own GIS applications or other planning processes. For instance, the islands of Oʻahu, Kauaʻi, and Maui have data related to groundwater recharge, which can be a critical consideration for local resilience planning; GIS users can incorporate local groundwater data with data from the Assessment downloaded through CREST into their more specific planning efforts. 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 Hawaiʻi 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 STUDIES

4.1 Watershed Restoration to Build Resilience

Coastal wetland and coral reef ecosystems provide myriad benefits, from offering coastal protection to providing habitat for numerous endangered and economically important species. Throughout Hawaiʻi, coastal wetlands play a critical role in shoreline stabilization and groundwater recharge, while also reducing the impacts of flooding and polluted runoff. However, extensive development coupled with the spread of invasive species have greatly reduced the number and condition of wetlands throughout the Archipelago (Hiromasa Browning 2020). In the most densely populated island of Oʻahu, as many as 65 percent of wetlands have been lost. Of those that remain, more than 75 percent are highly degraded offering limited ecological function (van Rees 2018). Degraded wetland systems have a reduced ability to retain stormwater and polluted runoff, 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 and around Kāneʻohe Bay on Oʻahu highlight how restoring multiple habitat types can strengthen coastal resilience for surrounding communities and important wildlife resources. For decades, community-led efforts in the ahupuaʻa (land division) of Heʻeia have worked mauka to makai to protect the watershed from the highest ridges to the outer coral reef. With funding from the National Coastal Resilience Fund[7] and other sources, two recent projects are working to restore both coastal wetlands and adjacent coral reefs in Kāneʻohe Bay. The Nature Conservancy will lead the restoration of 26 acres of coastal wetlands in the Heʻeia National Estuarine Research Reserve as researchers from the Hawaiʻi Institute for Marine Biology work to restore nearby coral reefs (Figure 19). The following case study describes both projects, using the Hawaiʻi Assessment results to demonstrate the utility of various outputs to evaluate potential locations to site and plan similar types of resilience efforts.

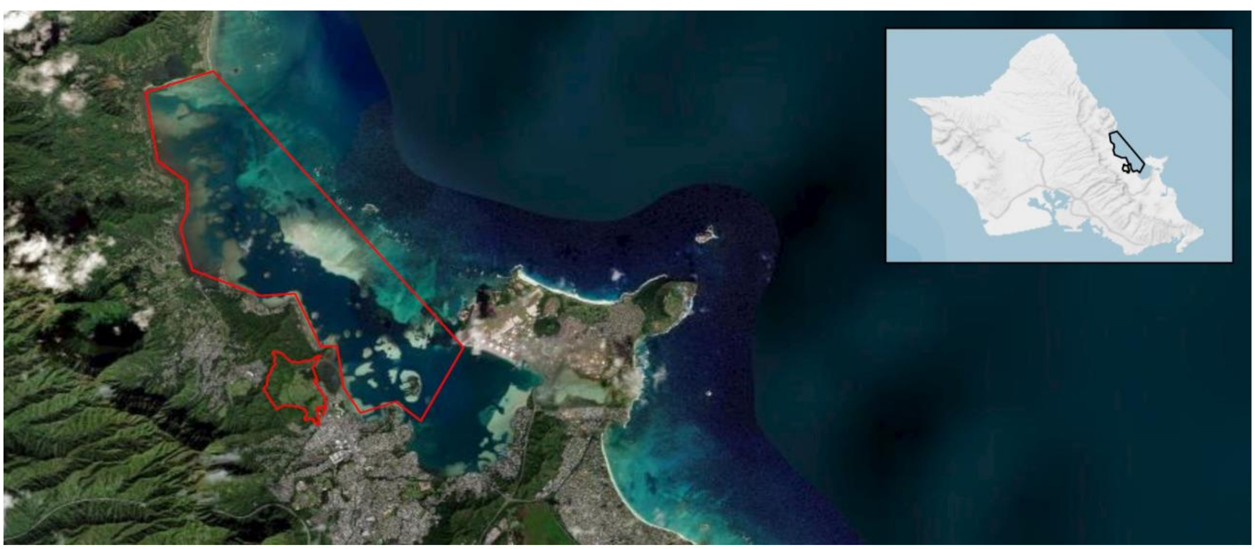

Figure 19. Map showing the location of wetland (left) and coral reef (right) restoration projects in Kāneʻohe Bay on east Oʻahu.

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

Including the communities of Kāneʻohe, ʻĀhuimanu, and Kahaluʻu, Kāneʻohe Bay is home to a growing population of over 30,000 residents. Decades of industrialized agriculture and urbanization have altered the landscape, leaving coastal communities vulnerable to flooding from large rain events. For instance, in 2016 Tropical Storm Darby produced over nine inches of rain in just 24 hours, causing widespread flooding. Such events also convey large volumes of sediment and nutrient-laden runoff into the Bay, threatening sensitive coral reef ecosystems. When the effects of inland flooding are coupled with the impacts of storm surge and sea level rise, the results of the Hawaiʻi Assessment reveal that the communities around Kāneʻohe Bay are exposed to significant flooding threats (Figure 20). With storms expected to increase in frequency and intensity due to climate change, projects that restore and protect natural systems are more important than ever to buffer communities from the impacts of flooding. For instance, the impacts of storm surge (Figure 21) and sea level rise (Figure 22) demonstrate the importance of the ongoing wetland and coral restoration efforts in the area.

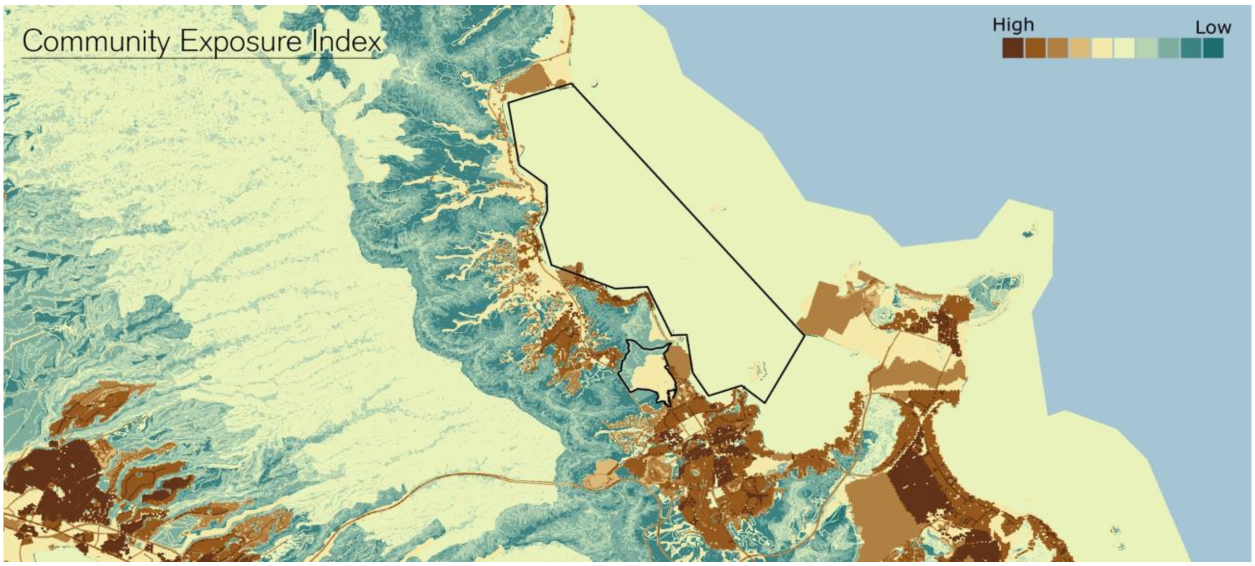

Figure 20. The Community Exposure Index results for Kāneʻohe Bay reveal significant exposure to flooding threats throughout the Bay. The black lines outline the wetland and coral restoration project locations.

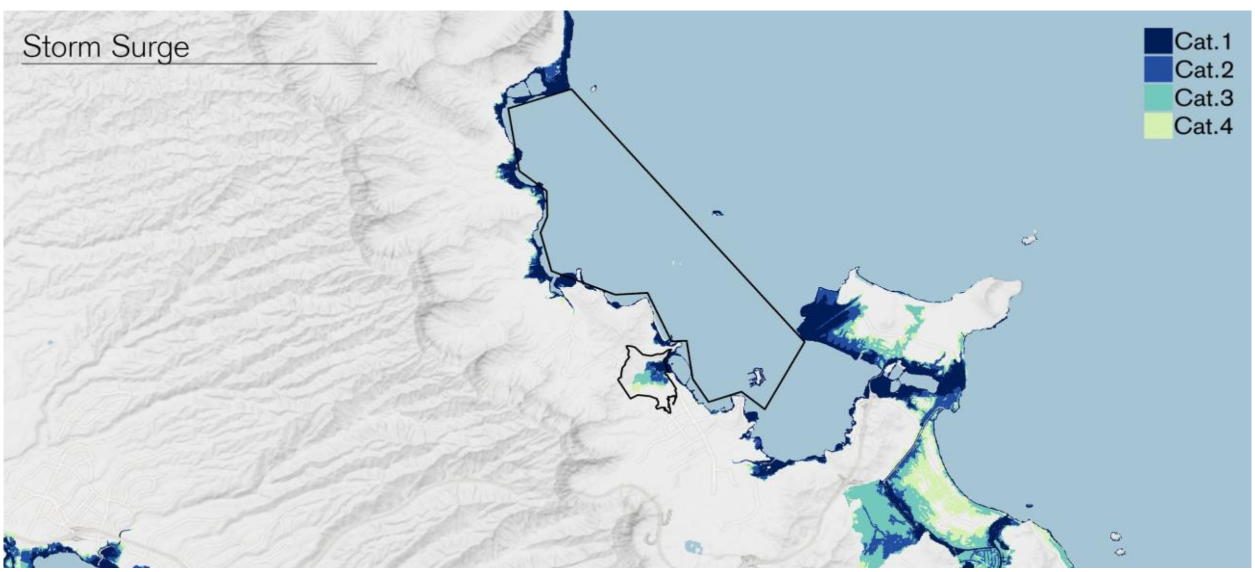

Figure 21. Wetland and coral reefs can help to minimize the impacts of flood threats such as storm surge. The black lines outline the wetland and coral restoration project locations.

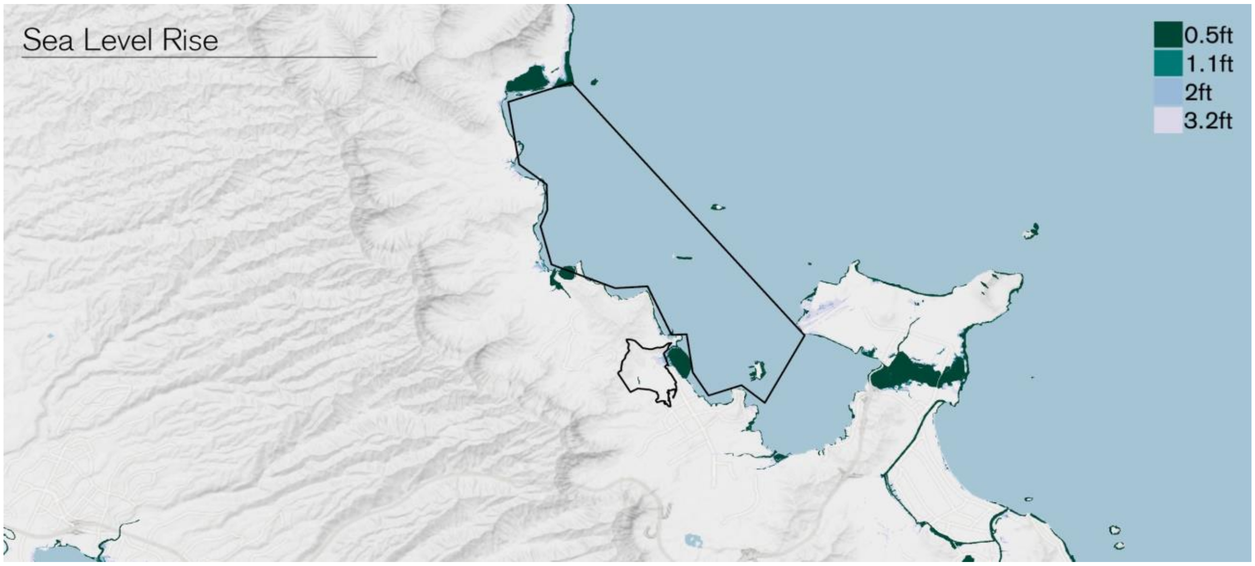

Figure 22. Wetland and coral reefs can help to minimize the impacts of flood threats such as sea level rise. Over time, sea level rise will exacerbate other flood-related threats. The black lines outline the wetland and coral restoration project locations

4.1.1 Restoring the He'eia Wetlands

Local planning efforts have long highlighted the importance of restoring and conserving the highly degraded wetland system at the mouth of the He'eia stream. In the early 1900s, red mangroves (*Rhizophora mangle*) were introduced to the Hawaiian Islands (Hiromasa Browning 2020). While in other parts of the world, mangroves are noted for their coastal protection and ecosystem benefits, in Hawai'i, invasive mangroves forests alter estuarine function and negatively impact native species. In the He'eia stream, thick mangrove stands block passage and reduce available nursery habitat for native and important resource fishes (Figure 23).

Figure 23. Degraded wetlands at the mouth of the He'eia stream. Left: Invasive red mangrove trees cover the streambanks while invasive mosquito fern (Azolla spp.) covers the water surface. Right: Restored area after mangroves have been cut but not removed, clearing the area so native species can be planted. Photo Credits: Bridget Lussier, NOAA (left), Kanekoa Shultz, TNC (right).

In response, The Nature Conservancy (TNC) in partnership with the Hawai'i Department of Aquatic Resources, is working to restore 26 acres of degraded coastal wetland to provide flood protection, reduce land-based sources of pollution, and remove barriers to fish passage on the He'eia stream. The project builds upon recent, successful efforts to remove invasive mangroves from six acres of wetland

(Figure 23). TNC and partners will work to remove mangroves from an additional six acres, taking measures to minimize sediment loss into the Bay by leaving the mangroves' submerged root system in place. With the mangroves removed, the team can plant native vegetation, helping to restore natural estuarine function while opening nearly half a mile of the stream channel for fish passage.

In addition to restoring the wetlands at the mouth of Heʻeia stream, TNC will also maintain and enhance the function of an additional 14 acres of wetland habitat further inland. The project will restore wetlands with loʻi kalo (taro fields), creating habitat for birds, fishes, and other species while maintaining traditional Hawaiian agricultural practices. The constructed wetlands will also serve as retention basins capable of slowing the flow of water during storm events, helping to protect the dense concentration of community assets surrounding the project site (Figure 24).

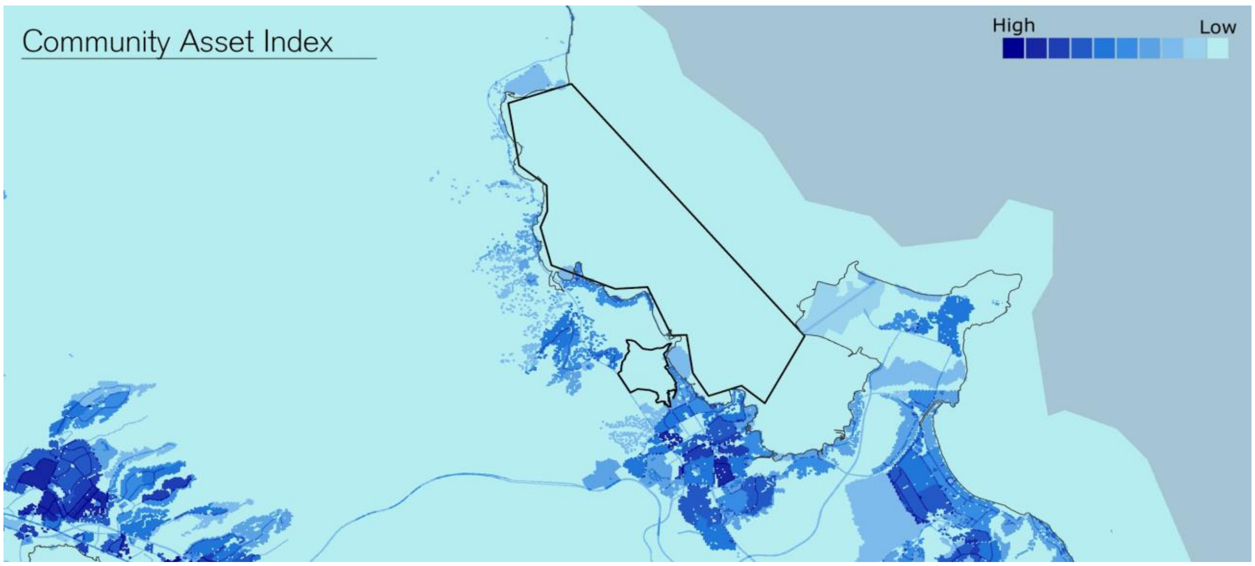

Figure 24. The Community Asset Index shows dense concentrations of community assets throughout the Kāneʻohe Bay. The black lines outline the wetland and coral restoration project locations. Note the high density of community assets surrounding the wetland restoration site north of Kāneʻohe.

The constructed wetlands will increase the residence time and facilitate sediment and nutrient retention. Together, these efforts are expected to retain approximately 400 tons of sediment per year on the landscape, reducing the amount of sediments reaching the nearshore fishpond and coral reefs (Figure 25). This project exemplifies integrating habitat restoration with food security, native and endangered species conservation, coastal storm protection, and managing land-based sources of sediment to protect coral reefs.

Figure 25. Aerial view of the Heʻeia watershed and wetlands. Extensive mangrove forests can be seen along the coast and border the Heʻeia fishpond. Portions of the cleared agricultural lands will be restored with constructed wetlands and loʻi kalo (taro fields). Photo Credit: Manuel Mejia, TNC.

4.1.2 Coral Reef Restoration

Kāneʻohe Bay is the largest sheltered bay in Hawaiʻi, supporting a large fringing coral reef that serves as a living seawall capable of dissipating wave energy and protecting nearby shorelines. However, multiple local and global stressors threaten coral reef ecosystems in Kāneʻohe Bay and across Hawaiʻi, potentially limiting their ability to provide both coastal protection and biodiversity benefits. The wetland restoration efforts described above and throughout the Heʻeia watershed will improve water quality for adjacent coral reefs by reducing sediment and nutrient pollution.

Despite these improvements, additional conservation efforts are required to help protect coral reefs from the devastating effects of warming ocean temperatures due to climate change. In the last five years, Hawaiʻi has experienced an unprecedented series of three bleaching events causing widespread coral morality. In Kāneʻohe Bay, researchers from the Gates Coral Lab at the Hawaiʻi Institute of Marine Biology (HIMB) discovered that some coral species, and individual colonies of the same species, are more resistant to bleaching than others and may be considered more thermally-tolerant (Figure 26). Identifying thermally-tolerant coral stocks and growing them in underwater coral nurseries will enable HIMB researchers to collaborate with DAR, NOAA, and local partners in restoring reefs with corals that not only survive today but persist under future conditions.

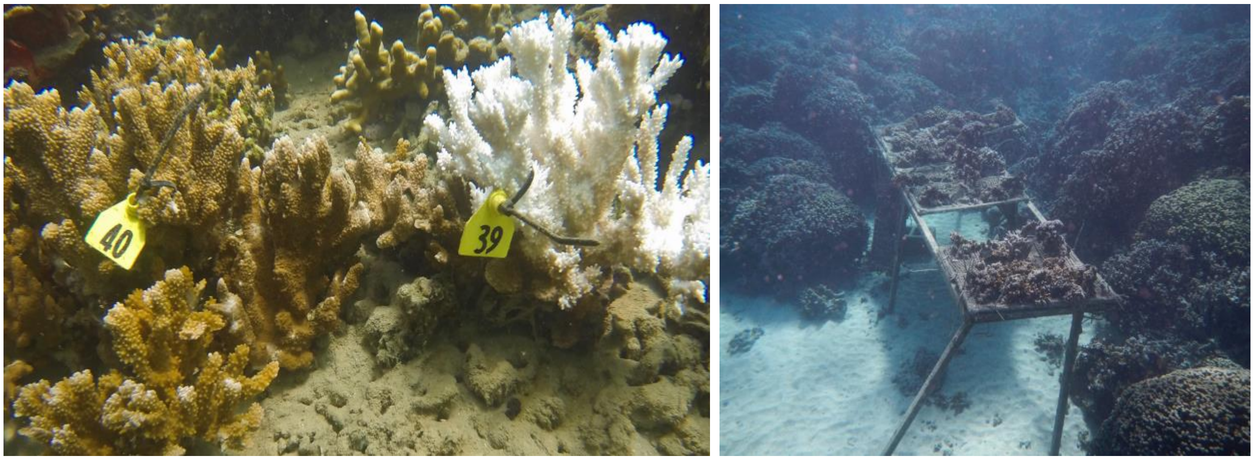

Figure 26. Coral restoration efforts in Kāneʻohe Bay. Left: During the 2015 bleaching event, both bleached (tag #39) and healthy (tag #40) coral colonies could be found side-by-side. Right: Bleaching resistant coral fragments are attached to nursery tables. Photo Credits: Chris Wall (left), Julia Royster, NOAA (right).

The project will establish two nurseries in Kāneʻohe Bay that will allow for stress-resistant corals to be outplanted to suitable sites throughout the area. The outplanted corals will provide immediate benefits to surrounding communities and are expected to continue to grow and provide benefits for years to come, even as temperatures and sea levels rise. As demonstrated by the Hawaiʻi Assessment, the Fish and Wildlife Index shows the highest values further offshore, indicating restoration efforts within the bay may also help enhance coral habitat for myriad reef-associated species (Figure 27).

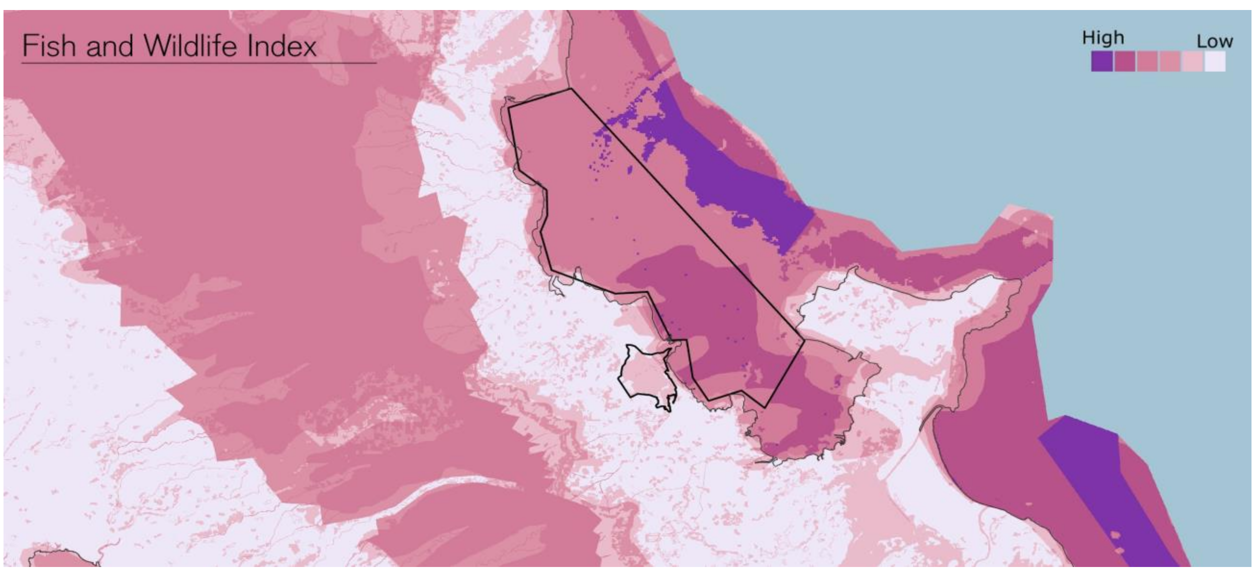

Figure 27. Fish and Wildlife Index results for Kāneʻohe Bay. The black lines outline the wetland and coral restoration project areas. Note the high fish and wildlife values within and adjacent to the nearshore coral restoration site. Efforts to restore corals in this location may help to expand areas of high fish and wildlife value.

In addition to transplanting in Kāneʻohe Bay, the project will also build nurseries and plant thermally-tolerant coral colonies in Maunalua Bay and along the urban south shore of Oʻahu to protect the Honolulu Airport. At Maunalua Bay, project partner Mālama Maunalua will lead outreach and community engagement through their existing networks to give a voice to residents and encourage community-based natural resource management. This partnership will empower volunteer citizen scientists to take part in this groundbreaking work that builds coral reefs adapted to warmer future conditions. This pilot study will result in a framework to determine how best to engage community groups to scale-up future climate-wise restoration work across the State of Hawaiʻi.

With the presence of considerable flooding threats, concentrations of coastal community assets, and wildlife habitat, the Kāneʻohe Bay 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 Kāneʻohe, a range of high-ranking Hubs are visible (Figure 28). Additionally, by visualizing the 4-hectare (10-acre) hexagonal grid, users can access finer-resolution information to understand the variation in scores within Resilience Hubs. The Resilience Hubs in Kāneʻohe Bay, and throughout Hawaiʻi, can help support the prioritization of habitats for similar types of projects in Oʻahu and elsewhere.

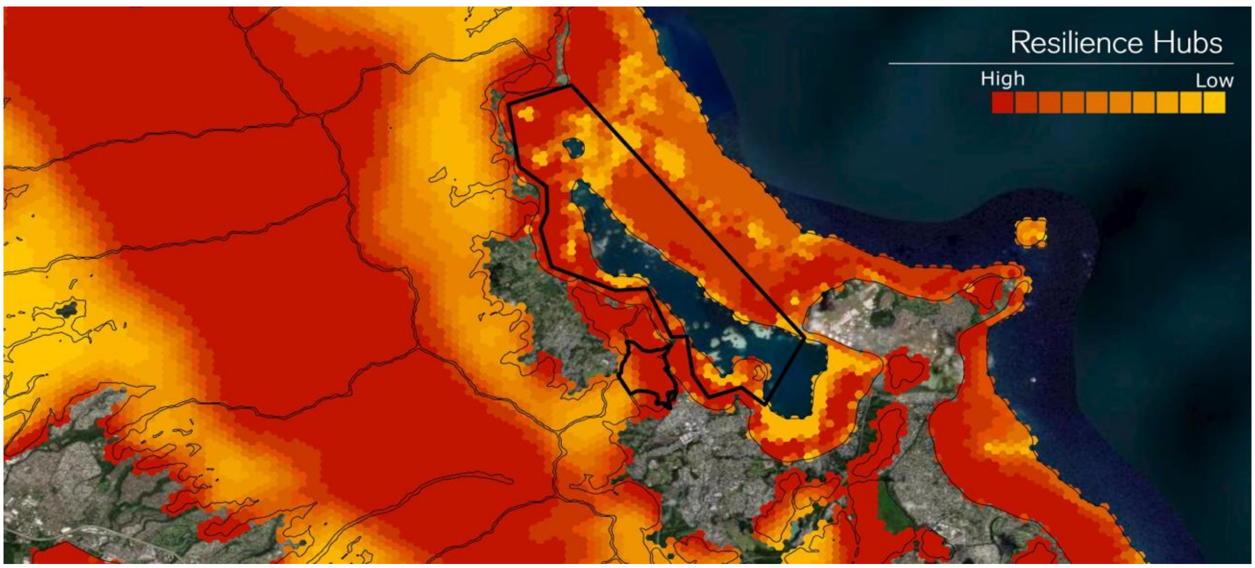

Figure 28. Resilience Hubs (black lines) indicate that there are multiple areas potentially well suited for restoration projects. Note the 4-hectare (10-acre) hexagons show variation in scores within Resilience Hubs. The thick black lines outline the wetland and coral restoration project areas.

CONCLUSION

5.1 Summary and Key Takeaways

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

With nearly 1,300 kilometers of coastline combined across all islands, Hawaiʻi remains exposed to a variety of coastal-flood related hazards. The effects of flood-related hazards are compounded in areas with higher populations and assets, such as in Honolulu, Kāneʻohe Bay, Kahului, Hilo, and Kailua Kona. Inland communities are not immune to flood-related threats, especially as they relate to heavy precipitation events and flash flooding. Furthermore, the effects of coastal flooding are exacerbated when combined with heavy precipitation inland, suggesting efforts to build resilience should consider the benefits of a holistic, watershed-wide approach.

Hawaiʻi is ecologically diverse, with an abundance of wildlife assets, both in the terrestrial and marine environments. Combining the information in the Fish and Wildlife Index with the Community Exposure Index, the Assessment identified numerous Resilience Hubs, or areas where resilience-building projects may benefit both human and wildlife communities throughout Hawaiʻi.

5.2 Future Work

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

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APPENDIX

The following sections describe data used for the Hawaiʻi 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 Hawaiʻi Assessment was completed at a 10-meter resolution, using the projection *NAD 1983 UTM Zone 4N* (WKID 26904).

A. Data Summary

A.1 Threat Index

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

Layer Name	Dataset and Source
Flood-prone Areas	FEMA National Flood Hazard Layers, USDA-NRCS SSURGO (2.2 or later)
Sea Level Rise	Pacific Islands Ocean Observing System, Tetra Tech, Inc., University of Hawaii Coastal Geology Group Sea Level Rise Exposure Area (2017)
Storm Surge	NOAA/NHC Sea, Lake, and Overland Surge from Hurricanes (SLOSH) model (2018 models)
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 (2010: Hawaiʻi, Kauaʻi, Maui, Molokaʻi, Niʻihau; 2011: Lānaʻi, Oʻahu)
Geologic Stressors: Landslide Susceptibility	USGS Preliminary Landslide Susceptibility Maps and Data for Hawaii (2018)
Tsunami Evacuation Zones	Pacific Disaster Center, City and County of Honolulu, County of Kauaʻi, County of Maui, and County of Hawaiʻi (via Hawaiʻi Statewide GIS Program)

A.2 Community Asset Index

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

Layer Name	Dataset and Source
Population Density	U.S. Census Bureau American Community Survey 5-year Estimates (2014-2018, Block Group)
Social Vulnerability	U.S. EPA Environmental Justice Screening and Mapping tool (2019)
Critical Facilities	Schools: Public Schools (HI State Dept. of Education), Private Schools (HI Association of Independent Schools), Preschools (HI Executive Office on Early Learning); Fire Stations: HI Statewide GIS Program/Office of Planning, Police Stations: HI Statewide GIS Program/Office of Planning; and Medical Facilities: Hospitals (Pacific Disaster Center), Skilled Nursing Facilities (HI Dept. of Public Health), Assisted Living Facilities (State of HI Dept. of Health)
Parcels	Hawaii Statewide GIS Program/Office of Planning
Building Footprints	Open Street Maps/digitized by NEMAC team
Critical Infrastructure *(Various Inputs, see below)*	
Primary roads	*Open Street Maps; TigerLine roads (2019)*
Bridges	*Federal Highway Administration: National Bridge Inventory via Hawaiʻi Statewide GIS Program/Office of Planning*
Airport runways	*Hawaii Dept. of Transportation, Airports Division (Hawaiʻi Statewide GIS Program)*
Ports	*Hawaii State Dept. of Transportation, Harbors Division: Commercial Harbors; USACE Ports*
Power Plants/Substations	*U.S. Energy Information Administration: EIA-860, Annual Electric Generator Report; EIA-860M, Monthly Update to the Annual Electric Generator Report; EIA-923, Power Plant Operations Report (2016 or later)*
Wastewater treatment facilities	*Hawaiʻi Statewide GIS Program/Office of Planning*
Railroads (urban train)	*HART guideway track alignments - CH2M*
Major dams	*USACE National Inventory of Dams (Hawaii Statewide GIS Program)*
Petroleum terminals	*U.S. Energy Information Administration: EIA-815, Monthly Bulk Terminal and Blender Report*
Petroleum Refineries	*U.S. Energy Information Administration: EIA-820 Refinery Capacity Report (2015 or later)*
Hazardous Sites	*U.S. EPA Facility Registry Service (2016 or later)*
Cultural & Historic Resources	*Hawaiʻi State Historic Preservation Division (Fishponds, existing archaeological sites, cultural resources, historic structures and buildings)*

A.3 Terrestrial Index

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

Dataset Name	Source and Year
C-CAP Land cover	NOAA Office for Coastal Management; 2010: Hawaiʻi, Kauaʻi, Maui, Molokaʻi, Niʻihau; 2011: Lānaʻi, Oʻahu
National Wetlands Inventory	U.S. Fish and Wildlife Service (most recent available)
National Hydrography Dataset	U.S. Geological Survey (USGS) 1:24,000
Carbon Assessment of Hawaiʻi - Land Cover - Biome Unit	USGS/Hawaiʻi Statewide GIS Program, Office of Planning (2015)
Important Bird Areas & Key Biodiversity Areas	BirdLife International (2020)
Environmental Sensitivity Index Species Habitat	NOAA Office of Response and Restoration (2000)
Critical Habitat Designations	NOAA & U.S. Fish and Wildlife Service (most recent available)
State Wildlife Action Plan species list	Hawaiʻi Dept. of Land and Natural Resources (2015)
Habitat Classification Scheme	IUCN Red List of Threatened Species (Version 3.1)
Protected Areas Database of the U.S. (PADUS)	USGS (Version 2.0)
Watershed Partnerships	State of Hawaiʻi, Dept. of Land and Natural Resources, Division of Forestry and Wildlife
Ridge to Reef Restoration Areas	West Maui Ridge to Reef Initiative, South Kohala Coastal Partnership
State Watershed Priority Areas	State of Hawaiʻi, Division of Forestry and Wildlife

A.4 Marine Index

The following table lists those datasets used to create the Marine Index for Hawaiʻi.

Dataset Name	Source and Year
Critical Habitat Designations	NOAA Fisheries (most recent available)
Essential Fish Habitat	NOAA Fisheries (2018)
Habitat Areas of Particular Concern	NOAA Fisheries (2018)
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program, strata-level data (2019)
Protected Areas Database of the U.S. (PADUS) - Marine Protected Areas	USGS (Version 2.0)
Bathymetric Data	NOAA NCEI Coastal Relief Model
Humpback Whale National Marine Sanctuary	NOAA National Marine Sanctuary Program
Marine Managed Areas in the Main Hawaiian Islands	Hawaiʻi Division of Aquatic Resources
Reef Fish Biomass	NOAA National Coral Reef Monitoring Program: Reef Fish Monitoring sector-level data (2019)

A.5 Resilience Hubs

The following table lists those datasets used to create the Resilience Hubs for Hawaiʻi.

Dataset Name	Source and Year
C-CAP Land Cover Atlas	NOAA Office for Coastal Management; 2010: Hawaiʻi, Kauaʻi, Maui, Molokaʻi, Niʻihau; 2011: Lānaʻi, Oʻahu
National Wetlands Inventory	U.S. Fish and Wildlife Service (most recent data available)
National Hydrography Dataset	U.S. Geological Survey (USGS) 1:24,000
Bathymetric Data	NOAA NCEI Coastal Relief Model
Coral Cover Surveys	NOAA National Coral Reef Monitoring Program, strata-level data (2019)
Benthic Habitat Maps	NOAA National Centers for Coastal Ocean Science (2007)
National Elevation Dataset	U.S. Geological Survey (USGS), EROS Data Center
SSURGO Soils Survey	USDA-NRCS SSURGO (2.2 or later)
Roads polyline	OpenStreetMap (latest data available)

B. Detailed Methodology: Threat Index

The Threat Index for Hawai‘i 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 Create the Sea Level Rise Exposure Area Input

Models from the University of Hawai‘i Coastal Geology Group and Tetra Tech, Inc., were combined into Sea Level Rise Exposure Areas. It was recommended during the Assessment workshop and by the Advisory Committee that these data were used in place of the NOAA sea level rise scenarios. The Sea Level Rise Exposure Area dataset uses modeled passive flooding, annual high wave flooding, and coastal erosion, all specific to the Hawaiian Islands.

A. Merge all sea level rise scenarios together.
    a. Geoprocessing > Merge
B. Create a “Rank” attribute in each Sea Level Rise layer
    a. Right click layer in attribute table > open attribute table
    b. Add field “Rank”; field type: Short Integer
    c. Right click the Rank field and use Field Calculator to add values according to the table below
C. Merge the individual sea level rise inundation vectors in ascending Rank value order to create one complete vector containing all levels of sea level rise.
    a. Geoprocessing > Merge
D. Expand resulting features to cover the entire regional area before rasterizing to ensure the data is continuous across the entire watershed region. This step is essential for the final raster calculations in the Assessment.
    a. Merge Sea Level Rise vector output with the watershed region.
        i. Geoprocessing > Merge
E. Make sure values outside of any Sea Level Rise inundation scenarios within the watershed region are a value of 0 in the Rank attribute field. If they are NULL, change them to 0.
F. Convert merged SLR vector to raster:
    a. Conversion Tools > To Raster > Polygon to Raster
        i. Value Field: Rank
        ii. Cell assignment type: Maximum Area
        iii. Priority field: Rank
        iv. Cell size: *varies by region*
G. Shift the raster input
    a. Data Management Tools > Projections and Transformations > Raster > Shift
        i. Shift X & Y Coordinates by: 1 (each)
        ii. Input Snap Raster: *varies by region*

Sea Level Rise	Rank Type	Rank Value
No inundation / No data	None	0
Inundation with 3.2ft rise in sea level	Low	2
Inundation with 2ft rise in sea level	Moderate	3
Inundation with 1.1ft rise in sea level	High	4
Inundation with 0.5ft rise in sea level	Very high	5

B.2 Create the Tsunami Evacuation Zones Input

A. Create a “Rank” attribute in each Tsunami Evacuation layer
  a. Right click layer in attribute table > open attribute table
  b. Add field “Rank”; field type: Short Integer
  c. Right click the Rank field and use Field Calculator to add values:
    i. Tsunami Evacuation Zones Rank = 2
    ii. Extreme Tsunami Evacuation Zones = 1

B. Merge the individual Tsunami Evacuation vectors in ascending Rank value order to create one complete vector containing all levels of sea level rise.
  a. Geoprocessing > Merge

C. Expand resulting features to cover the entire regional area before rasterizing to ensure the data is continuous across the entire watershed region. This step is essential for the final raster calculations in the Assessment.
  a. Merge Sea Level Rise vector output with the watershed region.
    i. Geoprocessing > Merge

D. Make sure values outside of any Evacuation Zone within the watershed region are a value of 0 in the Rank attribute field. If they are NULL, change them to 0.

E. Convert merged vector to raster:
  a. Conversion Tools > To Raster > Polygon to Raster
    i. Value Field: Rank
    ii. Cell assignment type: Maximum Area
    iii. Priority field: Rank
    iv. Cell size: *varies by region*

F. Shift the raster input
  a. Data Management Tools > Projections and Transformations > Raster > Shift
    i. Shift X & Y Coordinates by: 1 (each)
    ii. Input Snap Raster: *varies by region*

B.3 Create the Geostress: Landslide Susceptibility Input

A. Create a “Rank” attribute for each level of susceptibility
  a. Right click layer in attribute table > open attribute table
  b. Add field “Rank”; field type: Short Integer
  c. Right click the Rank field and use Field Calculator to add values according to the table below

B. Merge the landslide susceptibility feature to cover the entire regional area before rasterizing to ensure the data is continuous across the entire watershed region. This step is essential for the final raster calculations in the Assessment.
    a. Merge Sea Level Rise vector output with the watershed region.
        i. Geoprocessing > Merge
C. Make sure values outside of the landslide susceptibility areas within the watershed region are a value of 0 in the Rank attribute field. If they are NULL, change them to 0.
D. Convert merged vector to raster:
    a. Conversion Tools > To Raster > Polygon to Raster
        i. Value Field: Rank
        ii. Cell assignment type: Maximum Area
        iii. Priority field: Rank
        iv. Cell size: *varies by region*
E. Shift the raster input
    a. Data Management Tools > Projections and Transformations > Raster > Shift
        i. Shift X & Y Coordinates by: 1 (each)
        ii. Input Snap Raster: *varies by region*

Landslide Susceptibility	Rank Value
0	0
Moderate	1
High	2
Very High	3

B.4 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 Hawaiʻi Threat Index.

Hawaiʻi Threat Index Distribution

Threat Index Break Value	0	1	2	3	4	5	6	7 - 9	10	11 - 32
Final Rank Value	1	2	3	4	5	6	7	8	9	10

C. Detailed Methodology: Community Asset Index

The Community Assets Index for Hawaiʻi 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.2.

C.1 Population Density

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

Population Density Distribution for Hawaiʻi	Rank Value
0	0
<= 18.6	1
<= 73.8	2
<= 196.8	3
<= 378.3	4
<= 3205.3	5

C.2 Social Vulnerability

Following the methodology for social vulnerability as detailed in the Methodology and Data Report (Dobson et al. 2020), the distribution shown in the table below was used to rank social vulnerability in Hawaiʻi.

Social Vulnerability Distribution for Hawaiʻi	Rank Value
0	0
<= 49.7	1
<= 54.9	2
<= 60	3
<= 66.5	4
<= 88.3	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 Appendix A.2 identifies data source and data inputs that were included in the Hawaiʻi 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 to multiply them and ultimately create the Community Exposure Index. Below is the classification that was used for the Hawaiʻi Community Asset Index.

Hawaiʻi Community Asset Index Distribution

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

D. Detailed Methodology: Community Exposure Index

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

Hawaiʻi Community Exposure Index Distribution

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

E. Detailed Methodology: Fish and Wildlife Index

E.1 Calculating the Terrestrial Index

The Terrestrial Index for Hawaiʻi 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 species groups and associated species were incorporated into the Terrestrial Index for Hawaiʻi.

Forest Birds

Palila *(Loxioides bailleui)*
Kauaʻi ʻĀkepa (ʻAkekeʻe) (*Loxops caeruleirostris*)
Hawaiʻi ʻĀkepa (*Loxops coccineus coccineus*)
Kiwikiu (Maui Parrotbill) (*Pseudonestor xanthophrys*)
ʻŌʻū (*Psittirostra psittacea*)
ʻIʻiwi (*Vestiaria coccinea*)
Kauaʻi Nuku puʻu (*Hemignathus lucidus hanapepe*)
Hawaiian Crow (ʻAlalā) (*Corvus hawaiiensis*)
Maui Nuku puʻu (*Hemignathus lucidus affinis*)
ʻApapane (*Himatione sanguinea*)
ʻAkiapōlāʻau (*Hemignathus munroi*)
Mauʻi ʻĀkepa (*Loxops coccineus ochraceus*)
Lesser ʻAmakihi (ʻAnianiau) (*Magumma (Hemignathus) parva*)
Molokaʻi Thrush (Olomaʻo) (*Myadestes lanaiensis*)
Hawaiʻi Thrush (ʻŌmaʻo) (*Myadestes obscurus*)
Small Kauaʻi Thrush (Puaiohi) (*Myadestes palmeri*)
Kauaʻi Creeper (ʻAkikiki) (*Oreomystis bairdi*)
Crested Honeycreeper (ʻĀkohekohe) (*Palmeria dolei*)
Oʻahu Creeper (Oʻahu ʻAlauahio) (*Paroreomyza maculata*)
Maui Creeper (Maui ʻAlauahio) (*Paroreomyza montana*)
Oʻahu ʻElepaio (*Chasiempis sandwichensis ibidis*)
Kauaʻi ʻElepaio (*Chasiempis sandwichensis sclateri*)
Oʻahu ʻAmakihi (*Hemignathus flava*)
Kauaʻi ʻAmakihi (*Hemignathus kauaiensis*)
Hawaiʻi ʻAmakihi (*Hemignathus virens*)

Seabirds

Black Noddy (Noio) (*Anous minutus*)
Brown Noddy (Noio Kōhā) (*Anous stolidus*)
Bulwer's Petrel (ʻOu) (*Bulweria bulwerii*)
Blue-gray Noddy (*Procelsterna cerulea*)
Masked Booby (ʻĀ) (*Sula dactylatra*)
White Tern (Manu-o-Kū) (*Gygis alba*)
Newell's Shearwater (ʻAʻo) (*Puffinus auricularis newelli*)
Brown Booby (ʻĀ) (*Sula leucogaster*)
Red-footed Booby (ʻĀ) (*Sula sula*)
Dark-rumped Petrel (*Pterodroma phaeopygia sandwichensis*)
Black-footed Albatross (Kaʻupu) (*Phoebastria nigripes*)
Great Frigatebird (*Fregata minor*)
Christmas Shearwater (*Puffinus nativitatis*)
Band-rumped Storm Petrel (ʻAkēʻakē) (*Oceanodroma castro*)
Tristram's Storm-Petrel (*Oceanodroma tristrami*)
Sooty Tern (ʻEwaʻewa) (*Sterna fuscatus*)
Spectacled Tern (*Onychoprion lunatus*)
White-tailed Tropicbird (Koaʻe kea) (*Phaethon lepturus*)
Red-tailed Tropicbird (Koaʻe ʻula) (*Phaethon rubricauda*)
Short-tailed Albatross (*Phoebastria albatrus*)
Laysan Albatross (Mōlī) (*Phoebastria immutabilis*)
Bonin Petrel (*Pterodroma hypoleuca*)
Hawaiian Petrel (ʻUaʻu) (*Pterodroma sandwichensis*)
Wedge-tailed Shearwater (ʻUaʻu kani) (*Puffinus pacificus*)

Waterbirds

Hawaiian Duck (Koloa maoli) (*Anas wyvilliana*)
Hawaiian Goose (Nēnē) (*Branta sandvicensis*)
Hawaiian Coot (ʻAlae keʻokeʻo) (*Fulica alai*)
Black-crowned Night Heron (ʻAukuʻu) (*Nycticorax nycticorax hoactli*)
Hawaiian Common Moorhen (ʻAlae ʻula) (*Gallinula chloropus sandvicensis*)
Hawaiian Stilt (Aeʻo) (*Himantopus mexicanus knudseni*)

Migratory Birds

Northern Pintail (Koloa Māpu) (*Anas acuta*)
American Wigeon (*Anas americana*)
Northern Shoveler (Koloa Mōhā) (*Anas clypeata*)
Ruddy Turnstone (ʻAkekeke) (*Arenaria interpres*)
Lesser Scaup (*Aythya affinis*)
Bristle-thighed Curlew (Kioea) (*Numenius tahitiensis*)
Wandering Tattler (ʻŪlili) (*Heteroscelus incanus*)
Sanderling (Hunakai) (*Calidris alba*)
Pacific Golden Plover (Kōlea) (*Pluvialis fulva*)

Raptors

Hawaiian Hawk (ʻIo) (*Buteo solitarius*)
Pueo (*Asio flammeus sandwichensis*)

Terrestrial Mammals

Hawaiian Hoary Bat (ʻōpeʻapeʻa) (*Lasiurus cinereus semotus)*

Reptiles

Loggerhead (*Caretta caretta*)
Green Sea Turtle (Honu) (*Chelonia mydas*)
Leatherback Turtle (*Dermochelys coriacea*)
Hawksbill Sea Turtle (*Eretmochelys imbricata*)
Olive Ridley Sea Turtle (*Lepidochelys olivacea*)
Yellowbelly Sea Snake (*Hydrophis platurus*)

Freshwater Fish

Pacific River Goby (*Awaous guamensis*)
Hawaiian Sleeper (ʻōʻopu akupa) (*Eleotris sandwicensis*)

Invertebrates - Snails & Insects

Achatinella spp.
Achatinella concavospira
Achatinella fulgens
Achintella fuscobasis
Achatinella pupukanioe
Achatinella sowerbyana
Anthricinan Yellow-Faced Bee (*Hylaeus anthracinus*)
Assimulans Yellow-Faced Bee (*Hylaeus assimulans*)
Easy Yellow-Faced Bee (*Hylaeus facilis*)
Achatinella bulimoides
Achatinella byronii/decepiens
Achatinella lila
Achatinella mustelina
Newcombia cumingi
Hawaiian Yellow-Faced Bee (*Hylaeus longiceps*)
Hilaris Yellow-Faced Bee (*Hylaeus hilaris*)
Hawaiian Yellow-Faced Bee (*Hylaeus mana*)
Hawaiian Yellow-Faced Bee (*Hylaeus kuakea*)

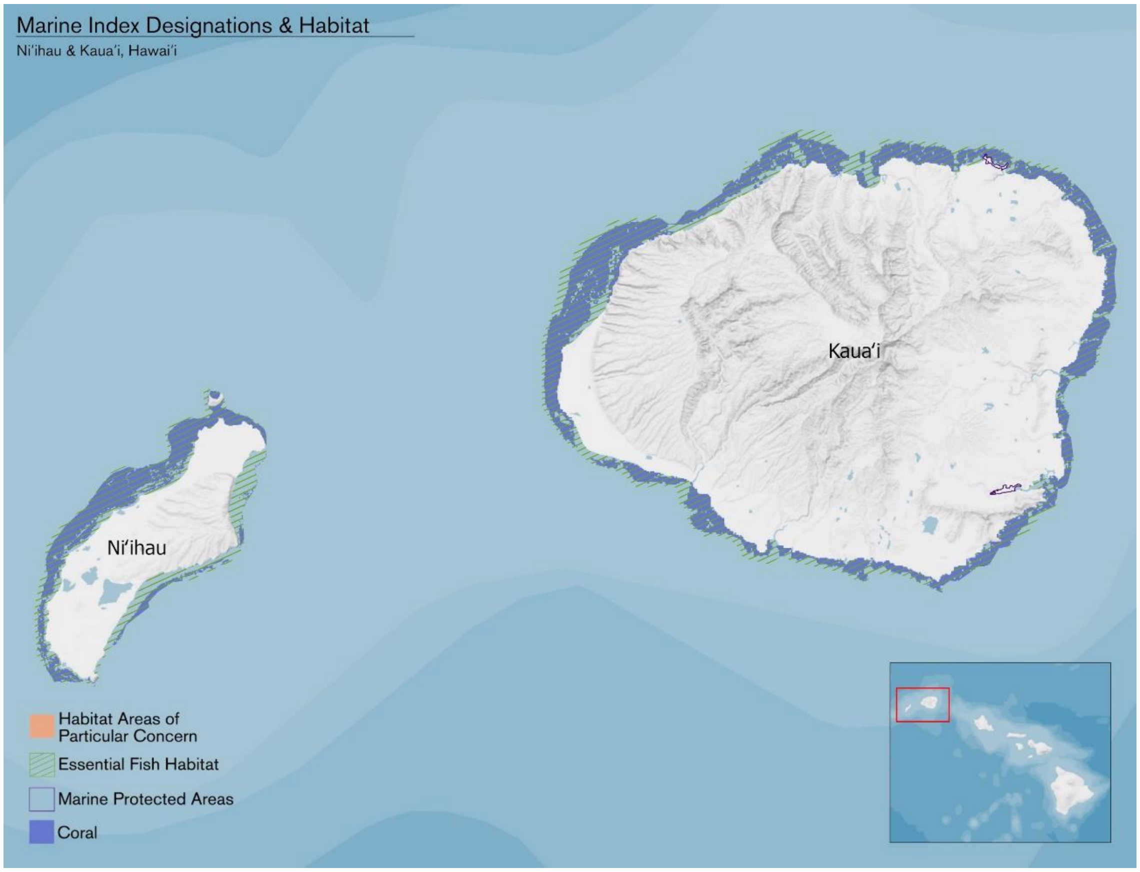
The distribution for the Hawaiʻi Terrestrial Index is displayed below. The final rank value was determined using a quantile distribution and was then combined with the Marine Index to create the Fish and Wildlife Index.

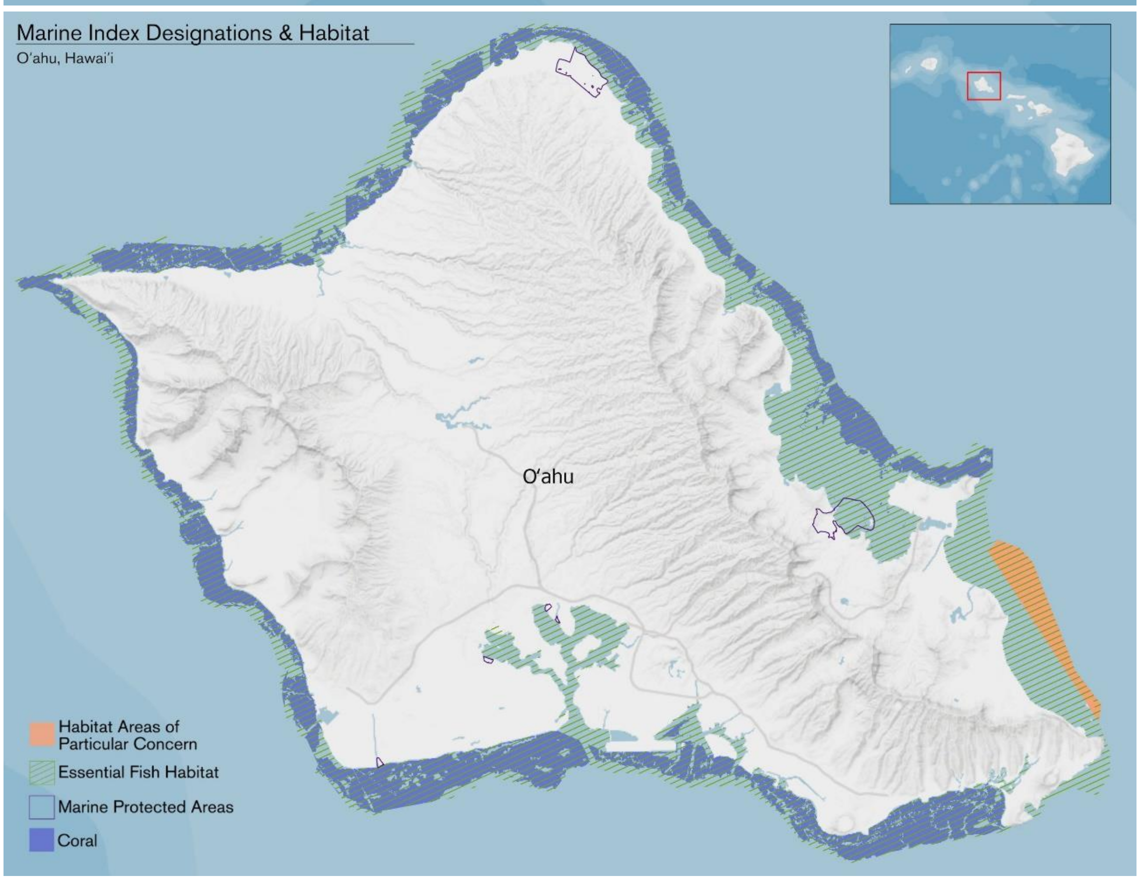
Hawaiʻi Terrestrial Index Distribution

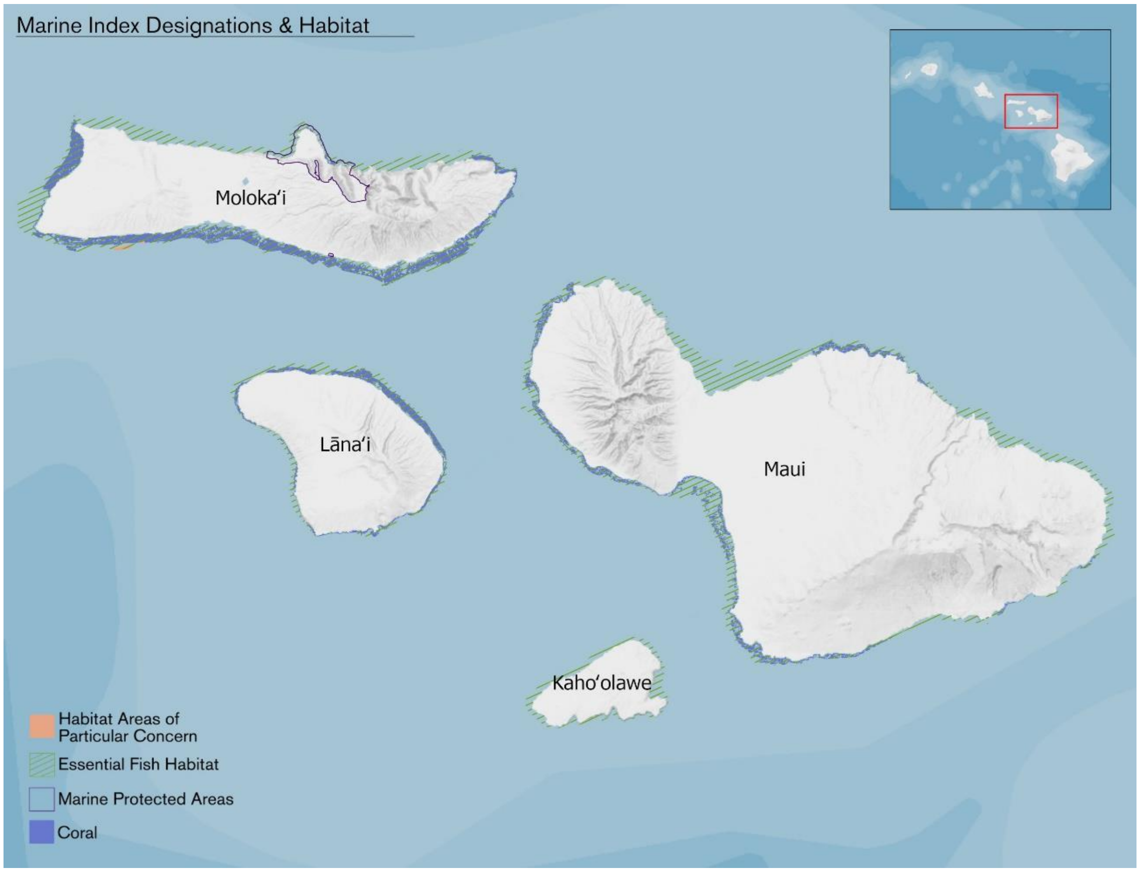
Terrestrial Index Break Values	0 - 2	3 - 5	6 - 8	9 - 17
Final Rank Value	1	2	3	4

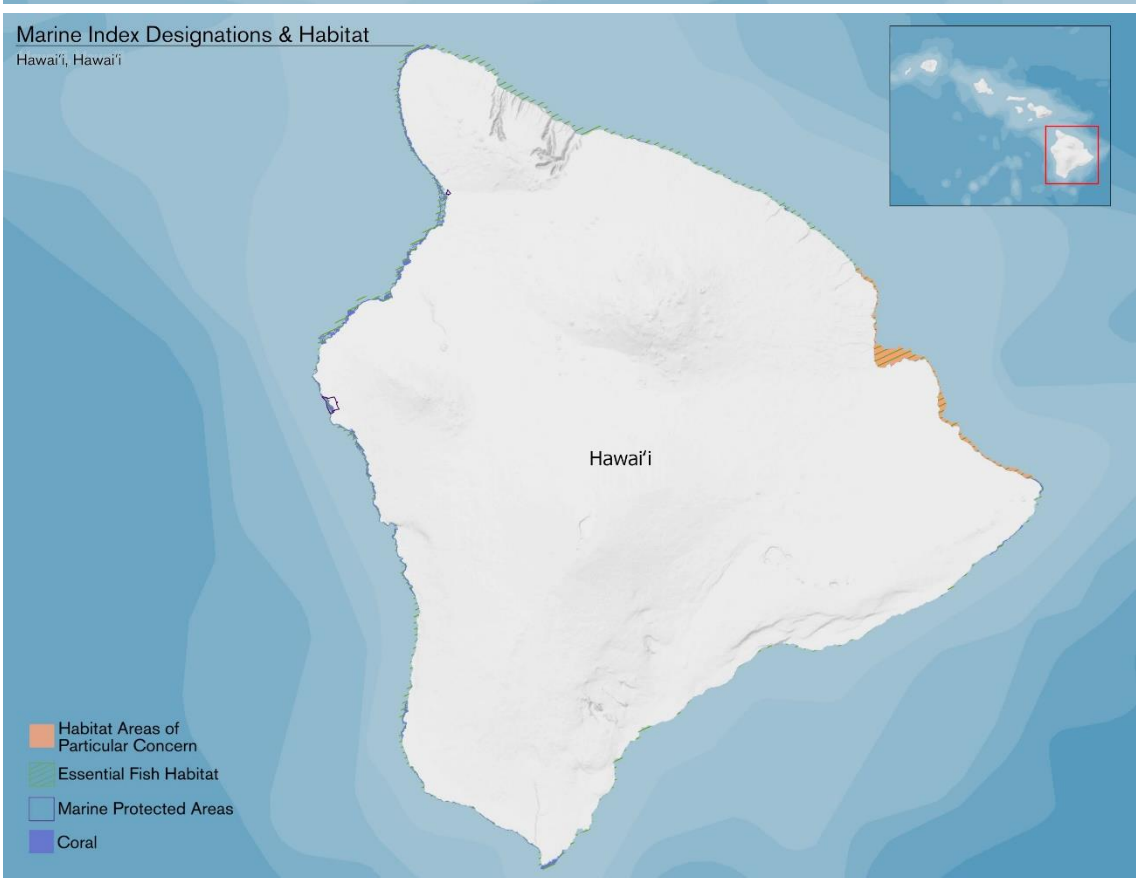
E.2 Calculating the Marine Index

In general, the same overarching methods were applied to Hawaiʻi 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 were necessary. These are discussed in the following sections. See Appendix A.4 for details on datasets used in this analysis. The map below shows the spatial extent of coral reefs and the distribution of Essential Fish Habitat, Marine Protected Areas, and Habitat Areas of Particular Concern used in the Assessment. Rankings for coral cover in Hawaiʻi are shown in the tables below, using data collected in 2019. These distributions differ by region.


Marine Index Designations & Habitat
Ni'ihau & Kaua'i, Hawai'i
Kaua'i
Ni'ihau
Habitat Areas of Particular Concern
Essential Fish Habitat
Marine Protected Areas
Coral


Marine Index Designations & Habitat
O'ahu, Hawai'i
O'ahu
Habitat Areas of Particular Concern
Essential Fish Habitat
Marine Protected Areas
Coral


Marine Index Designations & Habitat
Moloka'i
Lāna'i
Maui
Kaho'olawe
Habitat Areas of Particular Concern
Essential Fish Habitat
Marine Protected Areas
Coral


Marine Index Designations & Habitat
Hawai'i, Hawai'i
Hawai'i
Habitat Areas of Particular Concern
Essential Fish Habitat
Marine Protected Areas
Coral

Coral Cover

The benthic habitat maps available for Hawai'i were completed in 2007, and thus are potentially unreliable given the bleaching events that have occurred since those data were collected. 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 islands using a natural breaks distribution and five classes. The following ranking scheme was used to rank the coral by strata-level in Hawai'i. The rank value of '0' shown below is the land area of each island and benthic areas designated as "soft".

Percent Coral Cover in Hawai'i	Rank Value
0	0
<= 3.10	1
<= 4.075	2
<= 8.732	3
<= 15.525	4
<= 49.48	5

Reef Fish Biomass

Reef Fish Biomass was used to further identify areas of high biodiversity. Biomass was ranked at the sector level using a quantile distribution of the mean total fish biomass and then ranked and rasterized into five classes to be included in the Index. The ranking scheme for Hawai'i is shown below. The rank value of '0' is the land area of the islands.

Reef Fish Biomass in Hawai'i	Rank Value
0	0
<= 18.6	1
<= 24.1	2
<= 37	3
<= 65.5	4
<= 85.6	5

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

Hawaiʻi Marine Index Distribution

Marine Index Break Values	0 - 2	3 - 5	6 - 8	9 - 13
Final Rank Value	1	2	3	4

E.3 Calculating the Fish and Wildlife Index

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

Hawaiʻi Fish and Wildlife Index Distribution

Fish & Wildlife Index Break Values	0 - 2	3	4	5	6	7 - 8
Final Rank Value	1	2	3	4	5	6

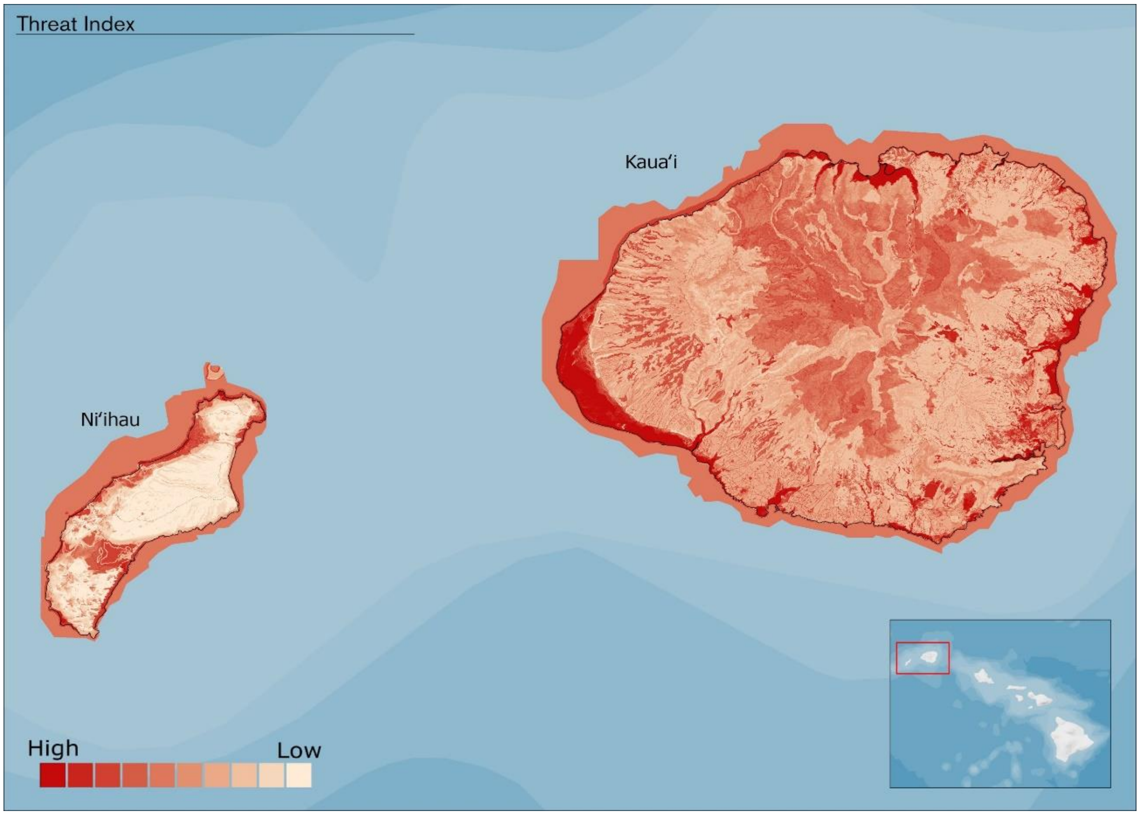
Using a quantile distribution, the Fish and Wildlife Index was reclassified to remain consistent with other Regional Assessments and allows readers to distinguish values more easily.

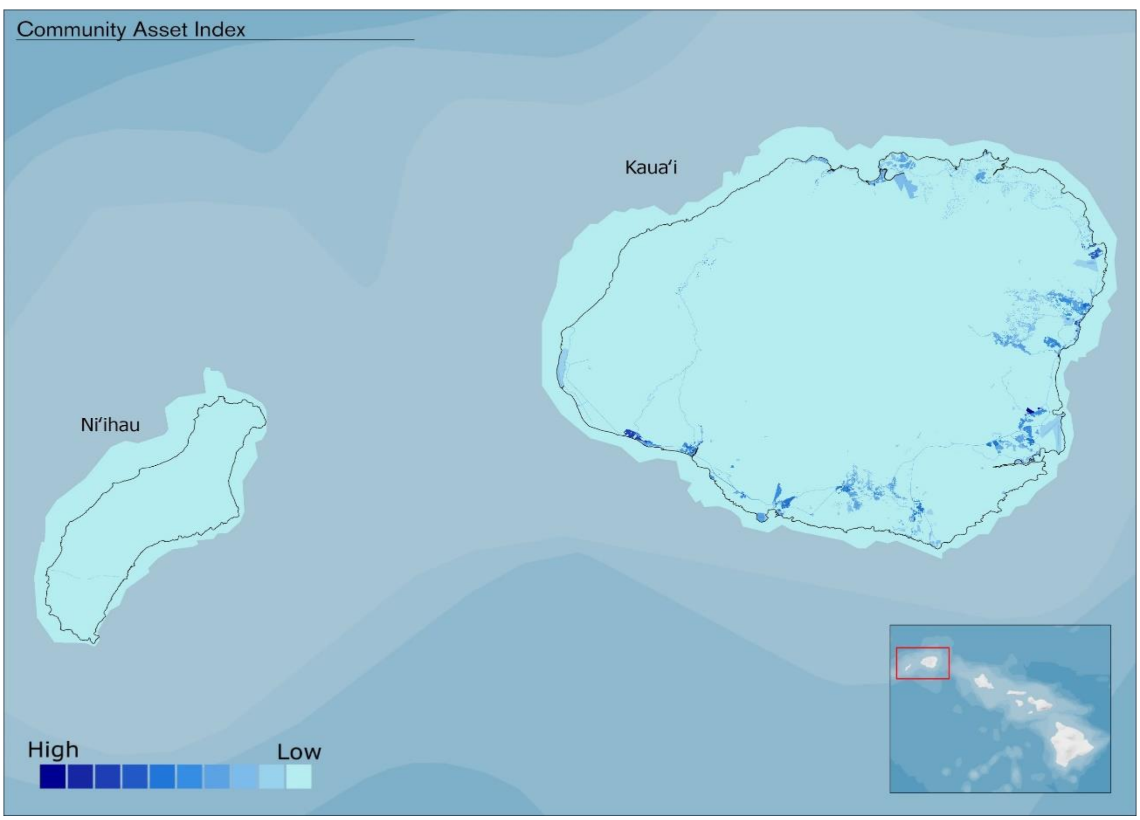
F. Detailed Methodology: Resilience Hubs

The methodology outlined in the Methodology and Data Report (Dobson et al. 2020) for creating the Resilience Hubs was followed for Hawaiʻi, with the following exceptions. The methodology outlined in the Methodology and Data Report (Dobson et al. 2020) for creating the Resilience Hubs was followed for Hawaiʻi, with the following exceptions: mangroves were not considered as a designated habitat, reef crest height was included as a designated habitat, and only coastal wetlands that are classified as tidally influenced (both saltwater and freshwater) and regularly flooded were considered as a habitat designation.

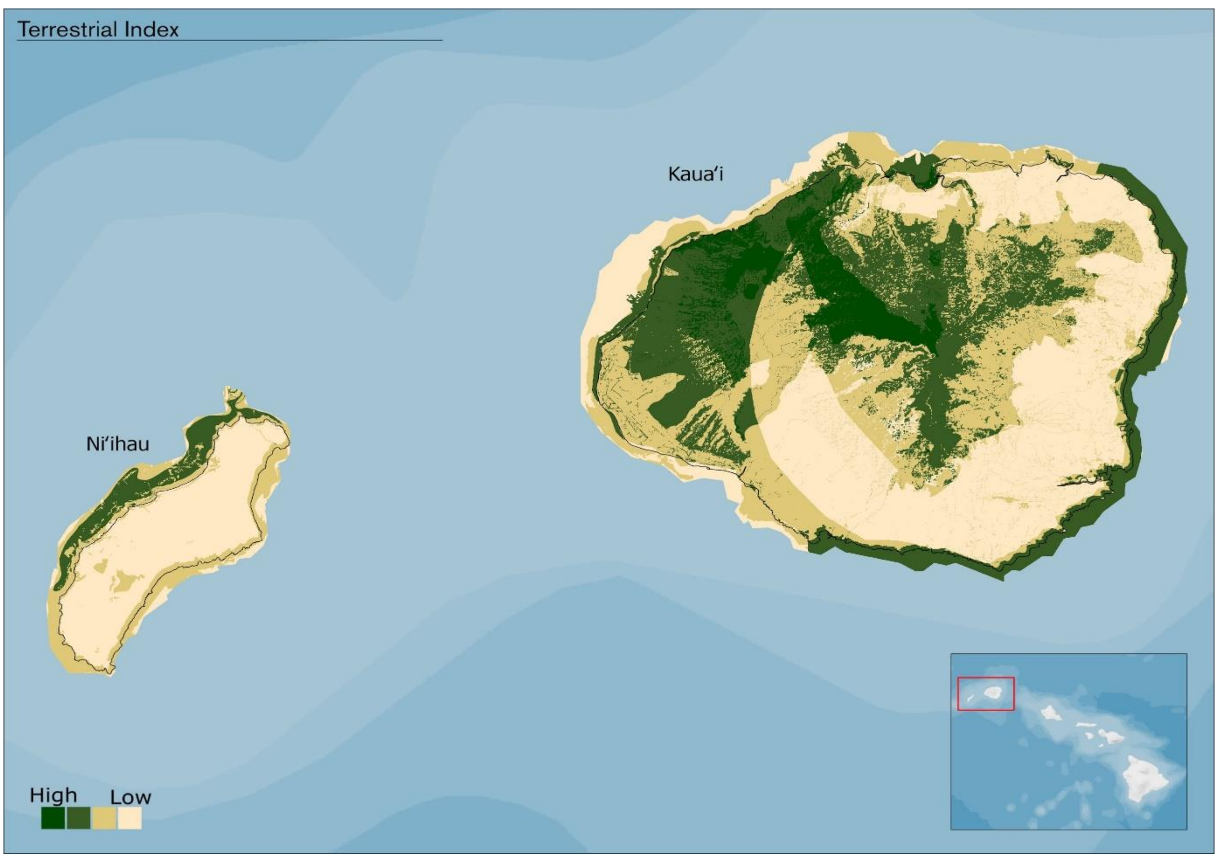
G. Maps

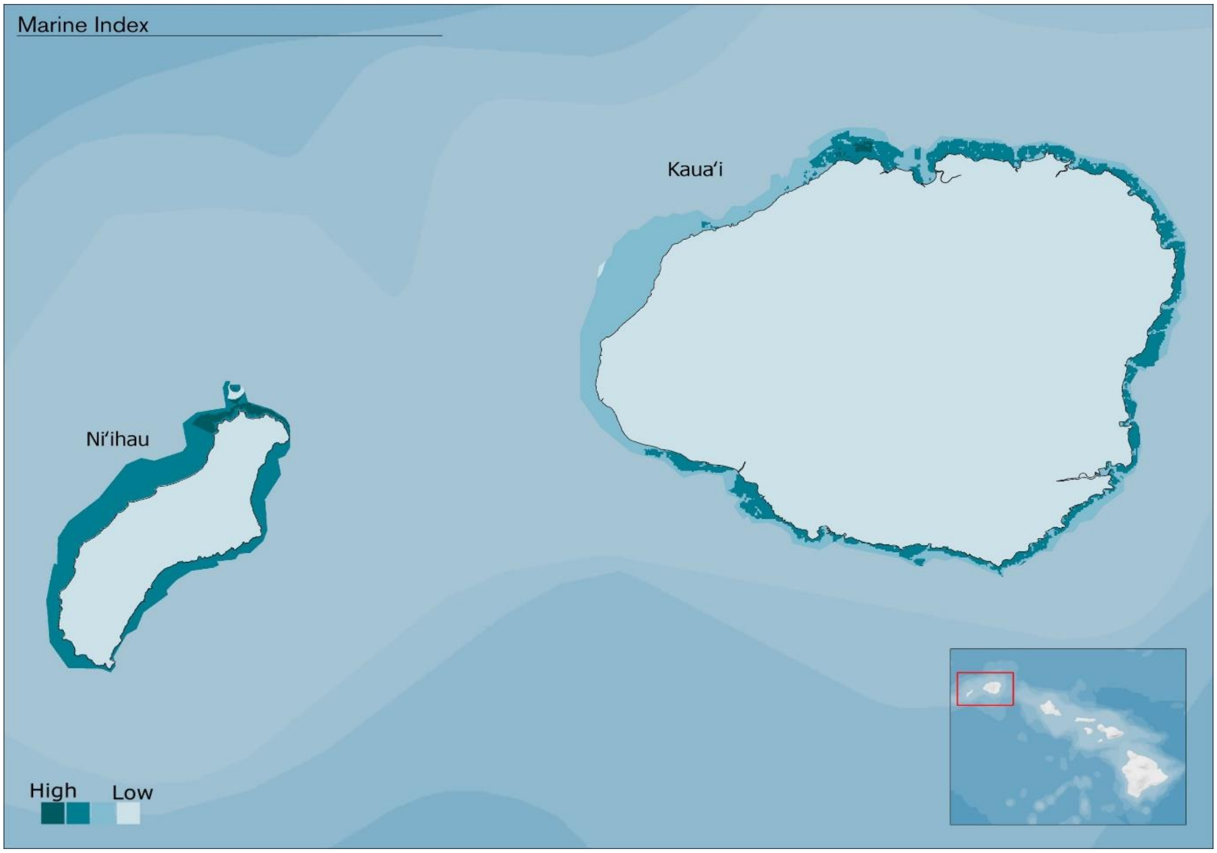
G.1. Maps of Ni'ihau and Kaua'i

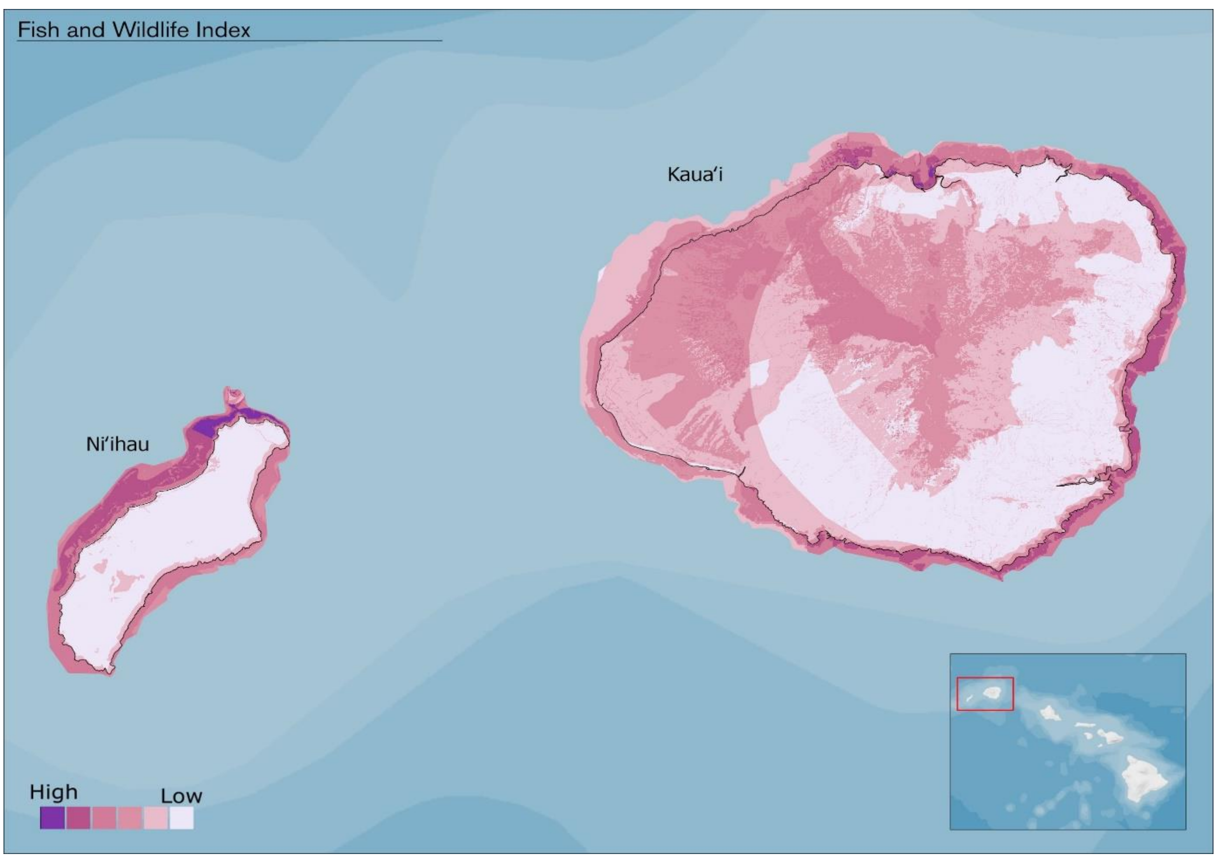


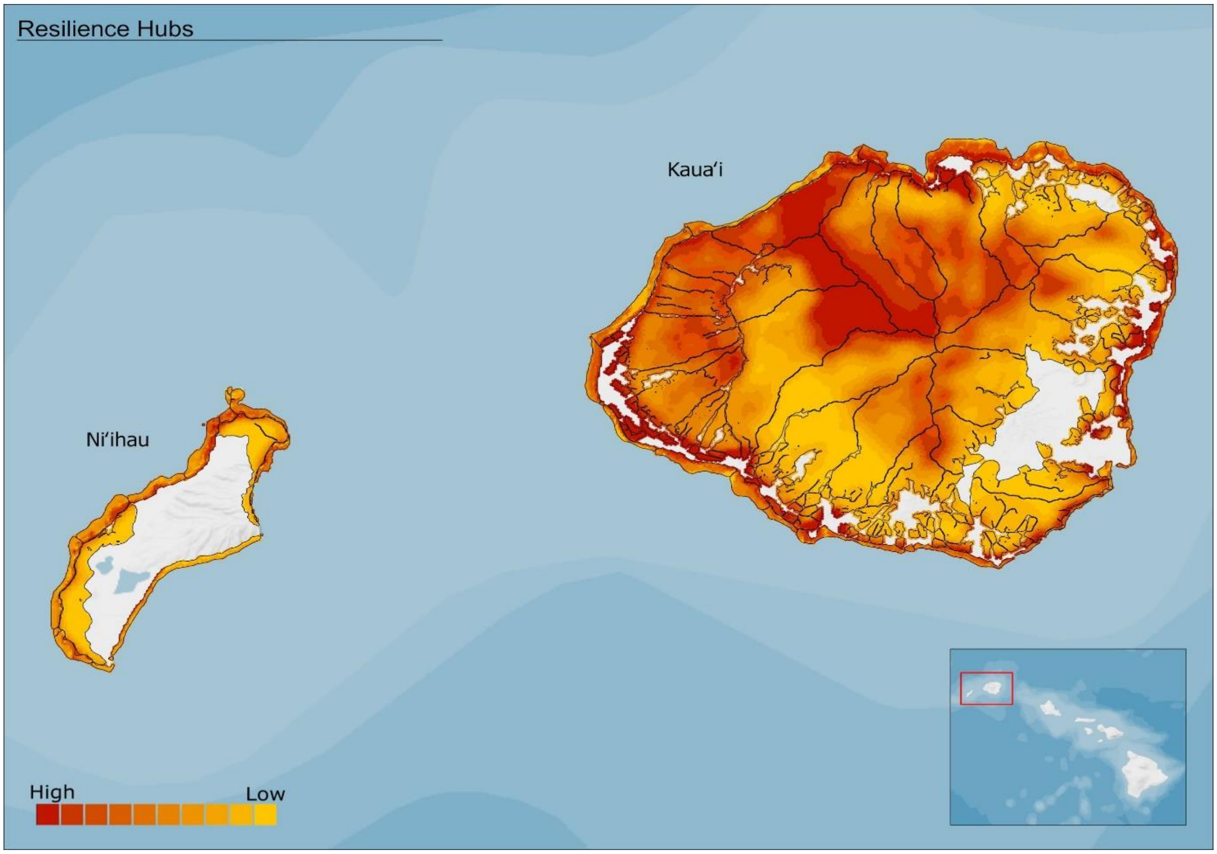



Community Exposure Index
Kaua'i
Ni'ihau
High
Low


Terrestrial Index
Kaua'i
Ni'ihau
High
Low

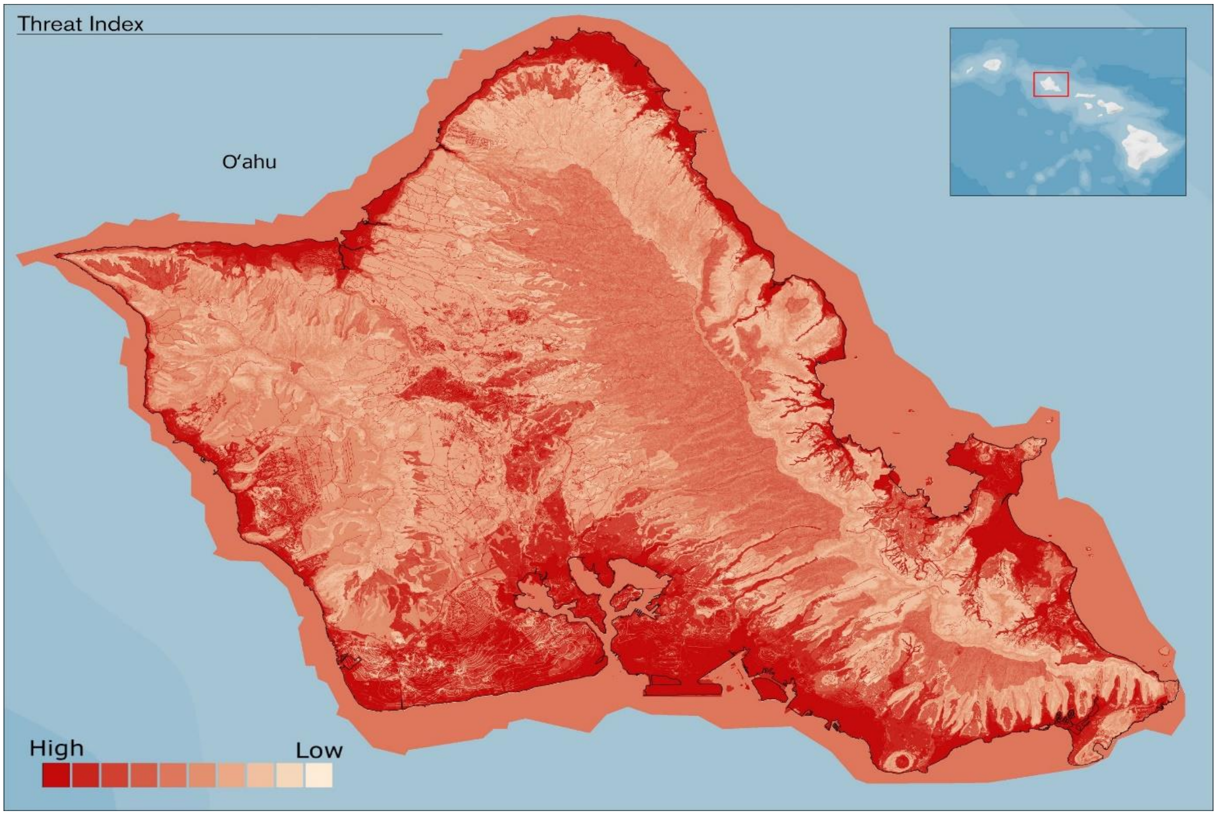

Marine Index
Kaua'i
Ni'ihau
High
Low

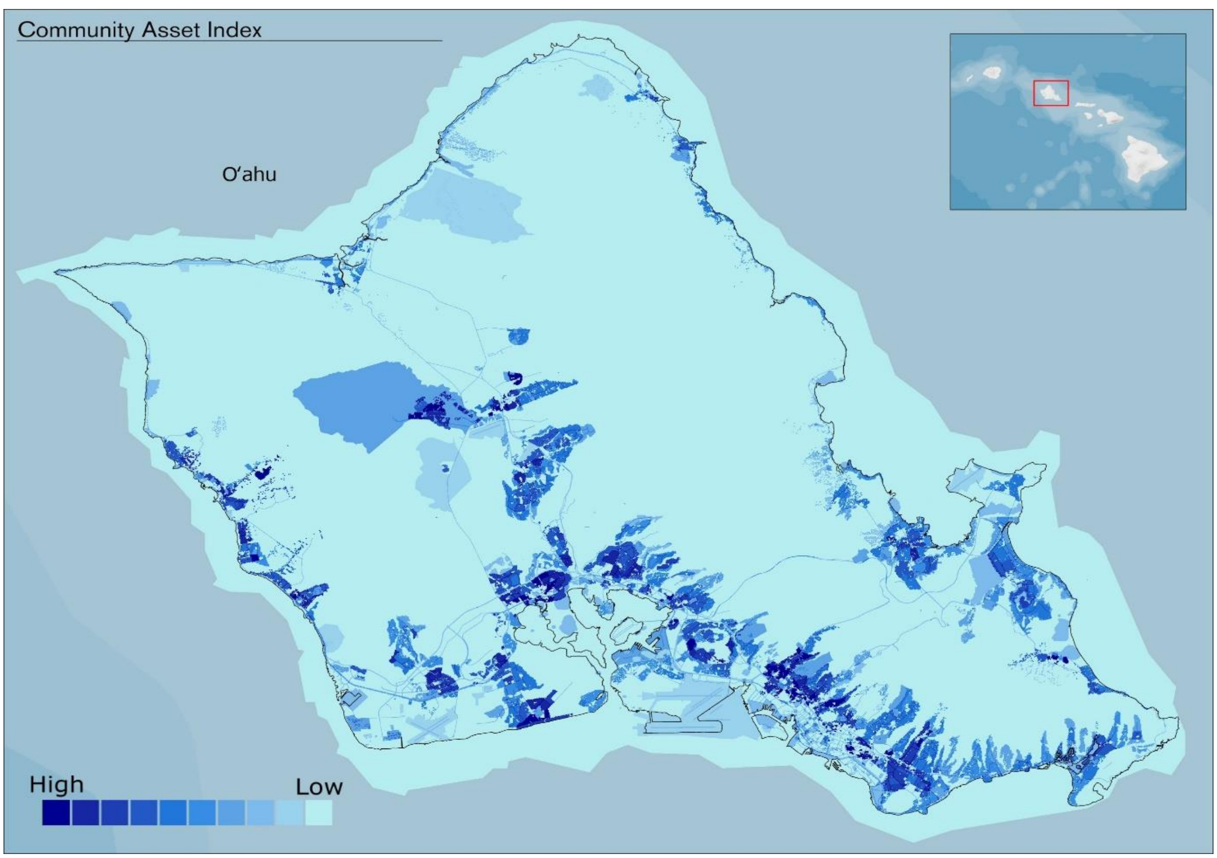

Fish and Wildlife Index
Kaua'i
Ni'ihau
High
Low

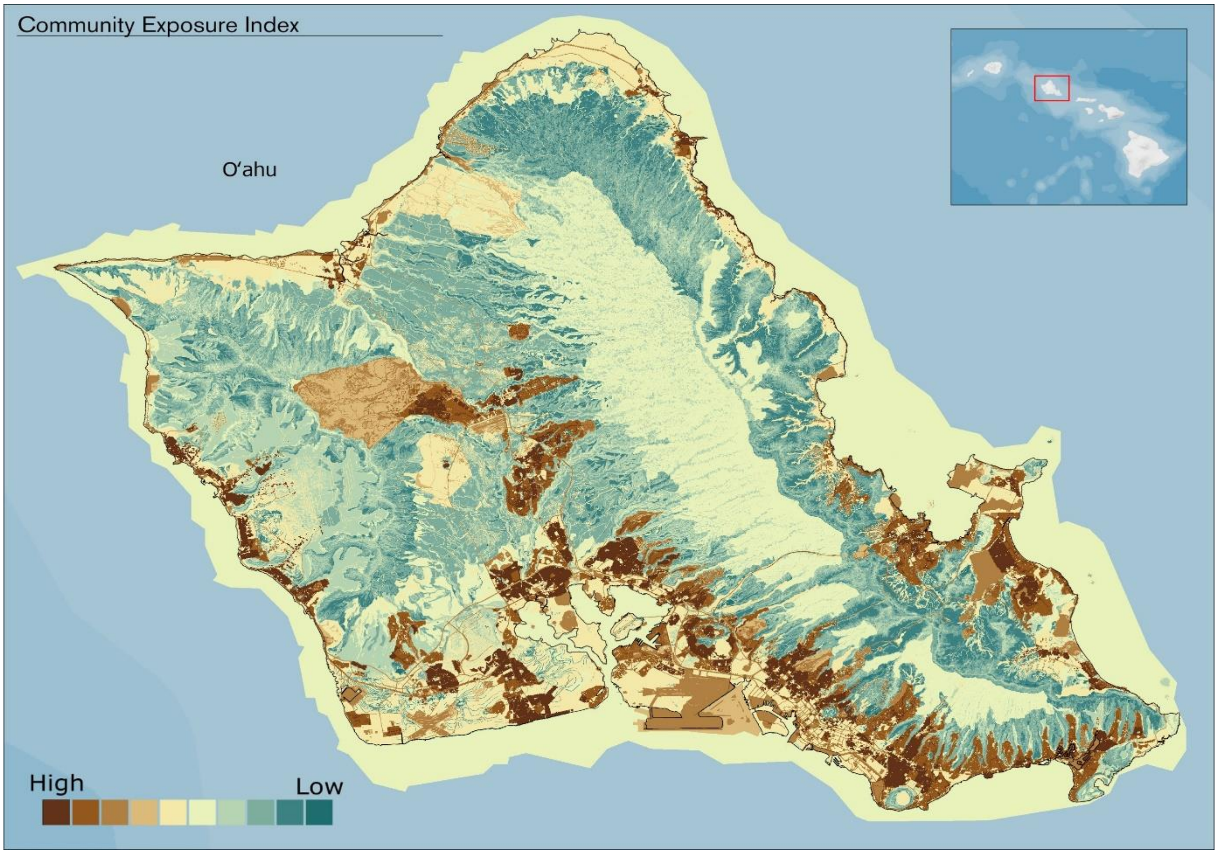


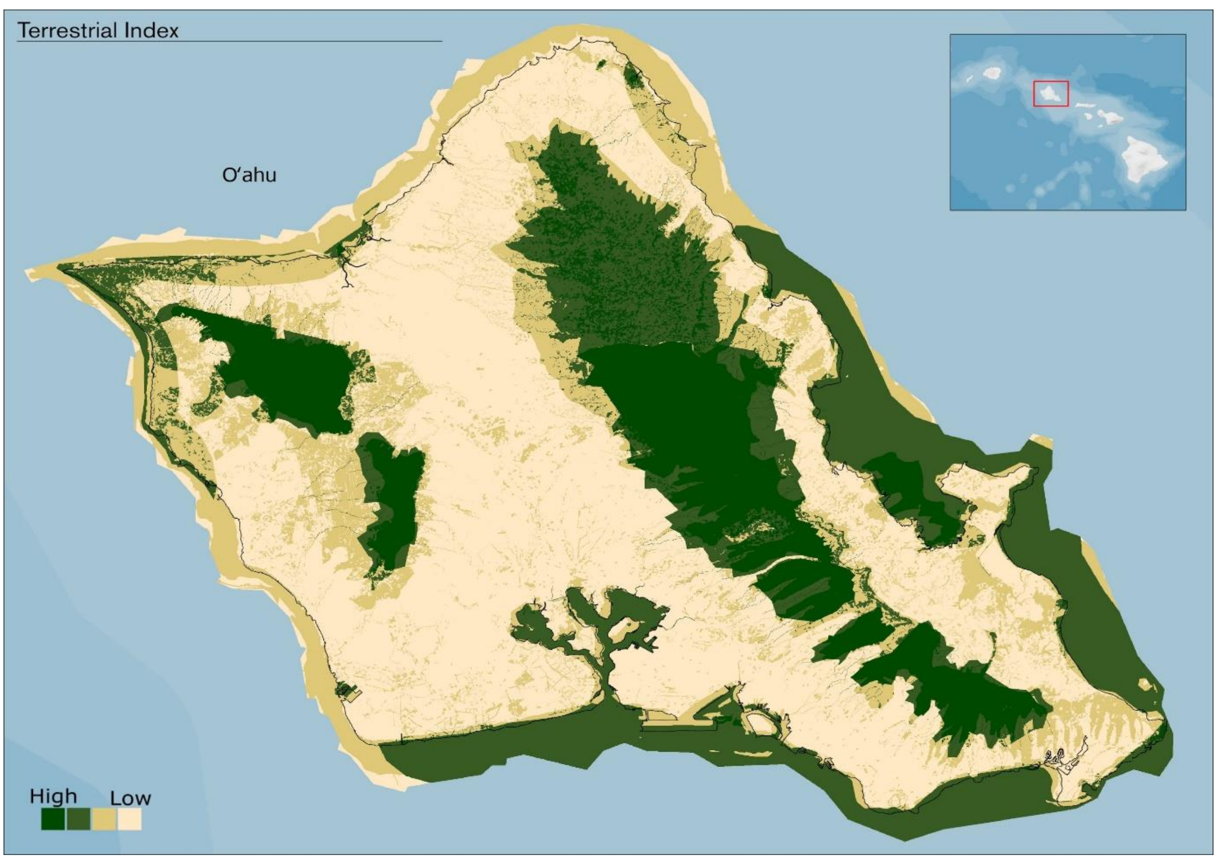
Resilience Hubs
Kaua'i
Ni'ihau
High
Low

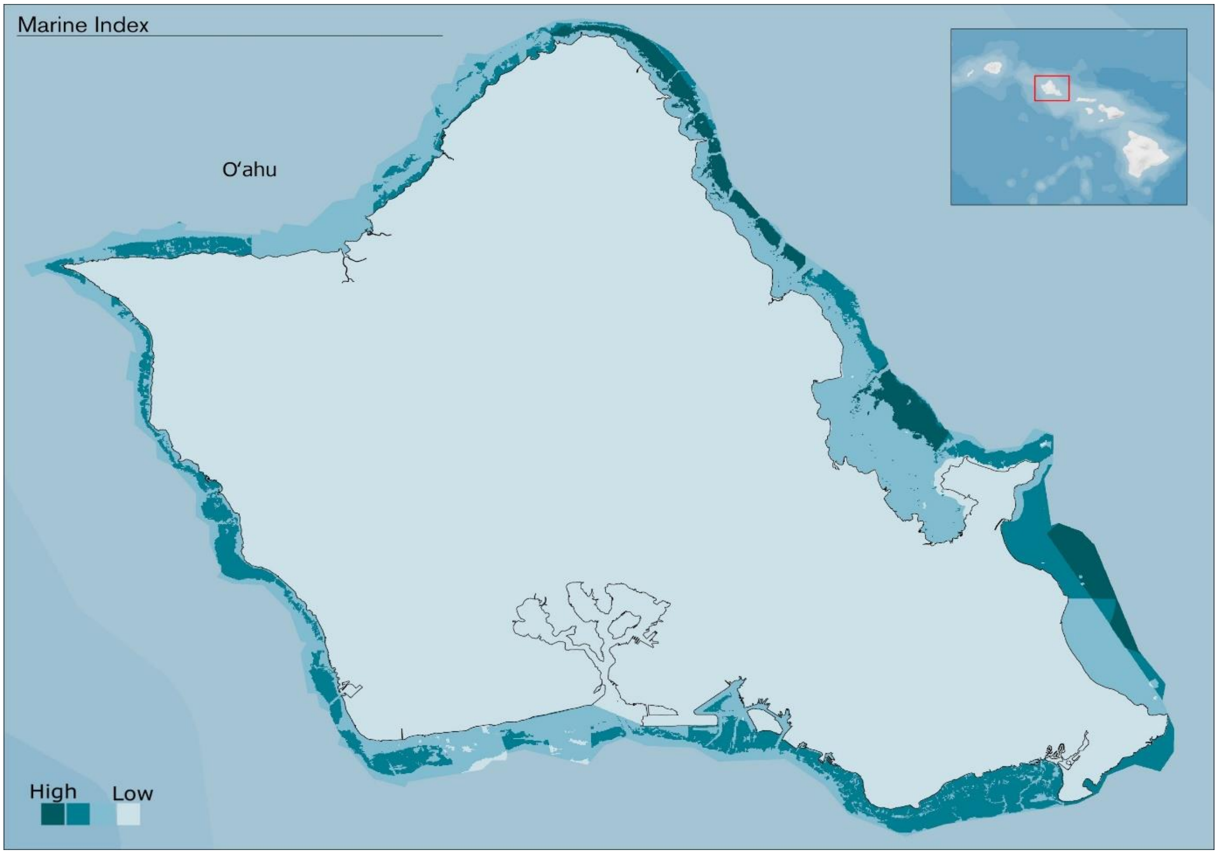
G.2. Maps of O'ahu



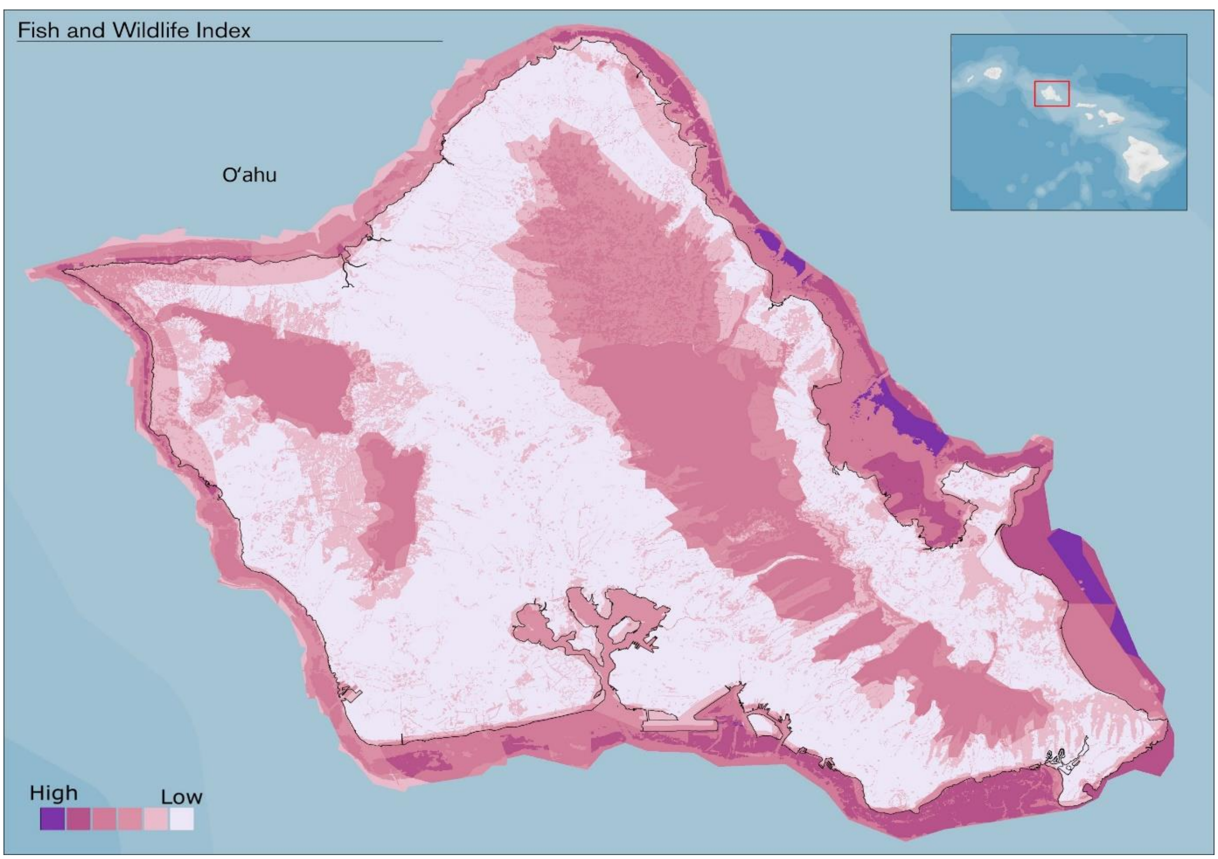



Community Exposure Index
O'ahu
High
Low

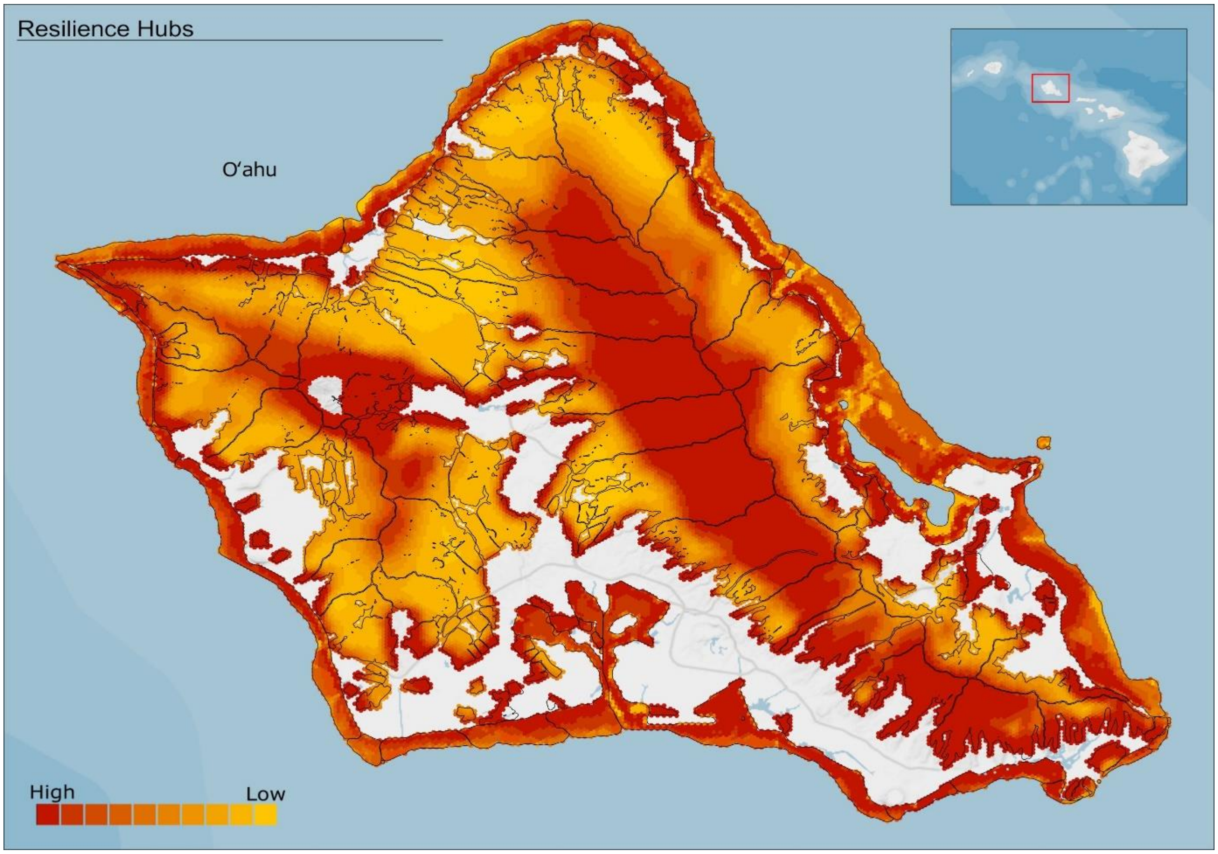

Terrestrial Index
O'ahu
High
Low



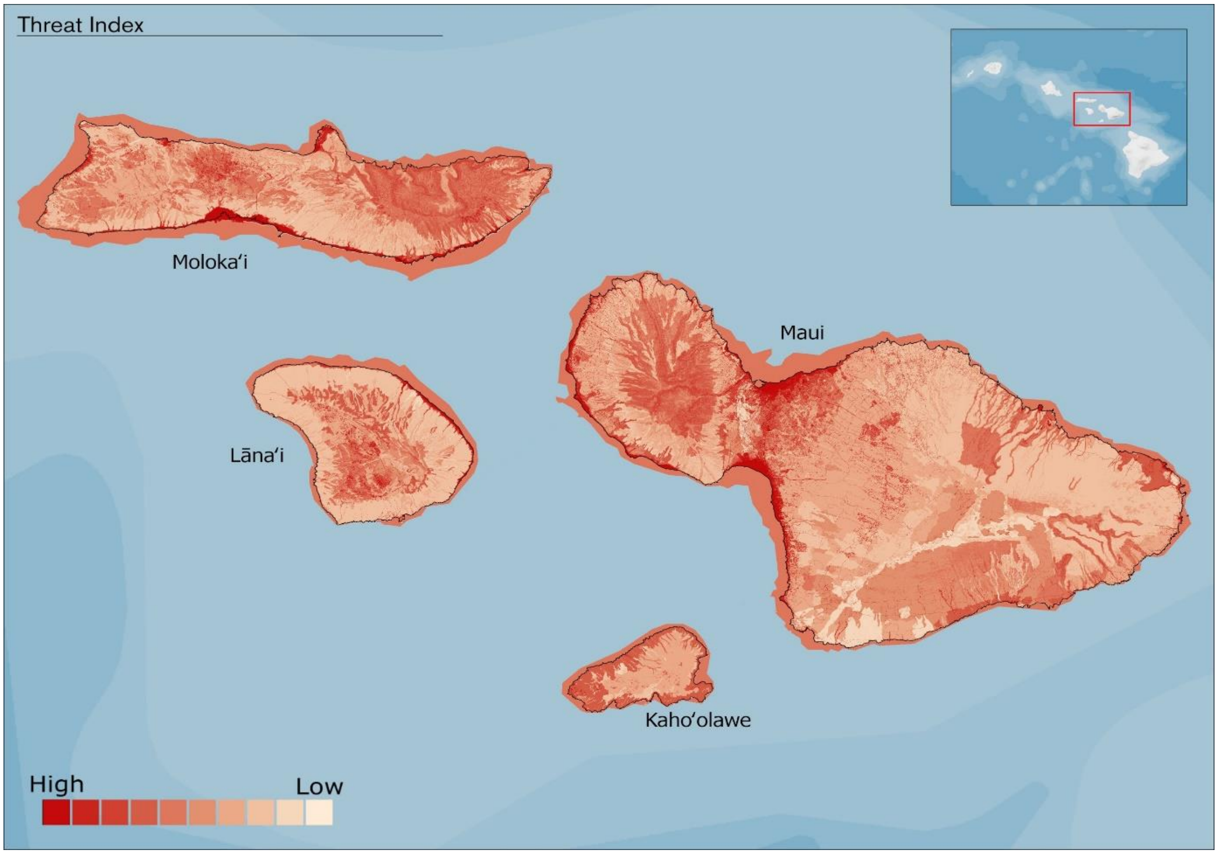
Marine Index
O'ahu
High
Low

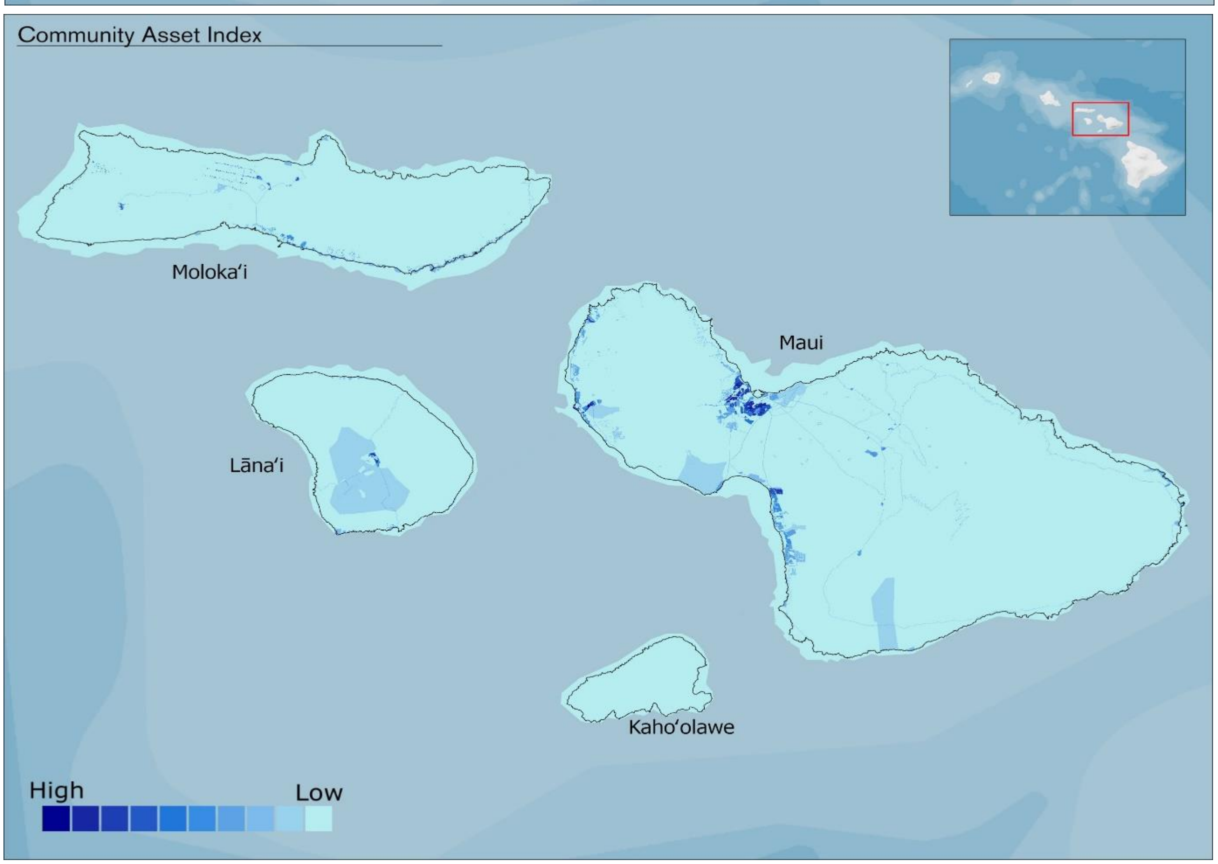


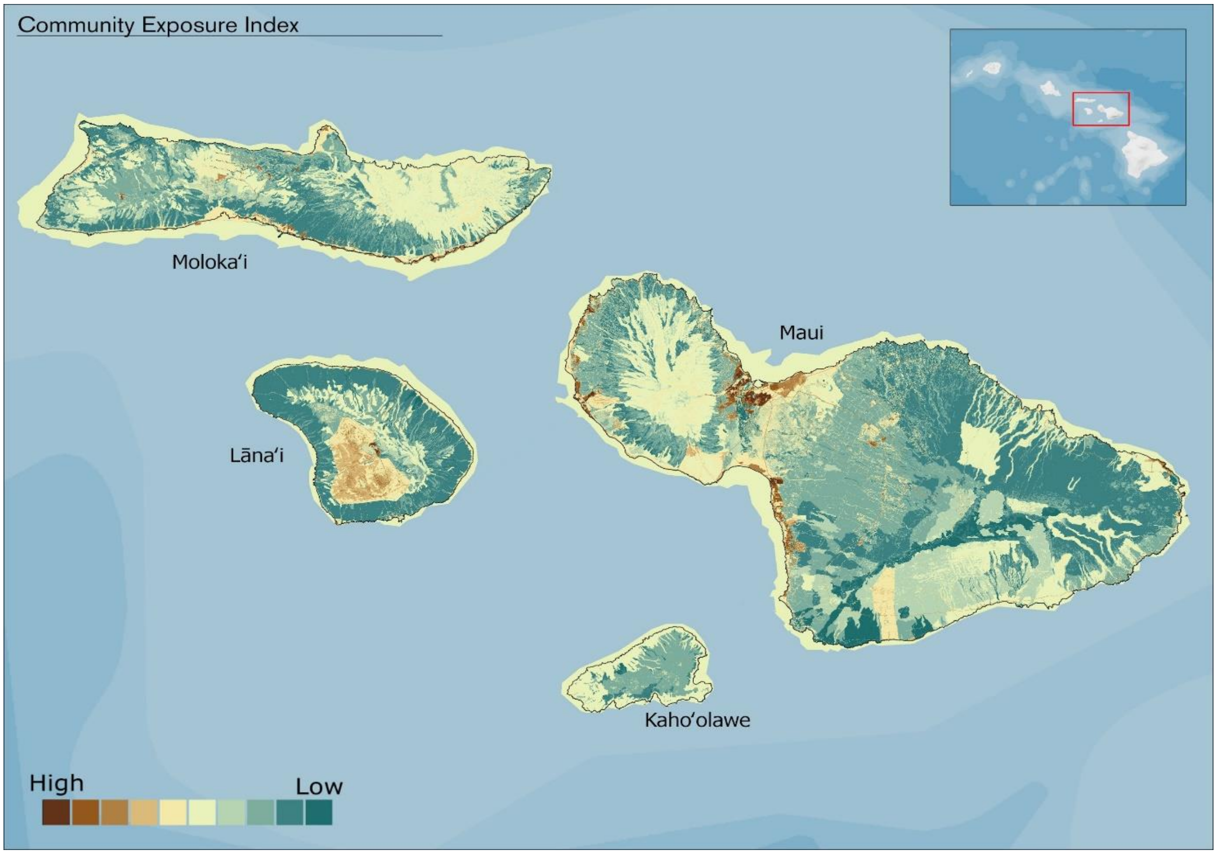
Fish and Wildlife Index
O'ahu
High
Low

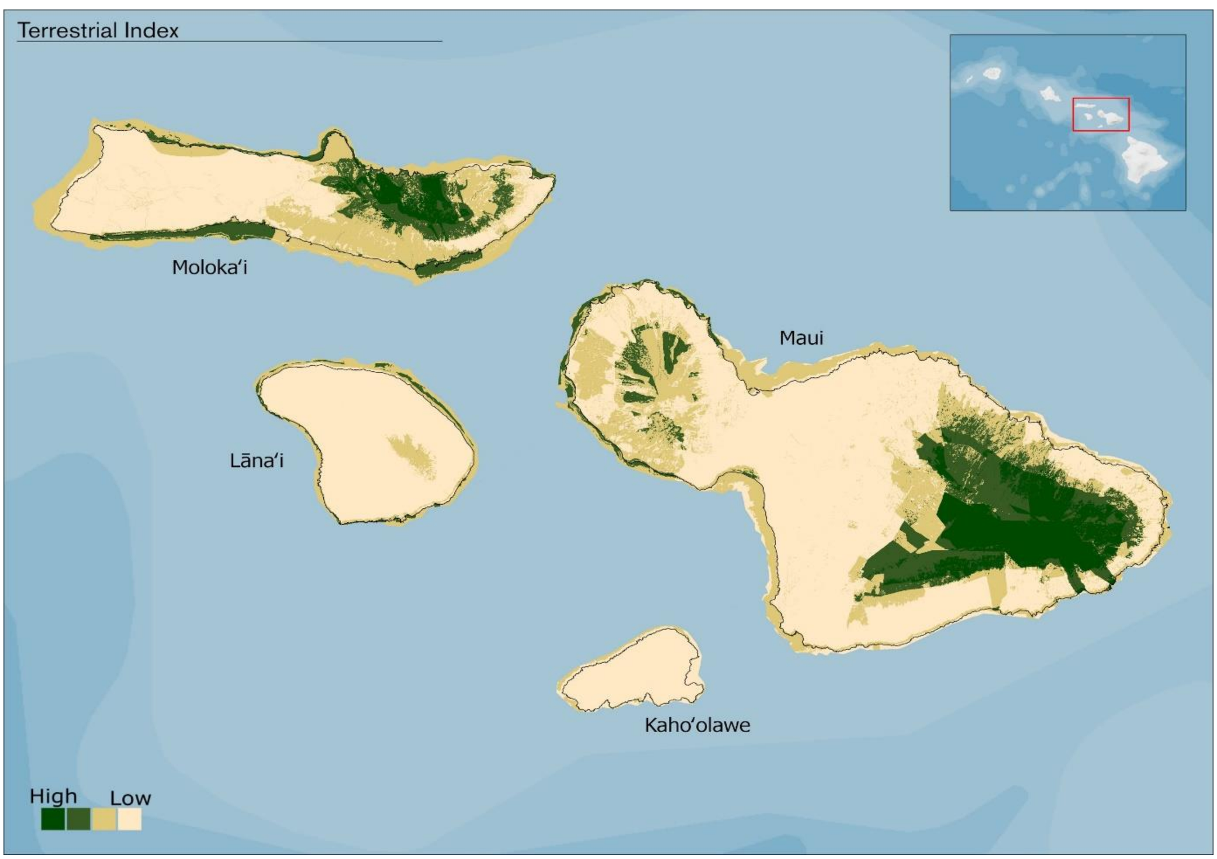

Resilience Hubs
O'ahu
High
Low

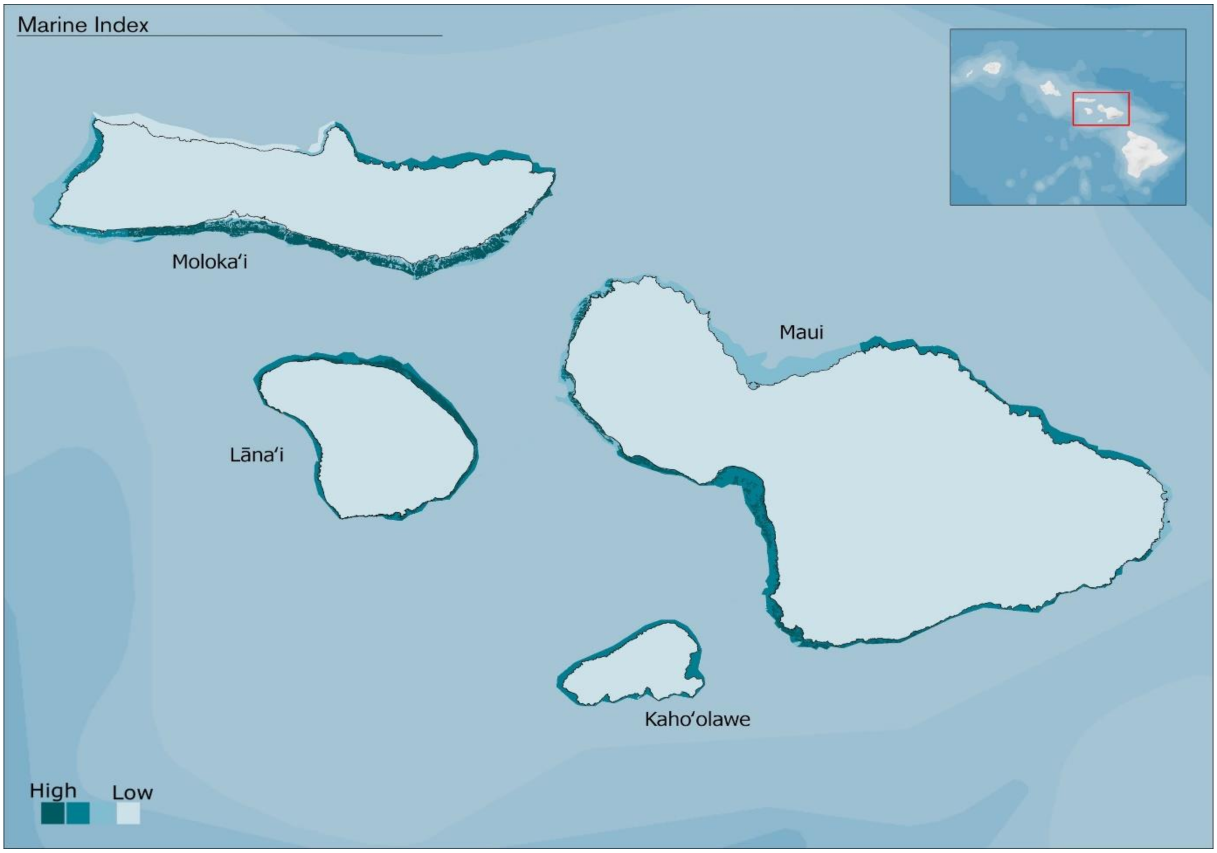
G.3. Maps of Molokaʻi, Maui, Lānaʻi, and Kahoʻolawe

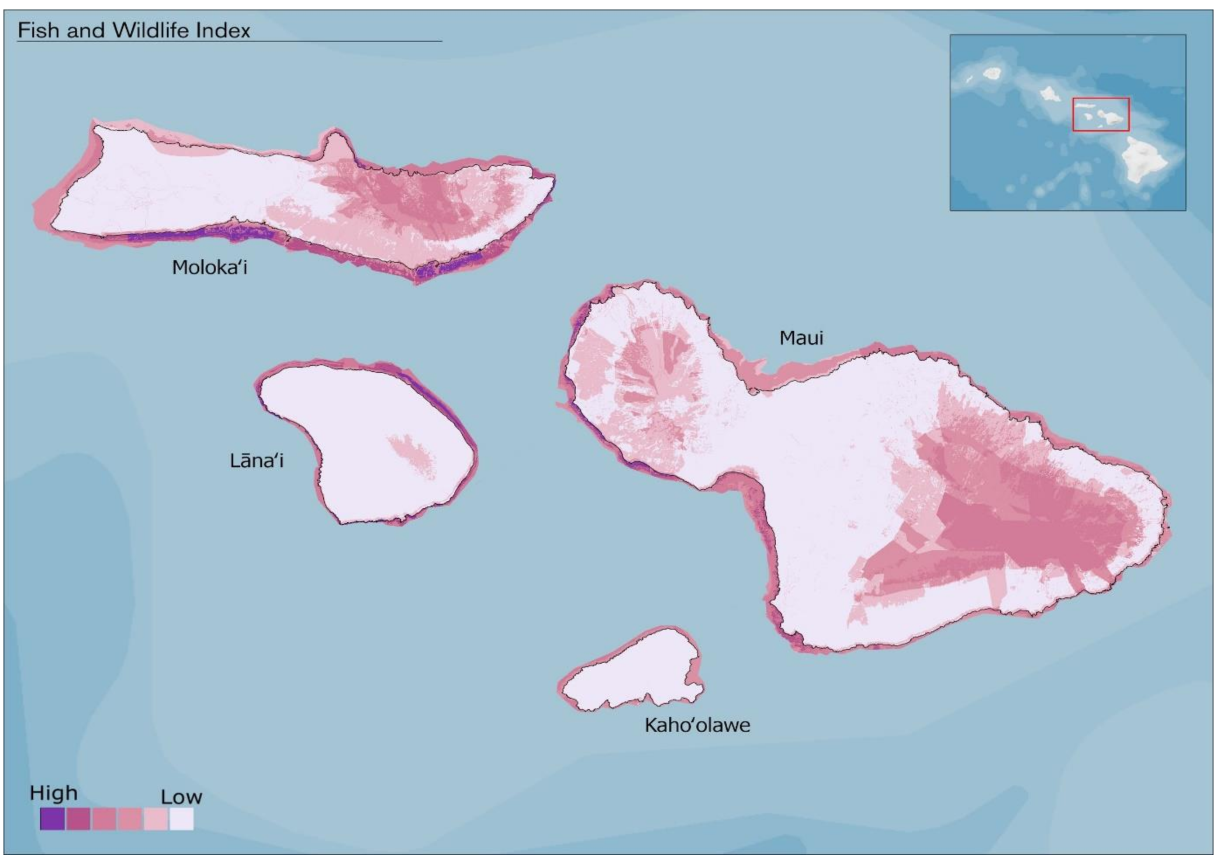


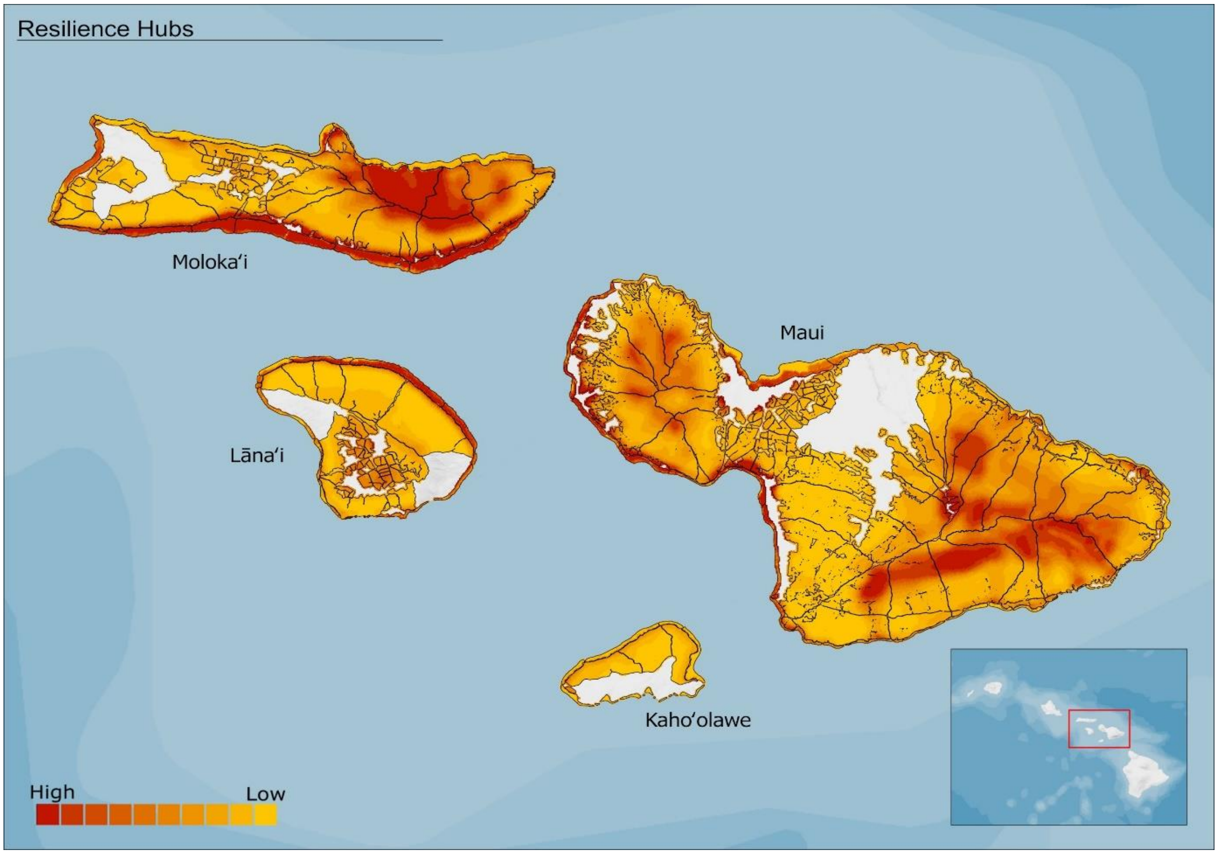



Community Exposure Index
Moloka'i
Maui
Lāna'i
Kaho'olawe
High
Low

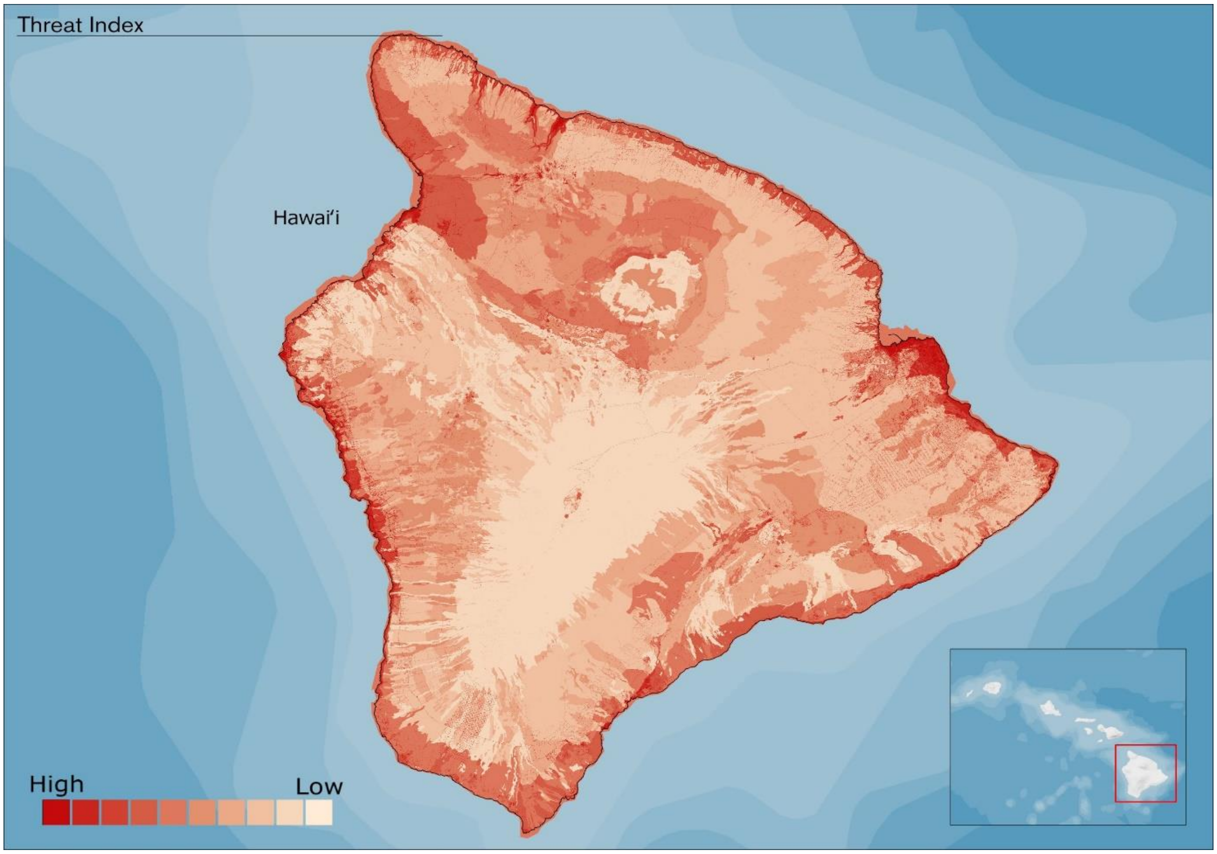

Terrestrial Index
Moloka'i
Maui
Lāna'i
Kaho'olawe
High
Low

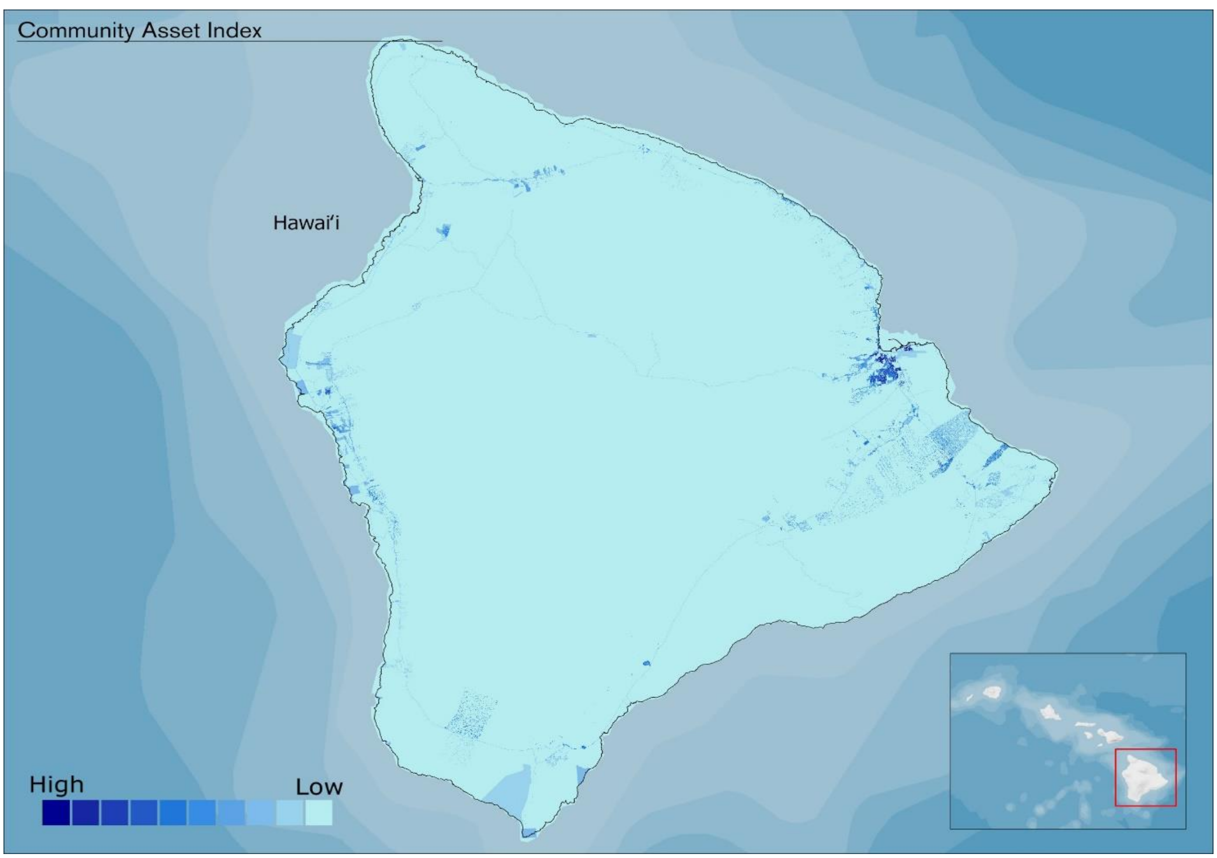

Marine Index
Moloka'i
Maui
Lāna'i
Kaho'olawe
High
Low

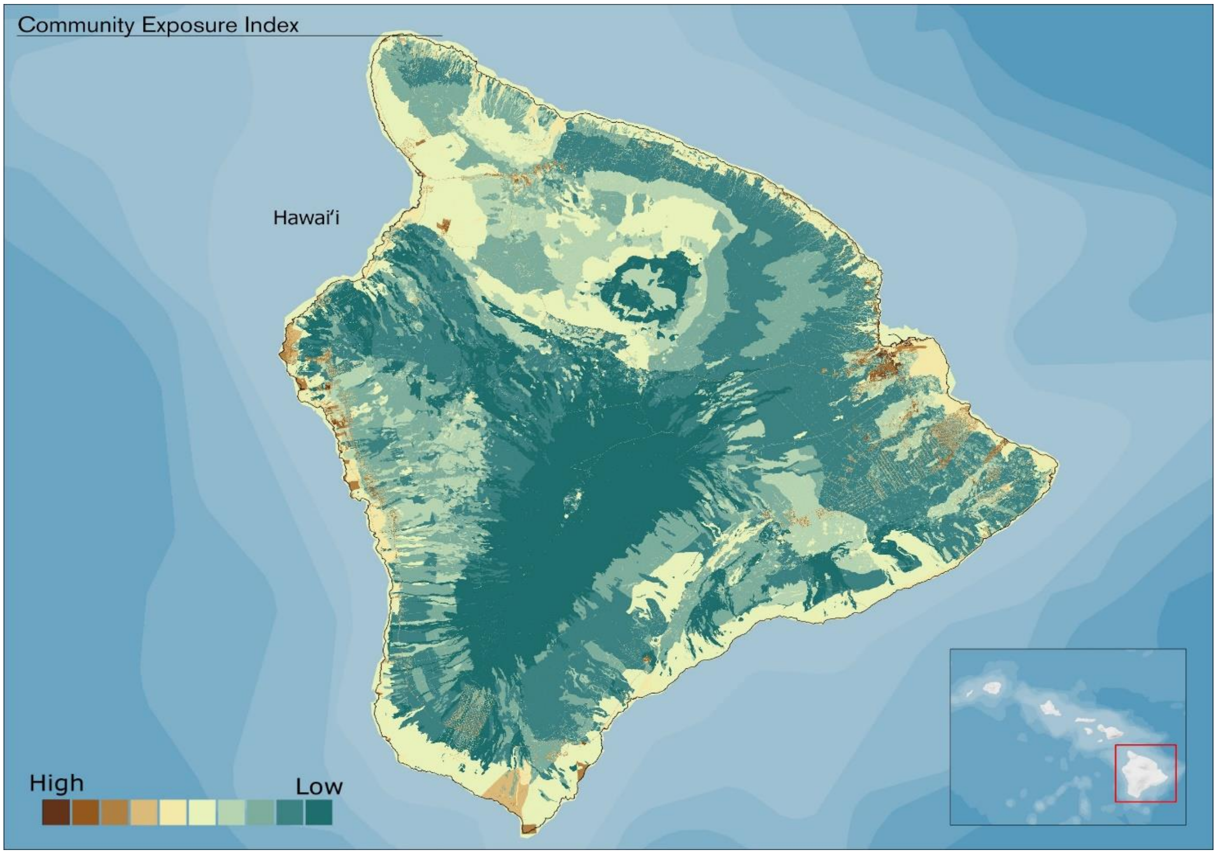

Fish and Wildlife Index
Moloka'i
Maui
Lāna'i
Kaho'olawe
High
Low

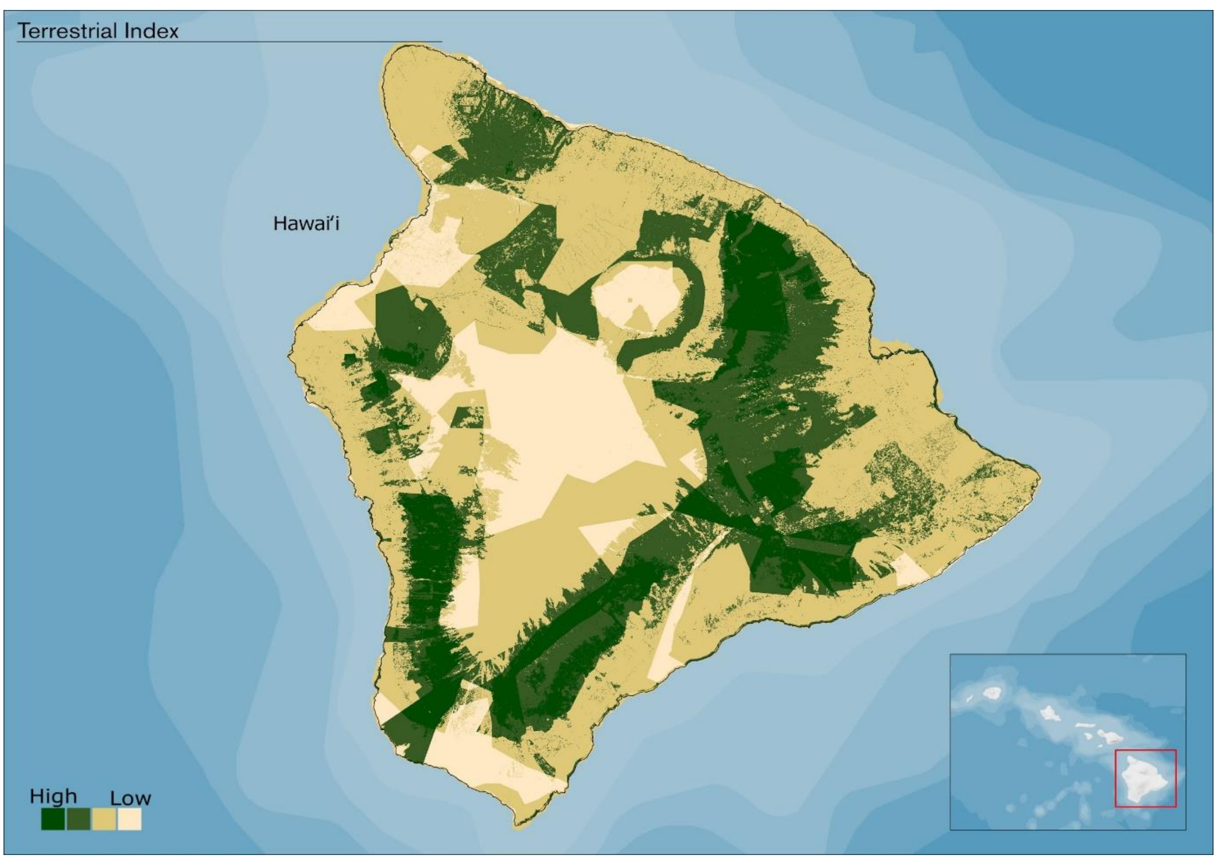

Resilience Hubs
Moloka'i
Maui
Lāna'i
Kaho'olawe
High
Low

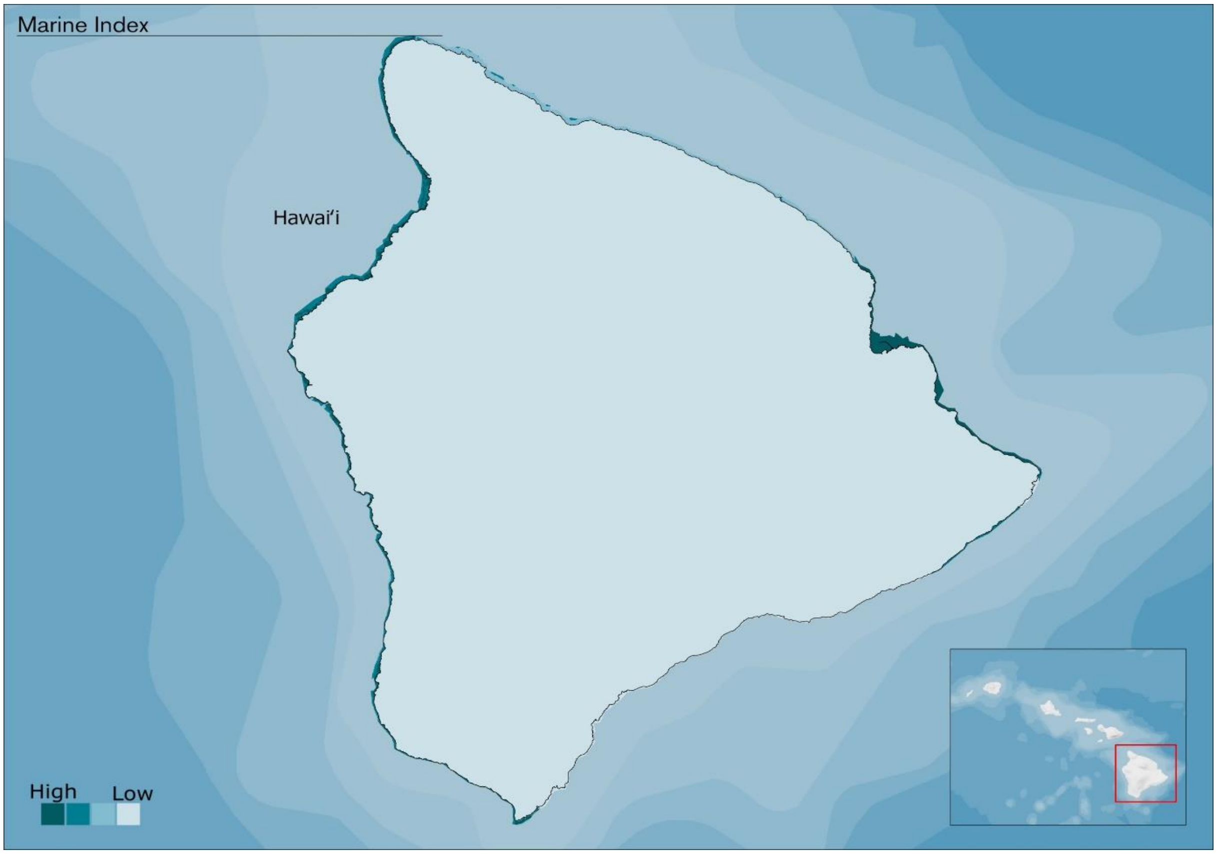
G.4. Maps of Hawai'i Island

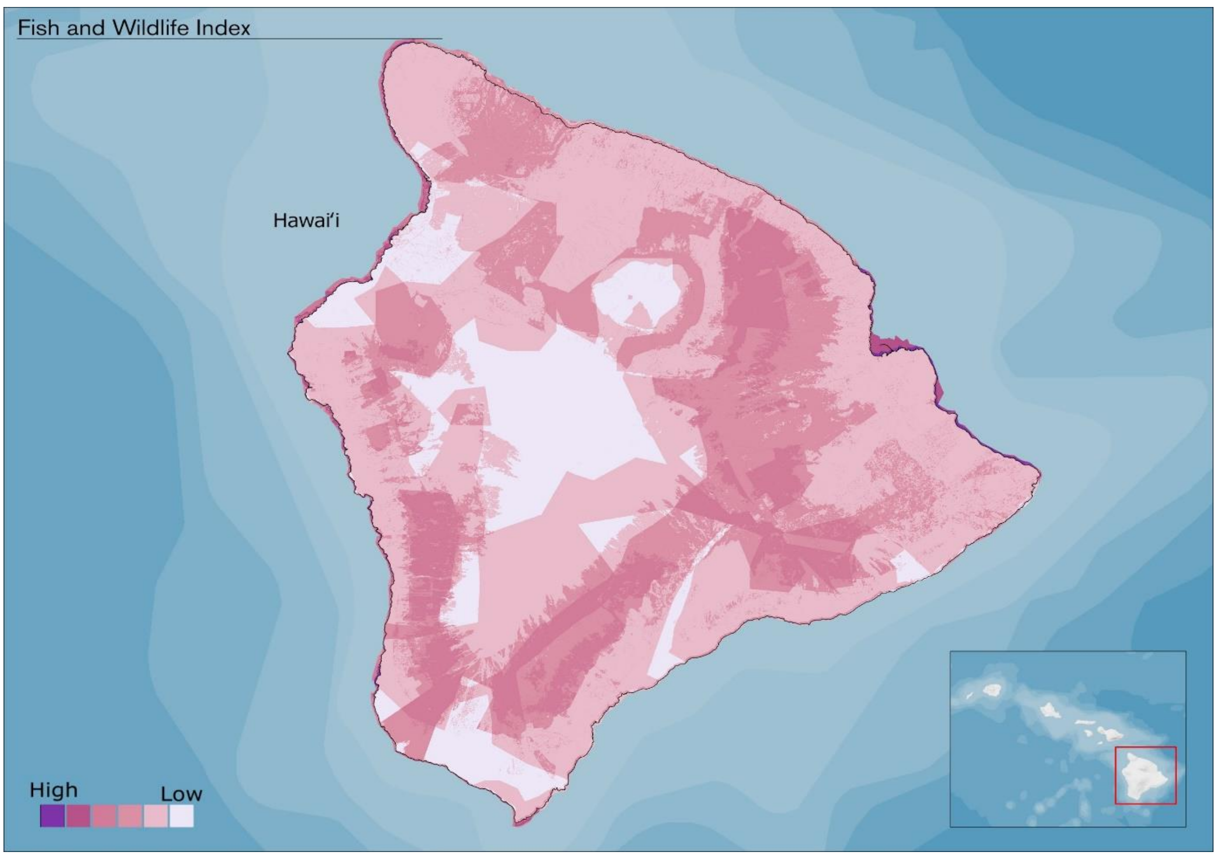


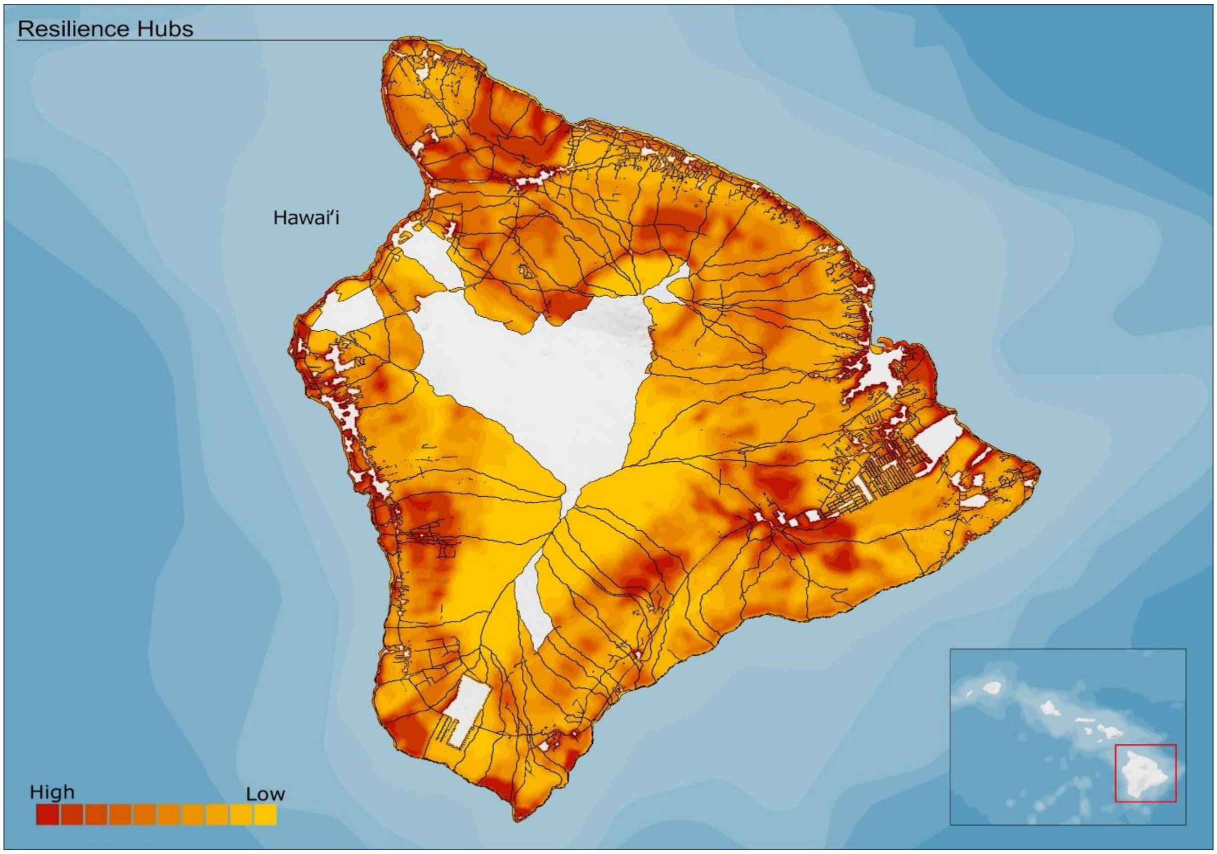



Community Exposure Index
Hawai'i
High
Low


Terrestrial Index
Hawai'i
High
Low


Marine Index
Hawai'i
High
Low


Fish and Wildlife Index
Hawai'i
High
Low



Resilience Hubs
Hawai'i
High
Low