NOAA FISHERIES

Pacific Islands Fisheries Science Center

ECOSYSTEM STATUS REPORT FOR HAWAI‘I

2022 ECOSYSTEM STATUS REPORT FOR HAWAIʻI

Authors: Jamison M. Gove[1,#,†], Jeffrey A. Maynard[2,†], Joey Lecky[1,3], Dieter P. Tracey[2,4], Mary E. Allen[5], Gregory P. Asner[6], Eric Conklin[7], Courtney Couch[1,8], Kimberly Hum[7,9], Rebecca J. Ingram[1,10,11], Tye L. Kindinger[1], Kirsten Leong[1], Kirsten L.L. Oleson[12], Erica K. Towle[5], Ruben van Hooidonk[13,14], Gareth J. Williams[15], and Justin Hospital[1].

1 Pacific Islands Fisheries Science Center, National Oceanic and Atmospheric Administration, Honolulu, HI, 96818, USA

2 SymbioSeas, Carolina Beach, NC, 28428, USA

3 IBSS Corporation, Silver Spring, MD, 20910, USA

4 Science Graphics, Cairns, QLD, 4870, Australia

5 Office for Coastal Management, Coral Reef Conservation Program, National Oceanic and Atmospheric Administration, Silver Spring, MD, 20910, USA

6 Center for Global Discovery and Conservation Science, Arizona State University, Tempe, AZ 85281, USA

7 The Nature Conservancy, Honolulu, HI, 96817, USA

8 Cooperative Institute for Marine and Atmospheric Research, University of Hawaiʻi at Mānoa, Honolulu, HI, 96822, USA

9 Hawaiian Islands Humpback National Marine Sanctuaries, National Oceanic and Atmospheric Administration, Honolulu, HI, 96818, USA

10 Pacific States Marine Fisheries Commission, Portland, OR, 97202, USA

11 Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, WA, 98115

12 Department of Natural Resources and Environmental Management, University of Hawaiʻi at Mānoa, Honolulu, HI, 96822, USA

13 Cooperative Institute for Marine and Atmospheric Studies, Rosenstiel School of Marine, Atmospheric, & Earth Science, University of Miami, Miami, FL, 33149, USA

14 Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, Miami, FL, 33149, USA

15 School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey LL59 5AB, UK

Corresponding author. Email: jamison.gove@noaa.gov

† These authors contributed equally to this work

Suggested Citation: Gove JM, Maynard JA, Lecky J, Tracey DP, Allen ME, Asner GP, Conklin C, Couch C, Hum K, Ingram RJ, Kindinger TL, Leong K, Oleson KLL, Towle EK, van Hooidonk R, Williams GJ, Hospital J. 2022. *2022 Ecosystem Status Report for Hawaiʻi*. Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-23-01, 91p. doi:10.25923/r53p-fn97

Table of Contents

Executive Summary

The National Oceanic and Atmospheric Administration (NOAA) is charged with stewardship of our nation's ocean resources with the stated vision of healthy ecosystems, communities, and economies that are resilient in the face of change. NOAA has adopted an Integrated Ecosystem Assessment (IEA) approach to develop the science, tools, and partnerships required to address complex ecosystem challenges and make progress towards the agency's vision. The IEA program previously published two Ecosystem Status Reports (Gove et al. 2016 and 2019). These reports presented a suite of ecosystem indicators useful for tracking the status and trends of marine ecosystems in west Hawai'i. This report expands the geographic scope of the previous efforts and describes the status and trends of marine ecosystems in the main Hawaiian Islands.

Strong connections between people and the ocean environment are a hallmark of communities across all the Hawaiian Islands and this is the key theme throughout this report. These connections are often circular and reciprocal in nature, within which human communities affect, depend on, and care for ecosystem health. Our actions and activities influence ecosystem status and trends; they are also the conduits through which we experience values, feel meaning, or benefit from ecosystem goods and services. This report begins with a section on Human Connections to further highlight and explain human-land-sea connections. The report concludes with a description of some of the applied research most likely to inform management and conservation. Summaries and result highlights of each of the six report sections are below.

Section 1) *Human Connections*. Most people in Hawai'i live near the coast and maintain strong connections to the ocean. This cultivates an awareness and familiarity of ecosystem conditions as well as the human activities that impact ecosystem health. This section presents indicators on the distribution and growth of resident population in Hawai'i over the past two decades (2000 – 2020). Survey results are also presented from the Socioeconomic Component of NOAA's National Coral Reef Monitoring Program on Hawai'i residents' perceptions of pressures, threats, and overall status and trends in nearshore marine ecosystems.

Result Highlights. The population of the main Hawaiian Islands (MHI) in 2020 was approximately 1.5 million, which represents a 20% increase since 2000. Across the MHI, 83% of people live within 5 km of the ocean, and 94% live within 10 km. Over 70% of survey respondents are increasingly aware of the many threats to coastal marine ecosystems. Most of the respondents (59–72%) also perceived nearshore ecosystem health as getting worse (Allen et al. 2022). Visitor arrivals to Hawai'i in 2019 totaled nearly 10.3 million, which is 6.7 times greater than the local resident population (HTA 2019). This was the most people ever to visit Hawai'i in a single year and the first time when the number of arrivals surpassed 10 million.

Section 2) *Small Boat Commercial Fishers*. The fishers that comprise the small boat commercial fishing fleet in Hawai'i are important in supporting local food systems, nutrition, food security, and community social cohesion (Allen 2013). The small boat commercial fishing fleet has high levels of community participation and uses a broad range of gear types to catch a variety of target fish species.

The small boat fleet represents a small fraction of total commercial landings in Hawaiʻi, but the fishers and their catch are undeniably important for local communities. This section describes fisher engagement and fisher revenue in communities from 2000–2019 for Pelagic, Deep 7 Bottomfish (six snapper and one grouper species), and Nearshore fisheries. We also provide indicators for each fishery related to catch, specifically total catch and catch per trip, for the 1990 to 2019 timeframe.

Result Highlights. Honolulu (Oʻahu) and North Kona (Hawaiʻi Island) had the highest Fishing Engagement Index values for all 3 fisheries between 2000 and 2019. During this period, catch of pelagics generated the greatest total revenue for all communities in Hawaiʻi, with a 4- to 6-fold higher total revenue than Deep 7 Bottomfish and nearshore fish. Total revenue for each of the 3 fisheries was 35–58% less in 2019 than in 2000. Revenue declines directly relate to declines in catch. Over the past 30 years (1990–2019), reported catch for the 3 fisheries declined by 53–68%. Changes in reported catch were mirrored by a 26–47% decrease in the total number of fishers reporting commercial catch over the same time period (PIFSC 2022). Declines in catch were principally driven by declines in tuna catch for pelagics, opakapaka and onaga for bottomfish, and ʻōpelu and akule for nearshore fish. While total commercial catch has mostly declined over time, catch per trip for many species groups, such as the Deep 7 Bottomfish, showed minimal changes or slight increases in recent years. These trends are also supported by the recent Deep 7 Bottomfish stock assessment, which indicated the fishery is not overfished nor subject to overfishing (Syslo et al. 2021). Diverse factors have likely negatively affected engagement in small boat fisheries over the study period including the increasing costs of fishing, high cost of living in Hawaiʻi, economic shocks, regulatory changes, and the greying of the fleet (Hospital and Beaver 2011; Chan and Pan 2017; NMFS 2021). The contrasting results of declining commercial catch and stable catch per trip may indicate changes in fleet composition with fewer, more experienced fishers active in small boat commercial fisheries in Hawaiʻi.

Locations where small boat commercial fishers catch fish have also changed in the last 30 years. When comparing average reported catch between historical (1990–2014) and more recent (2015–2019) time periods, pelagic catch increased by 20,000–50,000 lb/year in commercial reporting blocks north and east of Maui, and southeast of Hawaiʻi Island, and by more than 50,000 lb/year near east Kauaʻi. Deep 7 Bottomfish catch also increased near North Kona and most Inshore reporting blocks near Hawaiʻi Island. However, overall, the catch by small boat fishers has decreased for the vast majority of reporting blocks in Hawaiʻi. The greatest changes occurred in Coastal reporting blocks, where declines in catch have occurred in 63–73% of reporting blocks. Along with reported catch, small boat commercial fisher participation changed over time. The average number of small boat fishers that reported commercial catch between the two time periods (1990–2014 and 2015–2019) declined by 16–31% (PIFSC 2022). Such large declines in active fishers presumably contributed to, in part, the declines in total catch and other similar trends in small boat commercial fisheries indicators. Ultimately, we do not have a clear understanding of the various socioeconomic, ecological, and environmental drivers that underpin the changes observed. This is an area of active research that we will continue to pursue in the future.

Section 3) *Coral Reefs and Reef Fish*. Coral reef ecosystems are productive, biologically diverse, and provide critically important services to local communities in Hawai‘i including cultural practices, livelihoods, food-resources, fisheries, and coastal protection. This section presents reef surveys of the MHI by NOAA's National Coral Reef Monitoring Program for 2010 to 2019 and describes patterns in indicators of nearshore coral reef benthic (hard coral cover, calcifiers cover, reef-builder ratio) and reef fish communities (total fish biomass, herbivore biomass, resource fish biomass).

Result Highlights. The status of coral cover in 2019 was relatively high for 32% of sectors, medium for 14%, and low for 50% of all sectors surveyed across the MHI (N = 22). Coral cover was greatest in north Lāna‘i (39.7%) and lowest in west Ni‘ihau (0.4%). Coral cover varied considerably by depth, with the highest cover generally found at moderate depths (6–18 m). Between 2010 and 2019, coral cover significantly increased in 1 sector (north Lāna‘i) and decreased in 30% of the sectors, which included west and east Hawai‘i, south Moloka‘i, and both sectors on Kaua‘i. The remaining 41% (7 of 17) of sectors had no significant direction of change. The spatial and temporal patterns were similar across coral reef benthic indicators.

The status of reef fish biomass in 2019 was relatively high for 39% of sectors, medium for 14%, and low for 50% of all sectors surveyed across the MHI (N = 18). Fish biomass was greatest in north Kaho‘olawe (656 kg/ha) and lowest in west Maui (93 kg/ha). Fish biomass varied considerably by depth, with the lowest biomass generally found in shallow depths (< 6 m). Change over time in reef fish biomass could only be calculated for half of the sectors in the MHI, where the majority of change was not significantly positive or negative. Change in reef fish biomass differed across depths in west Hawai‘i, indicating temporal differences may be depth-specific within sectors. The status and trends in reef fish biomass were generally mirrored in herbivore and resource fish biomass.

Section 4) *Climate and Ocean*. Fisheries productivity, species interactions, food-availability, and ecosystem dynamics are all intrinsically linked to climate and ocean conditions in Hawai‘i. Climate change will continue to drive variations in local conditions in the coming decades, directly influencing ecosystem health. Tracking the status and trends of climate and ocean conditions is critically important for coastal planning and management of nearshore marine ecosystems. This section includes climate and ocean indicators such as the El Niño-Southern Oscillation and Pacific Decadal Oscillation, and describes annual rainfall, peak rainfall events, the water quality advisories that can follow heavy rainfall, and historical and future projected changes in sea level and sea surface temperature.

Result Highlights. Rainfall at Hilo (Hawai‘i Island) was 3 to 11 times greater between 1990 and 2021 — than in Kona (Hawai‘i Island), Kahului (Maui), Līhu‘e (Kaua‘i), or Honolulu (O‘ahu). However, Hilo had the lowest rainfall during peak events with an average of just 19.5% of rain occurring within the top 5 days (other locations: 34–47%). The total rainfall during peak events has increased over time at all locations except Hilo. Heavy rainfall events can result in brown water advisories (BWAs). BWAs are issued by the State of Hawai‘i Clean Water Branch when excessive runoff of water carries land-based pollution into the ocean, compromising nearshore water quality and posing a threat to coastal ecosystems (Fabricious 2005) and human health (Whittier and El-Kadi. 2014). At the island-scale, BWAs occurred most frequently on O‘ahu; there were approximately 60 per year between 2018 and 2021.

Long-term sea level measurements from Honolulu indicate a clear positive trend; it has increased by 0.30 m (0.89 ft) in the past 120 years. Over the past 3 decades, sea surface temperatures (SST) have increased between 0.15 and 0.25 °C per decade in the MHI. The Intergovernmental Panel on Climate Change (IPCC) emissions scenario most representative of current emissions concentrations and growth is SSP5-8.5. Under this scenario, the extreme ocean temperatures of 2015 in Hawaiʻi that caused severe coral bleaching and mortality (Gove et al. 2019) are projected to occur annually by 2048 (MHI average), with considerable spatial variation in the timing of exposure among and between islands.

Section 5) *Human Impacts*. The great majority of human activity in Hawaiʻi takes place in and adjacent to the nearshore environment. Land-based impacts like wastewater pollution and sediment input combine with sea-based impacts, such as overfishing. These are cumulative impacts that disrupt natural ecological processes and reduce ecosystem health, function, and resilience.

Understanding these cumulative impacts is essential to targeting management and restoration activities. This section presents the first-ever assessment of spatial variation in cumulative impacts to nearshore ecosystems for the main Hawaiian Islands. Cumulative impact scores were generated as a function of stressor intensity and the vulnerability of coral reef, rocky reef, and sandy bottom habitat areas to human stressors.

Result Highlights. There is substantial spatial variation across the MHI in cumulative impacts. The highest cumulative impact scores were along the south shore of Oʻahu, between Diamond Head and Pearl Harbor. Almost every stressor co-occurred there with many at or near maximum intensity. High levels of cumulative impacts also occurred in Hilo Harbor on Hawaiʻi Island and Kahului, Maui. Like south Oʻahu, these areas primarily consist of non-coral-dominated habitat and have commercial harbors, shipping activity, high levels of habitat destruction, and high land-based pollution and fishing pressure. West Hawaiʻi Island also had comparably high cumulative impact scores even though relatively fewer stressors co-occur in the area. The high scores are a result of the habitat in west Hawaiʻi consisting primarily of coral reef which is the most vulnerable habitat type to human stressors.

Section 6) *Vulnerability of Coral Reefs to Climate Change*. Climate change poses a critical threat to ecosystems in Hawaiʻi. Nearshore coral reefs are particularly vulnerable as cumulative impacts combine with climate-driven disturbances to fundamentally change reef ecosystems. However, there will be significant spatial variation in coral reef vulnerability to climate change in Hawaiʻi. Coral reef vulnerability was assessed by combining information on human impacts, ecological resilience, and projected future exposure to climate impacts. Conservation and management actions that account for climate vulnerability can give reefs the best chance to continue to function and provide ecosystem and cultural services. This section describes climate model projections of future exposure to coral bleaching and inter-island and intra-island assessment results of climate vulnerability for coral reefs.

Result Highlights. Severe coral bleaching is projected to occur on an annual basis starting in 2048 (mean year across the MHI) under the IPCC emissions scenario most representative of current emissions concentrations and growth (SSP5-8.5). Onset of annual severe bleaching ranged from 2030 to 2066 across all reefs within the Hawaiian Islands, suggesting that some reefs may have decades more time to adapt and acclimate to climate change than others.

Differences in the projected onset of annual severe bleaching ranged from zero to 28 years between fossil fuel emission scenarios (SSP5-8.5 and SSP5-4.5). This highlights that climate policy may benefit some reefs much more than others by lengthening the time they have to adapt and acclimate to climate change.

Coral reef vulnerability to climate change was assessed at over 400 sites across the Hawaiian Islands. At the inter-island, or between-island scale assessment, there were low vulnerability sites at all islands except Oʻahu and Niʻihau. The greatest percentages (> 30%) of low vulnerability sites were on Lānaʻi, Molokaʻi, and Kahoʻolawe. The greatest percentages of high-vulnerability sites were on Hawaiʻi Island (25%), Oʻahu (24%), and Kauaʻi (20%). For the intra-island, or within-island assessment, there were sites in each relative category—low, medium-low, medium-high, and high—at all islands. These results highlight the importance of accounting for vulnerability both at the scale of individual islands and MHI-wide during conservation and management decision making.

Next Steps. The key theme of this report is strong connections; the human-land-sea connections between people and place, climate change and ecological communities, human activities and ecosystem health, and many more. This theme is also relevant for applying and building upon the findings in this report. Strong connections, especially collaborations and partnerships among government, academic, non-governmental organizations, and communities are necessary for setting and achieving effective management and conservation goals. Only through such strong connections can we ensure the ocean environment in Hawaiʻi continues to support human well-being in our changing climate.

All sections of this report contain data and information that can be improved and expanded upon in the coming years. In this sense, the report sections are launching pads for near-future research that can support and inform management and conservation. Research areas likely to be especially promising for improving human well-being and informing management include, from each report section:

1. Identifying pathways to positively influence cultural values, meanings, and other intangible benefits from ecosystems;
2. Identifying causes and consequences of decline in small boat fisher catch to help mitigate future human community level impacts;
3. Developing more detailed understanding of reef and reef fish changes across space and through time and the associated effects on human connections that contribute to human well-being in Hawaiʻi;
4. Understanding and mitigating impacts of changing rainfall patterns, rising sea levels, increasing ocean temperatures, and other climate-driven effects to marine ecosystems in Hawaiʻi;
5. Understanding and mitigating the cumulative impacts of land- and sea-based stressors on coastal ecosystems, and developing targeted actions that reduce habitat vulnerability;
6. Expanding climate change vulnerability assessments to include additional ecosystems and marine species and integrating results into management planning efforts.

Introduction

The National Oceanic and Atmospheric Administration (NOAA) is charged with stewardship of our Nation's ocean resources with the stated vision of healthy ecosystems, communities, and economies that are resilient in the face of change. NOAA has adopted an Integrated Ecosystem Assessment (IEA) approach to develop the science, tools, and partnerships required to address complex ecosystem challenges and make progress towards the agency's vision. The IEA in the Pacific Islands Region has conducted collaborative and interdisciplinary science to support current and future management needs for nearly a decade. These historical efforts have been focused in west Hawaiʻi, where there is a unique confluence of diverse ocean ecosystems, strong community connections to place, and overlapping government, academic, and non-governmental efforts.

The IEA program previously published two Ecosystem Status Reports (Gove et al. 2016; Gove et al. 2019). These reports presented a suite of ecosystem indicators useful for tracking the status and trends of marine ecosystems in west Hawaiʻi. This current report expands the geographic scope of the previous efforts and describes the status and trends of marine ecosystems across the main Hawaiian Islands. This broader scope is warranted as socio-cultural connections, climate and ocean ecosystem processes, and human impacts are highly variable across multiple spatial scales in Hawaiʻi. Further, the IEA program aims to better support Federal and State resource management needs in the region. This Hawaiʻi IEA Ecosystem Status Report also includes a greater focus on the diverse linkages between ecosystem health and human well-being.

Ph. Christine Shepard

Healthy marine ecosystems support the well-being of Hawaiian communities.

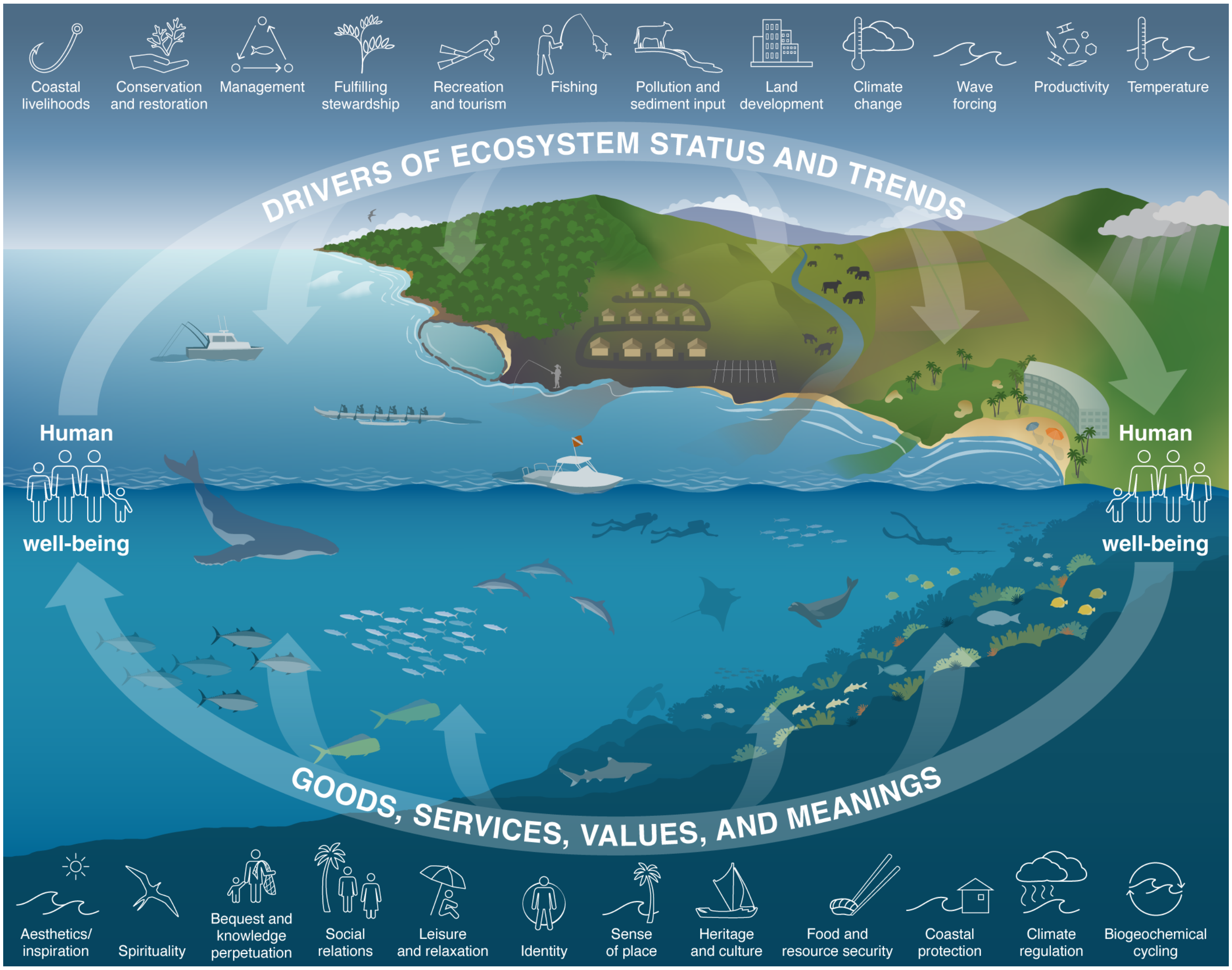


Fig. i. Conceptual diagram of coastal and marine ecosystems in Hawaiʻi highlighting that human actions and activities are both a driver of and dependent on ecosystem health. Human-land-sea connections are visualized here as a circle or cycle. In this integrated social-ecological system, change is constant and human well-being is complex, requiring that we conserve and adaptatively manage for socio-cultural values and meanings along with goods and services.

Human communities are an integral and influential part of coastal and marine ecosystems in Hawaiʻi. Deep-seated connections between people and the ocean environment are a hallmark of communities across the Hawaiian Islands. Marine ecosystems contribute substantially to the local economy and sustain culture, tradition, and social practices that are critical to human communities (Ingram et al. 2018). Over 85% of people in Hawaiʻi live within a few miles of the ocean. Residents regularly interact with the coastal environment through work, leisure, and cultural activities. The diagram above visualizes these human-land-sea connections as circular and reciprocal in nature, within which human communities affect, depend on, and care for ecosystem health (Fig. i). Our actions and activities influence ecosystem status and trends and are also the conduits through which we experience value, feel meaning, or benefit from ecosystem goods and services. The diagram also highlights the vitally important socio-cultural connections that contribute to human well-being in Hawaiʻi.

These connections include spirituality, heritage, sense of place, identity, and knowledge perpetuation (among many others). The intangible benefits that people derive through their relationships with ecosystems are critical to ecosystem health and human well-being (Ives et al. 2018; Dillard et al. 2013) yet are often missing in resource management (Leong et al. 2019; Kosanic and Petzold 2020).

This report begins with a section on Human Connections to further highlight and explain human-land-sea connections, along with resident familiarity of threats and their perceptions of ecosystem status and trends (1. Human Connections). The report then describes the status and trends of pelagic, Deep 7 bottomfish, and nearshore commercial landings by small boat commercial fishers that live within and bring their catch back to the communities in Hawaiʻi (2. Small Boat Commercial Fishers). In addition to fisheries, nearshore coral reef ecosystems provide critically important services to local communities in Hawaiʻi including cultural practices, livelihoods, food-resources, and coastal protection. The next section describes the status of coral reefs and reef fish as well as the extent and direction of change over this last decade (3. Coral Reefs and Reef Fish).

Physical drivers of coastal and marine ecosystem health are described next, along with climate change, which is projected to cause increases in both sea temperature and sea levels in Hawaiʻi (4. Climate and Ocean). Addressing the threats posed to marine and coastal ecosystems by climate change requires understanding and managing human impacts. The report provides the first Hawaiʻi-wide maps of cumulative human impacts on the nearshore marine environment (5. Human Impacts). Climate change impacts will vary greatly across the Hawaiian Islands and this variation will be driven in part by the vulnerability of marine ecosystems. The climate vulnerability of coral reefs is described in the last report section (6. Vulnerability of Coral Reefs to Climate Change). The report concludes with a description of some of the applied research most likely to inform management and conservation for each section of the report.

Connections between people and the ocean are central to identity and culture in Hawaiʻi.

Ph. Christine Shepard

1. Human Connections

Summary: *The majority of people in Hawai‘i live near the coast and have strong connections to the ocean. Residents are familiar with threats and pressures on ecosystems and have perceptions of the recent status and trends of ecosystem health and function. This section describes human population levels, distribution, and growth over the past two decades (2000–2020). This section also describes the results of surveys of 2,700 Hawai‘i residents conducted by the Socioeconomic Component of NOAA’s National Coral Reef Monitoring Program, including: percent of residents participating in various activities on and near coastal ecosystems, familiarity with ecosystem threats, and perceptions of the status and trends of ecosystem health indicators.*

Introduction

Most people in Hawai‘i live near the coast and maintain strong connections to the ocean. Residents regularly interact with the ocean environment through fishing, swimming, and spending time with family and friends on the beach. Ocean ecosystems contribute substantially to the local economy and sustain culture, tradition, and social practices that are critical to local communities (Ingram et al. 2018). Collectively these experiences and socio-cultural connections cultivate an awareness and familiarity of ecosystem conditions as well as the human activities that affect ecosystem health.

Fishing is a popular activity for residents and tourists, and major contributor to the Hawaiian economy. Ph. NOAA

A telephone and online web survey of 2,700 Hawai‘i residents was conducted between March and June of 2020, as part of the Socioeconomic Component of the NOAA National Coral Reef Monitoring Program (NCRMP; Allen et al. 2022). The overall goal of the surveys was to generate and track information on population, social, and economic structure, human interactions with coral reef resources, and the responses of local communities to reef ecosystem management. Survey results are assumed to be representative of the population of the State of Hawai‘i as a whole, as well as the islands of Hawai‘i, Kaua‘i, Maui, and O‘ahu.

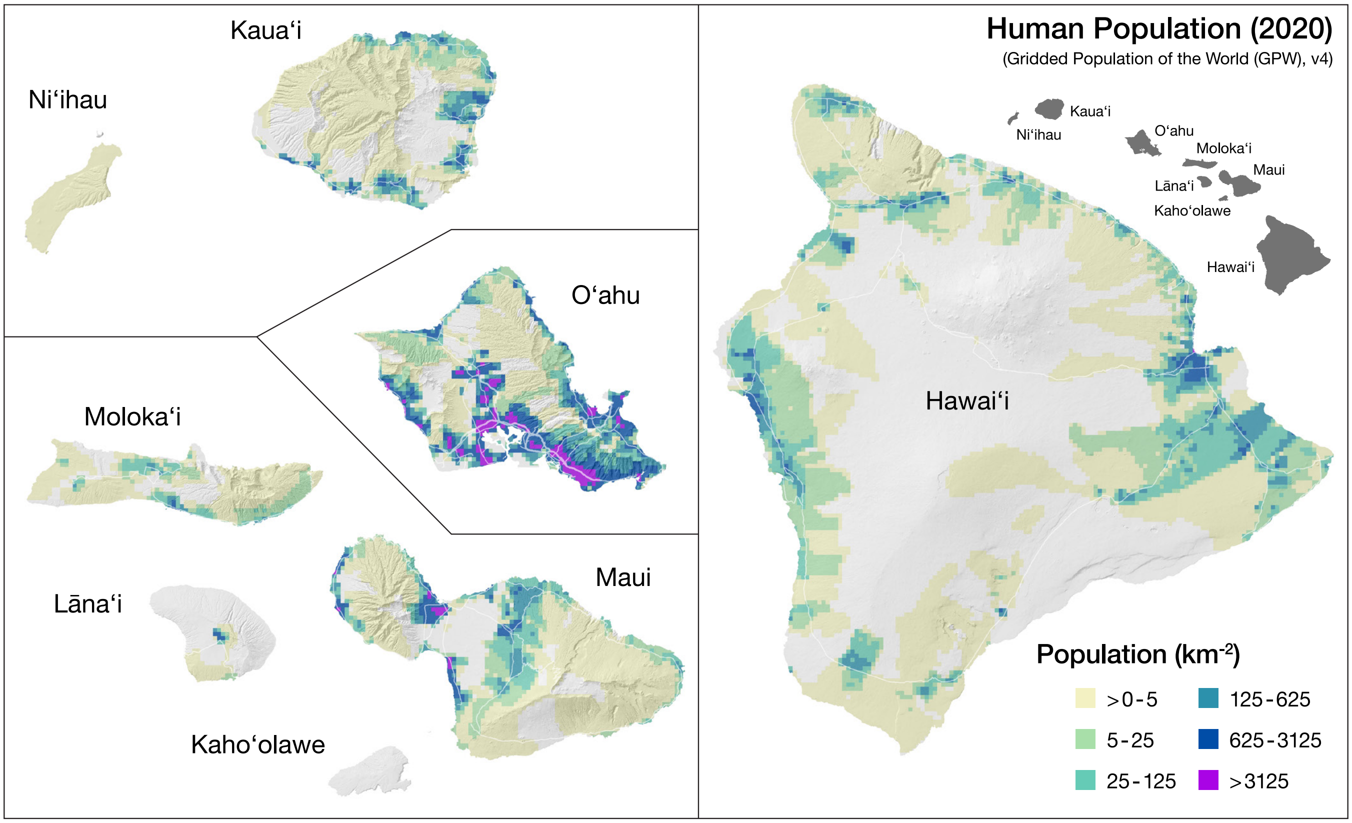
In this section we describe human population levels, distribution, and growth over the past two decades (2000–2020). This section also describes the NCRMP survey results, including percent of residents participating in various activities on and near coastal ecosystems, familiarity with threats to coral reefs, and perceptions of the status and trends of ecosystem health indicators and crowding of beaches. Results from the 2015 NCRMP survey (Gorstein et al. 2018) are also presented to show how social conditions and perceptions changed in 2020.

Human Population Density and Growth

As of 2020, the population of the MHI was approximately 1.5 million, a 20% increase since 2000 (Fig. 1.1). O‘ahu is the most populous island with over 1 million people as of 2020. However, percentage growth from 2000 to 2020 on O‘ahu (16%) was lowest among all islands. Percent growth from 2000 to 2020 was greatest for Hawai‘i Island (35%), followed by 28% for Maui County (inclusive of Lāna‘i and Moloka‘i), and 25% for Kaua‘i County (inclusive of Ni‘ihau) (Fig. 1.1).

Ph. Pixabay

Honolulu on O‘ahu is the most populous city in Hawai‘i.



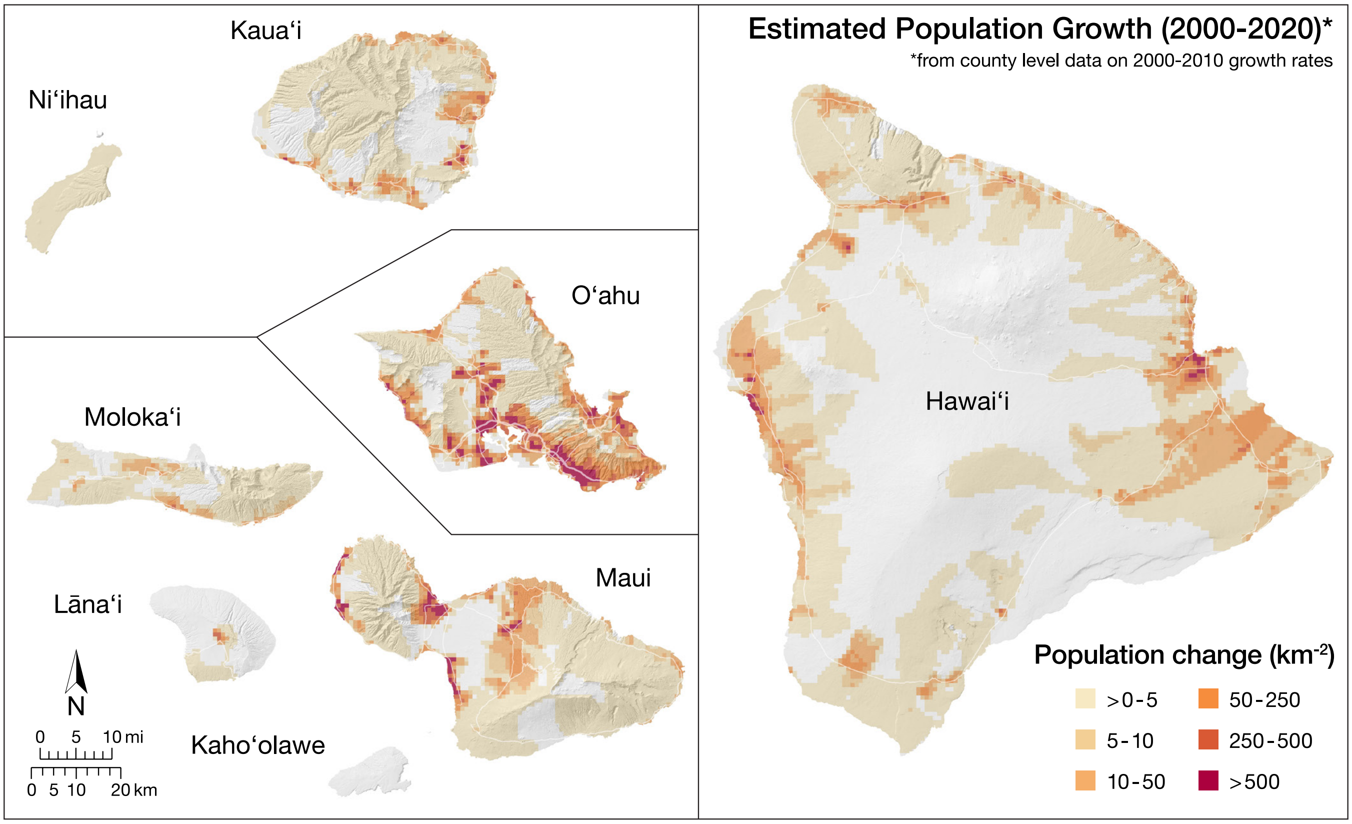


Fig. 1.1. Human population density for 2020 (top map) and estimated population growth between 2000 and 2020 (bottom map) for the main Hawaiian Islands. Data source: NASA GPWv4.

Human Connections

Resource Use and Perceptions of Threats, Status, and Trends

Most residents of Hawai‘i live near the ocean. Across the MHI, 83% live within 5 km, and 94% live within 10 km (Fig. 1.1). The majority of residents surveyed (78%) participate in beach recreation, and over half (52%) snorkel in the nearshore marine environment. Over a third of respondents participate in wave riding (43%), beach camping (41%), and fishing (33%) (Fig. 1.2).

Resource Use

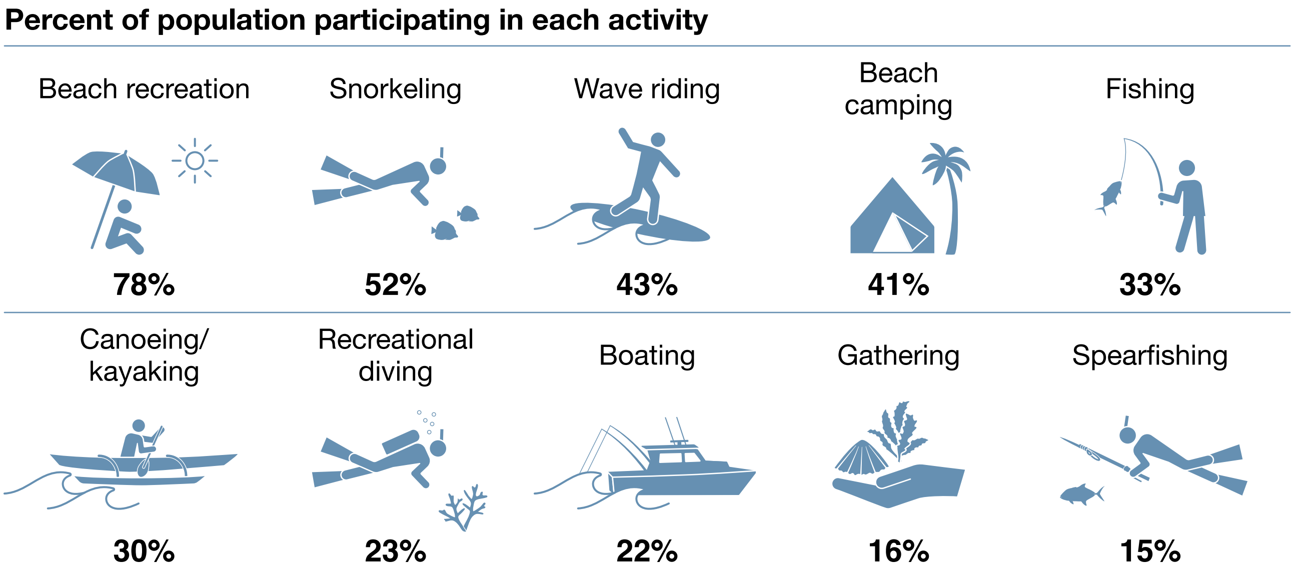


Fig. 1.2. Percent of population in Hawai‘i participating in activities in or near the marine environment (source NCRMP 2020 socioeconomic surveys, n=2,700 respondents).

Wave riding is one of the most popular recreational activities among Hawaiian residents.

Ph. Pixabay

Awareness of Threats

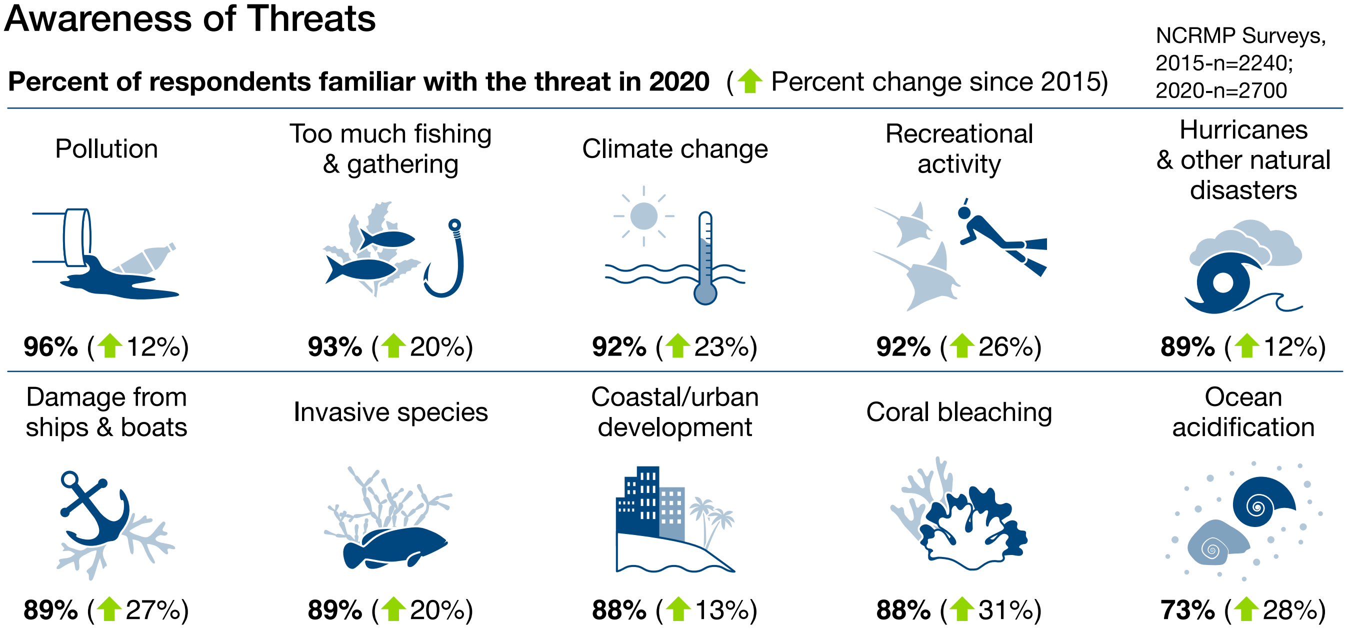


Fig. 1.3. Percent of respondents familiar with a range of major threats posed to the marine environment (categories for familiarity varied slightly between 2015 and 2020, but multiple options were offered each year for 'familiar'). Green arrows indicate increases between 2015 and 2020 in the absolute percentage of respondents familiar with each threat.

Hawai'i residents are increasingly aware that there are many threats to coastal marine ecosystems (Fig. 1.3). When asked how familiar they were with 11 different threats, including pollution, too much fishing, and coral bleaching, the majority of respondents (> 70%) reported being familiar with all threats included in the survey. Respondents were most familiar (96%) with pollution and least familiar (73%) with ocean acidification.

Awareness of the threat categories surveyed in both 2015 and 2020 among respondents increased between 12 and 31% (Fig. 1.3). Between 2015 and 2020, there was greater than a 20% increase in the percent of respondents familiar with too much fishing and gathering, climate change, recreational activity, damage from boats and shipping, invasive species, coral bleaching and ocean acidification. The greatest increases in familiarity were for coral bleaching (31%) and ocean acidification (28%).

Residents were also asked about their perceptions of the status and trends of 4 indicators of marine ecosystem health: ocean water quality, amount of live coral, and number and variety of fish (Fig. 1.4). More respondents perceived the status of variety of fish and ocean water quality as good rather than bad (fish status: 42% versus 27%; water quality status: 33% versus 30%). Conversely, more respondents perceived the status as bad rather than good for the amount of live coral (50% versus 17%) and number of fish (40% versus 22%). The majority of respondents (59–72%) perceived a negative trend in all 4 of the indicators of ecosystem health over the past 10 years.

Residents were also asked about crowding on beaches, which is an important determinant of quality of experience during beach recreation (Ingram et al. 2020, Fig. i). The majority of respondents (70%) perceived the status of crowding of beaches as bad, while less than 10% perceived the status as good.

Perceptions of Status and Trends

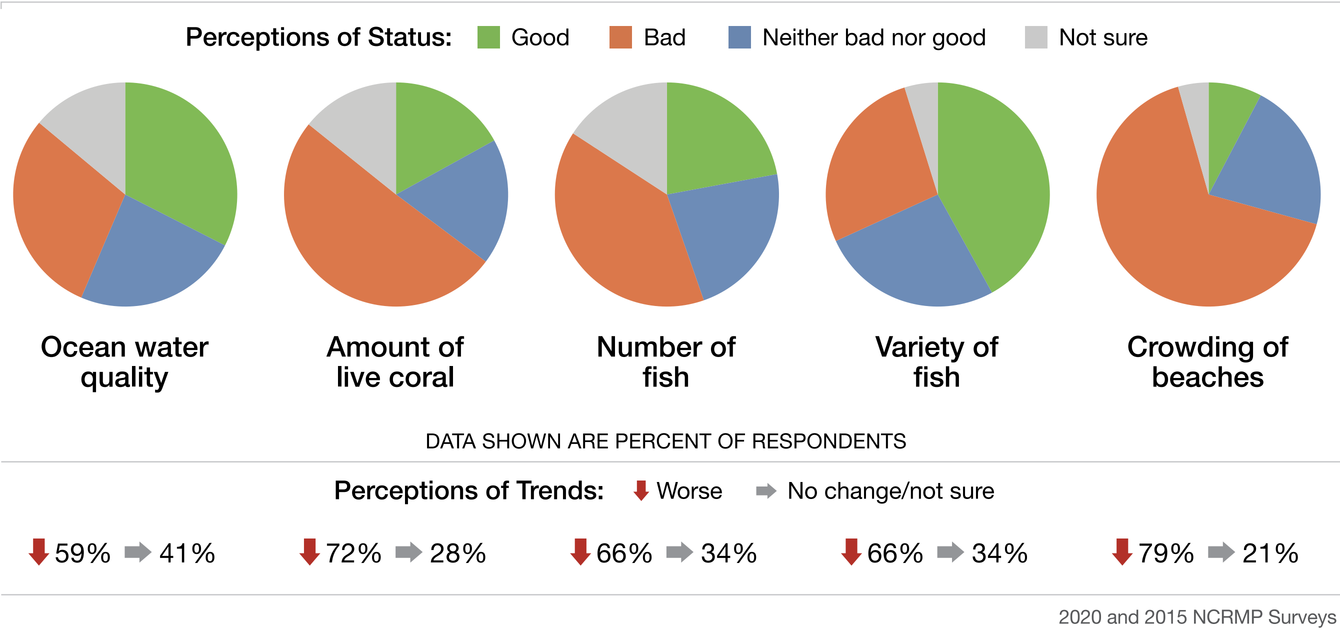


Fig. 1.4. Perceptions of current status and recent trends over the past 10 years for indicators of the marine environment and beach recreation. Data source: NCRMP surveys from 2015 and 2020.

Further, nearly 80% of respondents perceived crowding of beaches has worsened over the past 10 years. Beach crowding is in part a consequence of Hawaiʻi being an increasingly popular destination for tourists.

Visitor arrivals to the main Hawaiian Islands in 2019 totaled nearly 10.3 million, which is 6.7 times greater than the local resident population of 1.5 million people (HTA 2019). This was the most people ever to visit Hawaiʻi in a single year and the first time the number of arrivals had surpassed 10 million. The percentages of visitors spending time at each island were: 60% Oʻahu, 30% Maui, 17% Hawaiʻi, 13% Kauaʻi (numbers total more than 100% because people visit multiple islands).

Just one year later in 2020, visitor arrivals were less than one third of levels prior to the COVID-19 pandemic. At time of publication, visitor arrivals to Hawaiʻi were approaching ~80% of pre-pandemic levels (HTA 2022). Though tourism is a primary source of economic revenue for Hawaiʻi, having ~10 million visitors annually has raised many concerns about pressures to the natural resources, infrastructure, and culture of the Hawaiian Islands.

2. Small Boat Commercial Fishers

Summary: *Small boat commercial fishers are important for supporting local food systems, nutrition, food security, and community social cohesion in Hawai'i. The small boat commercial fishing fleet has high levels of participation and includes the pelagic (tunas and billfishes), Deep 7 Bottomfish (six snapper and one grouper species), and nearshore fisheries (e.g., scads, parrotfish, and goatfish). For each fishery, this section describes: 1) patterns in fishery engagement and regional quotients for revenue from 2000 through 2019 and, 2) patterns in annual catch and catch per unit effort from 1990 through 2019.*

Introduction

Small boat commercial fishers are important for supporting local food systems, nutrition, food security, and community social cohesion in Hawai'i (Allen 2013). The small boat commercial fishing fleet is composed of comparatively smaller vessels (16–33 ft) than the larger, longline-based commercial fleet (Chan and Pan 2017). Small boat commercial fishers are also distinct in that they employ a broad range of gear types to catch a variety of target fish species, with many fishers active across different fisheries. Small boat fishers have diverse and often overlapping commercial, recreational, cultural, and subsistence motivations, marketing their catch through the United Fishing Agency auction in Honolulu, with dealers and processors, restaurants, retail storefronts, and within their community (NMFS 2021). Fishers often sell catch for commercial purposes but also retain it for home consumption, share it with family and friends, and give it away for locally important occasions and events (Markrich and Hawkins 2016; Delaney et al, 2017). The small boat fishing fleet represents a small fraction of total commercial landings—approximately 10% of pelagic landings in 2019 for example (WPRFMC 2020)—but has comparatively higher levels of fisher participation. The fishers and their catch are undeniably important for communities in Hawai'i.

We present a series of indicators related to small boat commercial fishers that target pelagics, Deep 7 bottomfish, and nearshore fish. Small boat fishers targeting pelagic fishes (henceforth Pelagic Fishery) represent the largest of the 3 target groups with respect to catch and revenue. Species targeted include tunas such as skipjack and yellowfin, billfish species such as marlins, and other pelagic species such as mahimahi and ono. The fishery uses a variety of gear types and methods, including trolling and handline (e.g., ika shibi and palu ahi) (Boggs and Ito 1993). This fishery also includes a subset of larger vessels (~45 ft) that use pelagic handline, troll, and other specialized gear to target juvenile bigeye and yellowfin tuna at offshore seamounts and weather buoys which act as fish aggregation devices (Itano 1999). Small boat fishers that target bottomfish represent a smaller economic scale than the Pelagic Fishery but are comparable in terms of rich tradition and cultural significance. In particular, the Deep 7 Bottomfish Fishery, which is composed of six snapper species and one grouper species that live at depths between 75 and 400 m, represents the most culturally important and highly valued bottomfish species in Hawaiʻi. Unlike fisheries focused on pelagics and bottomfish, fisheries in the nearshore (hereafter Nearshore Fishery) comprise hundreds of species using a wide range of gear types such as rod and reel, spear, nets, and traps. The Nearshore Fishery is similar in economic scale as the Deep 7 Bottomfish Fishery and the species play a central role in many aspects of culture in Hawaiʻi including customary diets, spiritual practices, local food security, and leisure activities.

In order to capture the societal relevance of the small boat commercial fleet, we present two indicators of community engagement and revenue for the 2000–2019 time frame: the Fishing Engagement Index (FEI) and the Regional Quotient (RQ) revenue (Hospital and Leong 2021). The FEI is a composite index that includes community-level fishery participation metrics such as pounds landed, revenue, active commercial fishers, and seafood dealers. The RQ revenue complements the FEI and is an indicator of a community's economic importance to the fishery. RQ revenue is the community revenue from a fishery divided by the total revenue of that fishery across the State of Hawaiʻi. We also provide indicators for each fishery related to catch, specifically total catch and catch per trip, for the 1990 to 2019 timeframe. These indicators are intended to capture the status and historical trends in the targeted groups and subgroups within each fishery.

Commercial fisheries in Hawaiʻi, including those within the small boat commercial fleet, were severely impacted by the COVID-19 pandemic. A sharp and substantial drop in catch, revenue, and participation was observed starting in 2020 (NMFS 2021). To remove the substantial and confounding effects of the COVID-19 pandemic on fisheries indicators, we have excluded the most recent two years (2020–2021) and end all time series in 2019. By doing so, the changes in indicators across space and time are more reflective of the historical trends and recent status of the small boat fishing fleet, including the influences of ocean conditions, management policies, socioeconomic pressures, and fisheries productivity.

Fishing Engagement Index

The Fishing Engagement Index (FEI) is a composite index that measures community-level fishery participation based on the number of active commercial fishers, pounds landed, revenue, and seafood dealers within a community. FEI scores were generated and compared for each community, where scores of 1.0 or greater are considered highly engaged. FEI scores are presented as the average for each census county division (CCD) from the most recent 5 years (2015–2019) and as annual time series for the top 5 communities from 2000 to 2019 (Fig. 2.1).

In the most recent 5 years (2015–2019), the communities of Honolulu (Oʻahu), ʻEwa (Oʻahu), and North Kona (Hawaiʻi Island) had high FEI scores for all 3 fishery-specific indices (Fig. 2.1). The Oʻahu communities are the two most populous communities, with Honolulu hosting the largest fishery auction in Hawaiʻi. North Kona, while a small community in terms of population, is a major fishing port providing access to the favorable and deep-waters off the west coast of Hawaiʻi Island (Hospital and Leong 2021).

Over the last 20 years (2000–2019), FEI scores varied considerably between communities within each fishery (Fig. 2.1). Within the Pelagic Fishery, North Kona had by far the highest FEI values that varied little between the onset and ending of the 20-year period. This overall stability was also observed among the other top communities. In contrast, FEI scores within the Deep 7 Bottomfish Fishery showed considerable variability. North Kona had nearly a 2.5-fold difference in engagement index values over the data record, while Honolulu, which had the highest FEI values in the early 2000s, decreased by nearly 50% by 2015. FEI values for the Nearshore Fishery had less variability, but there were contrasting historical trends between communities. Wai‘anae (O‘ahu) had an overall positive trajectory and had the highest engagement index value in 2019, whereas Honolulu, which was the top community at the onset of the time series, declined by > 50% over the 20-year time period.

Regional Quotient for Revenue

To compare communities in Hawai‘i with respect to revenue generated by the small boat commercial fishing fleet, we calculated the Regional Quotient (RQ) for revenue. RQ revenue indicates the community revenue from the fishery divided by the total revenue of the fishery across the State of Hawai‘i. Tracking the RQ can provide useful information to fishery managers, especially for communities that lack specific elements within the FEI (e.g., seafood dealers) that are needed for a community to be considered highly engaged (Hospital and Leong 2021). RQ revenue values are presented as the average for each census county division (CCD) from the most recent 5 years (2015–2019) and as annual time series for all communities combined and the top 3 communities from 2000 through 2019 (Fig. 2.2). All revenue values have been adjusted for inflation.

In the most recent 5 years (2015–2019), the top communities in terms of RQ revenue varied by fishery (Fig. 2.2). For the Pelagic Fishery, values were concentrated among just a few communities, including North Kona, Hilo, and Honolulu. Importantly, these are all communities with major small boat commercial fishing ports and other fishing infrastructure. In contrast, regional quotient revenue from the Deep 7 Bottomfish Fishery is more widely dispersed across communities, but still greatest in North Kona. There are high RQ values for total revenue in multiple communities (census county divisions) on O‘ahu, Maui, and Hawai‘i. RQ revenue values for the Nearshore Fishery are greatest on O‘ahu, particularly in Wai‘anae.

Over the last 20 years (2000–2019), the Pelagic Fishery was the most dominant in terms of total revenue generated (Fig. 2.2). Revenue for all communities combined was 4- to 6-fold higher for the Pelagic Fishery compared to revenue from the Deep 7 Bottomfish and Nearshore Fisheries. Further, revenue generated by individual communities such as North Kona was higher for the Pelagic Fishery than revenue generated by communities for each of the other fisheries. In recent years, total revenue was not as high as in the early 2000s. For example, annual revenue differences from 2000 to 2019 were: -\$11 million (-48%), -\$2 million (-58%), and -\$1.2 (-35%) million for the Pelagic, Deep 7 Bottomfish, and Nearshore Fisheries, respectively (values adjusted for inflation to 2020).

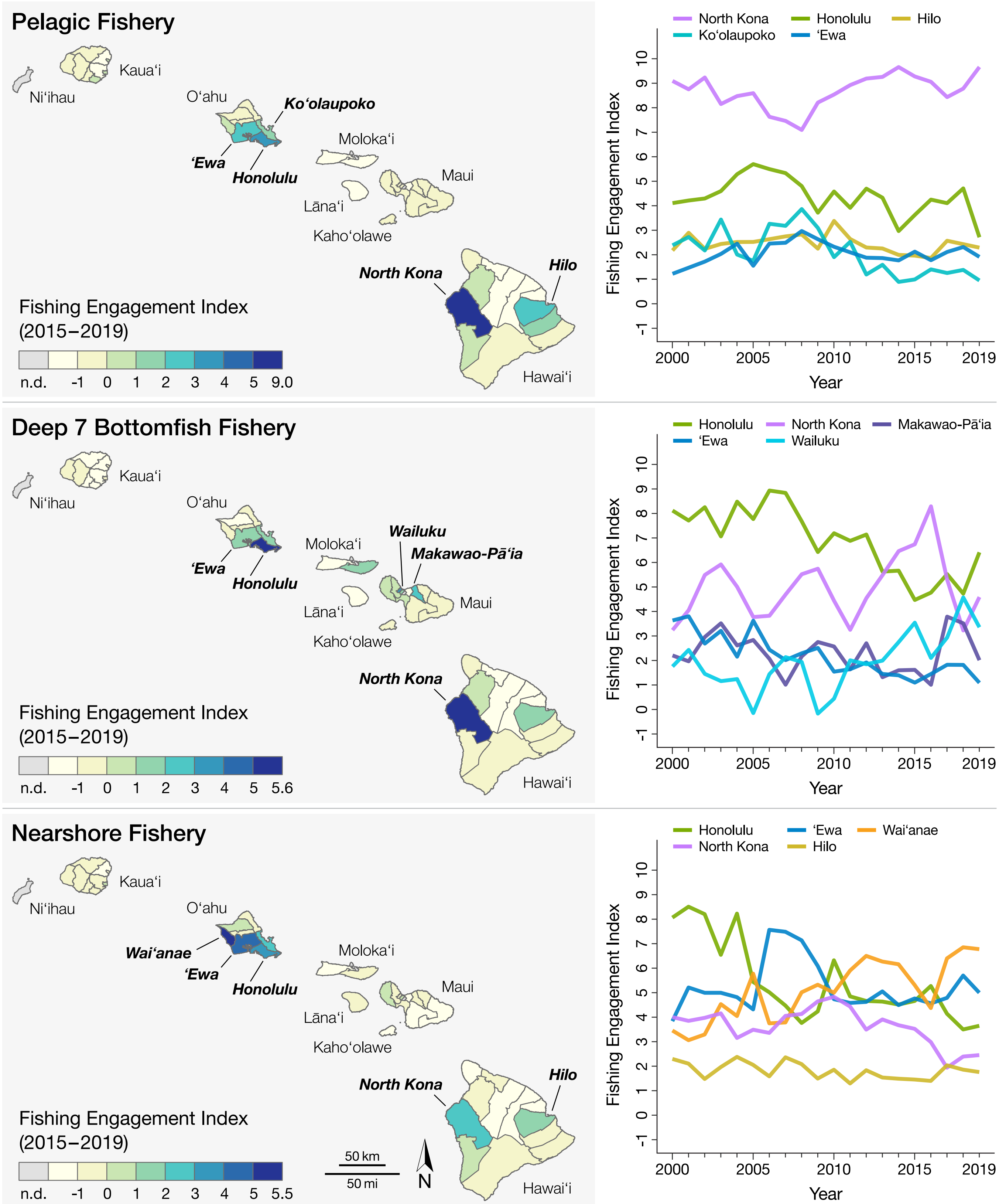


Fig. 2.1. Maps of commercial fishing engagement index (FEI) averaged for 2015 to 2019, with time series for communities with the highest FEI values within each fishery from 2000 to 2019 (labeled in bold on the map). Source: Hospital and Leong, 2021.

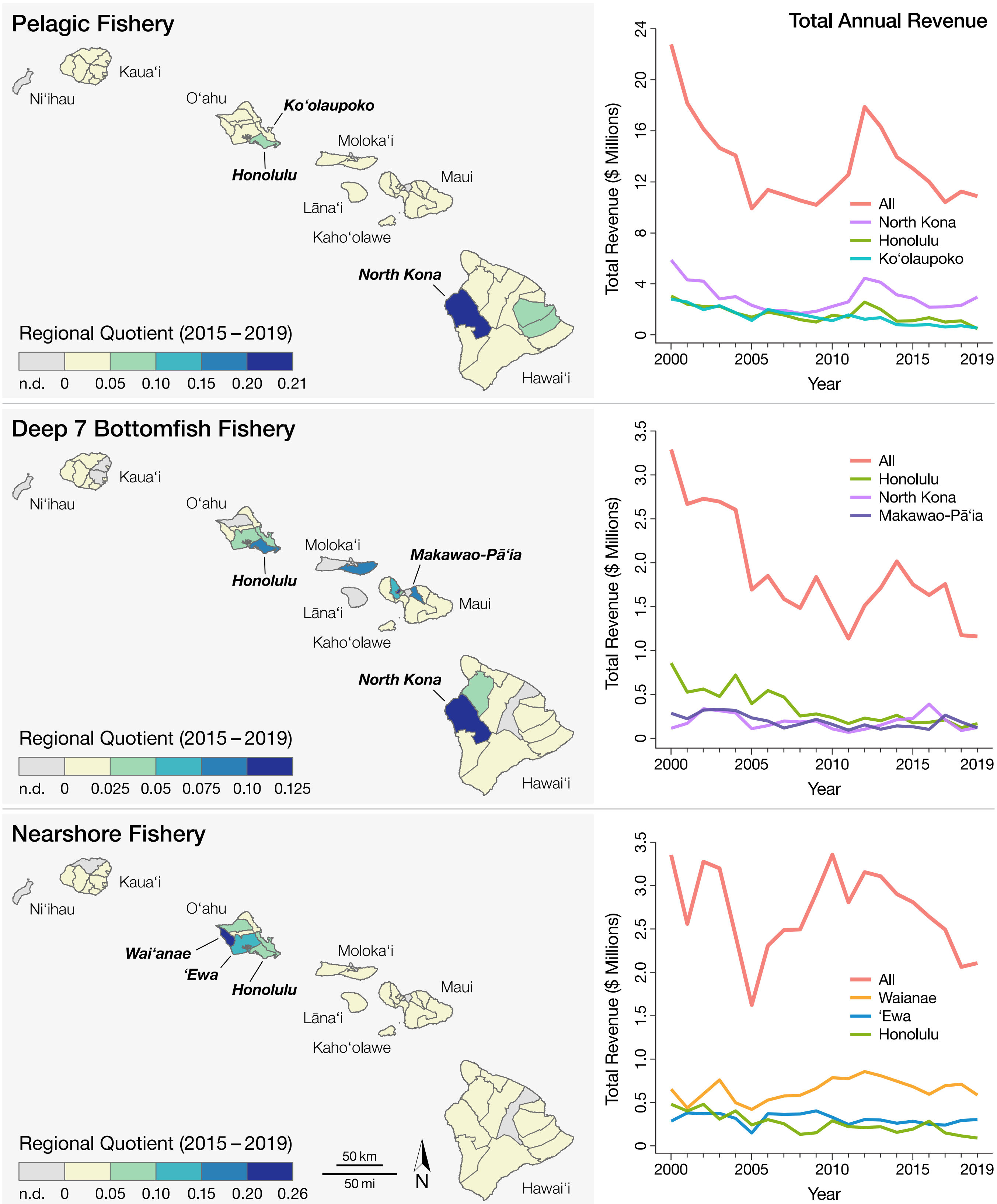


Fig. 2.2. Maps of Regional Quotient (RQ) for total commercial revenue averaged for 2015 to 2019, with a time series showing annual RQ values for revenue from 2000 to 2019 for all communities and for the 3 communities with the greatest RQ values. Revenues were adjusted for inflation. Source: Hospital and Leong, 2021.

Changes in Commercial Fish Catch through Time and Space

We present fisheries indicators for the small boat commercial fishing fleet related to Pelagic, Deep 7 Bottomfish, and Nearshore Fisheries from 1990 to 2019. We calculated the commercially reported total pounds landed by all small boat commercial fishers and calculated the commercially reported total pounds landed per trip. To assess year-to-year differences and historical trends in catch and catch per trip among each fishery, we calculated annual catch and catch per trip from 1990 to 2019 as an aggregate for each fishery and fishery subgroupings for the entire main Hawaiian Islands. We also assessed changes in each fishery by evaluating whether the spatial distribution in recent commercial catch differs from the spatial distribution in historical catch. To do this we calculated average commercial catch during the recent 5-years (2015–2019) and compared that to average historical commercial catch from the previous 25 years (1990–2014). All indicators are for catch reported from within the State of Hawai'i commercial fishing reporting blocks (Fig. 2.3).

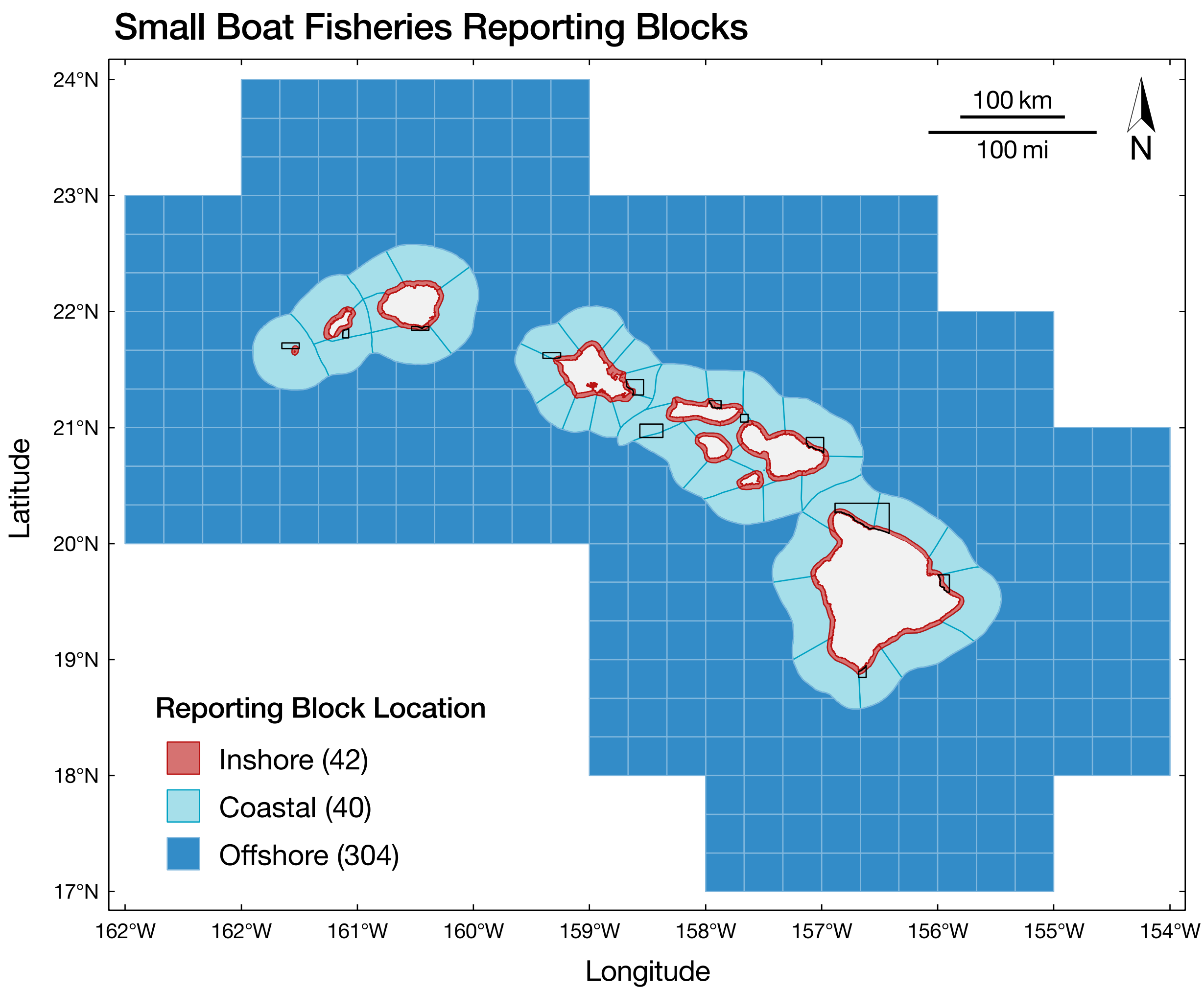


Fig. 2.3. State of Hawai'i Commercial Fishing Reporting Blocks for the main Hawaiian Islands. Reporting blocks are colored according to their official designation as Inshore, Coastal, or Offshore. All data presented are based on fish caught by the small boat fishing fleet within these reporting blocks.

Pelagic Fishery

Total reported catch of all pelagic fish has declined by 53% from the peak of 7 million pounds in the mid- to late-1990s to 3 million pounds in 2019 (Fig. 2.4). Catch declines coincided with a decline in the total number of fishers reporting commercial catch, which decreased by 26% over the same time period (PIFSC 2022). The catch of tunas mirrored the year-to-year and overall trend in pounds caught as they comprise the majority of catch for the fishery. Catch per trip for all pelagics, tunas, and billfishes also declined over the same time period. The catch per trip for other pelagics (e.g., mahimahi) was the only group that increased over the 30-year record. Comparing the spatial distribution in historical catch (1990–2014) with the most recent 5 years (2015–2019) shows that some reporting blocks increased and some decreased in total catch (Fig. 2.5). The greatest increases in catch occurred east of Kaua‘i, north and east of Maui, and southeast of Hawai‘i Island; the greatest decreases were in reporting blocks near O‘ahu and the west and east sides of Hawai‘i Island. Overall, the greatest changes occurred in Coastal reporting blocks; catch decreased in 73% (29 of 40) between the two time periods. The average number of small boat fishers that reported commercial catch of pelagics also changed over time, decreasing by 16% between the historical (1990–2014) and most recent (2015–2019) time periods (PIFSC 2022). Such large declines in active fishers presumably contributed to, in part, the declines in total catch and other similar trends in small boat commercial fisheries indicators.

Ph. Christine Shepard

The pelagic fishery includes billfish such as striped marlin (A‘u, Naragi), *Kajikia audax*.

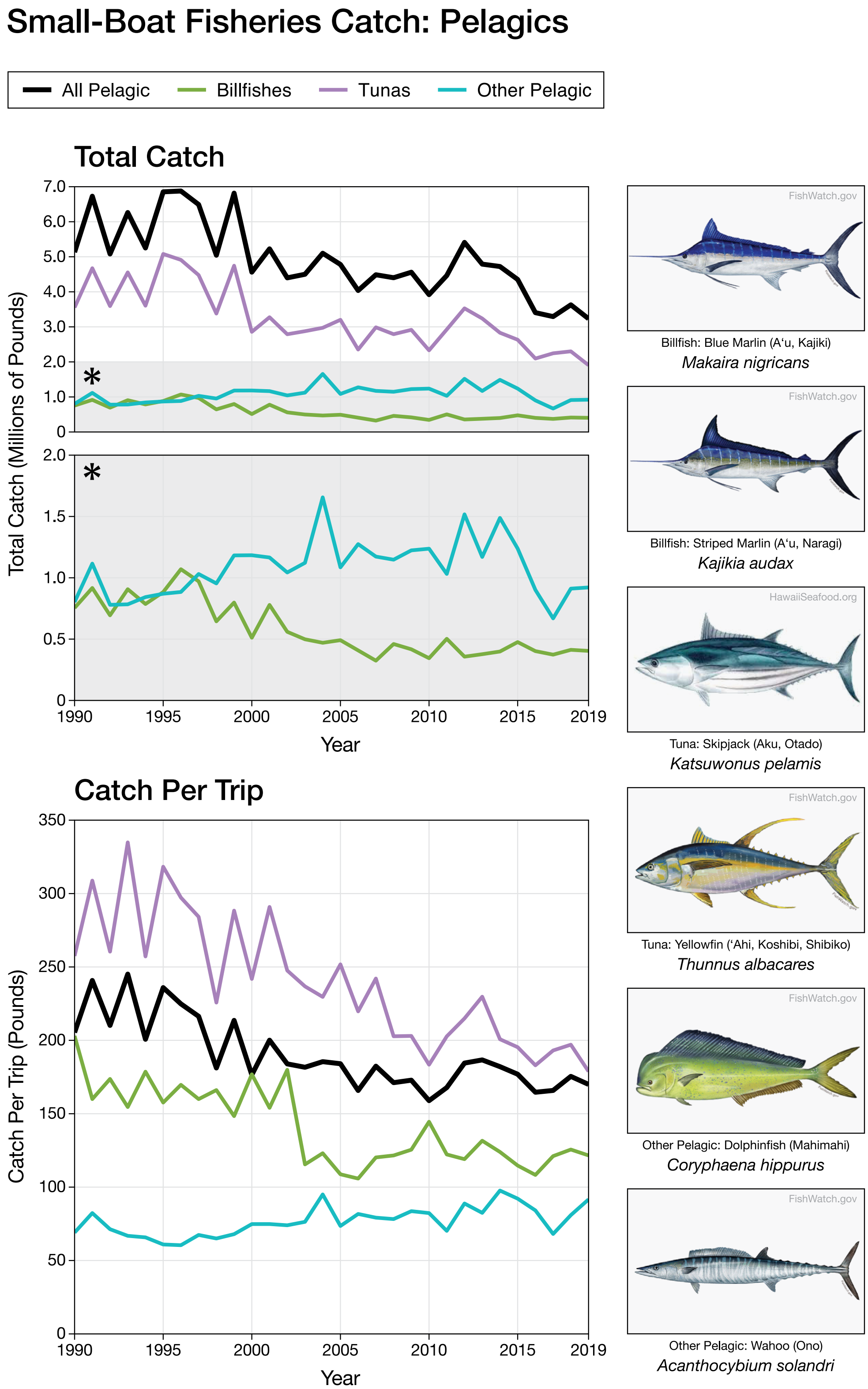


Fig. 2.4. Time series of total commercial catch and catch per trip for pelagic fish and pelagic fish subgroupings by small boat commercial fishers between 1990 and 2019. Images represent example fish within each pelagic fish subgroup. Shaded area and asterisk indicate the time series graphed again with a different y-axis scale to highlight the year-to-year dynamics in pelagic subgroupings with lower levels in total catch and catch per trip. Data source: State of Hawaiʻi and NOAA's Pacific Islands Fisheries Science Center.

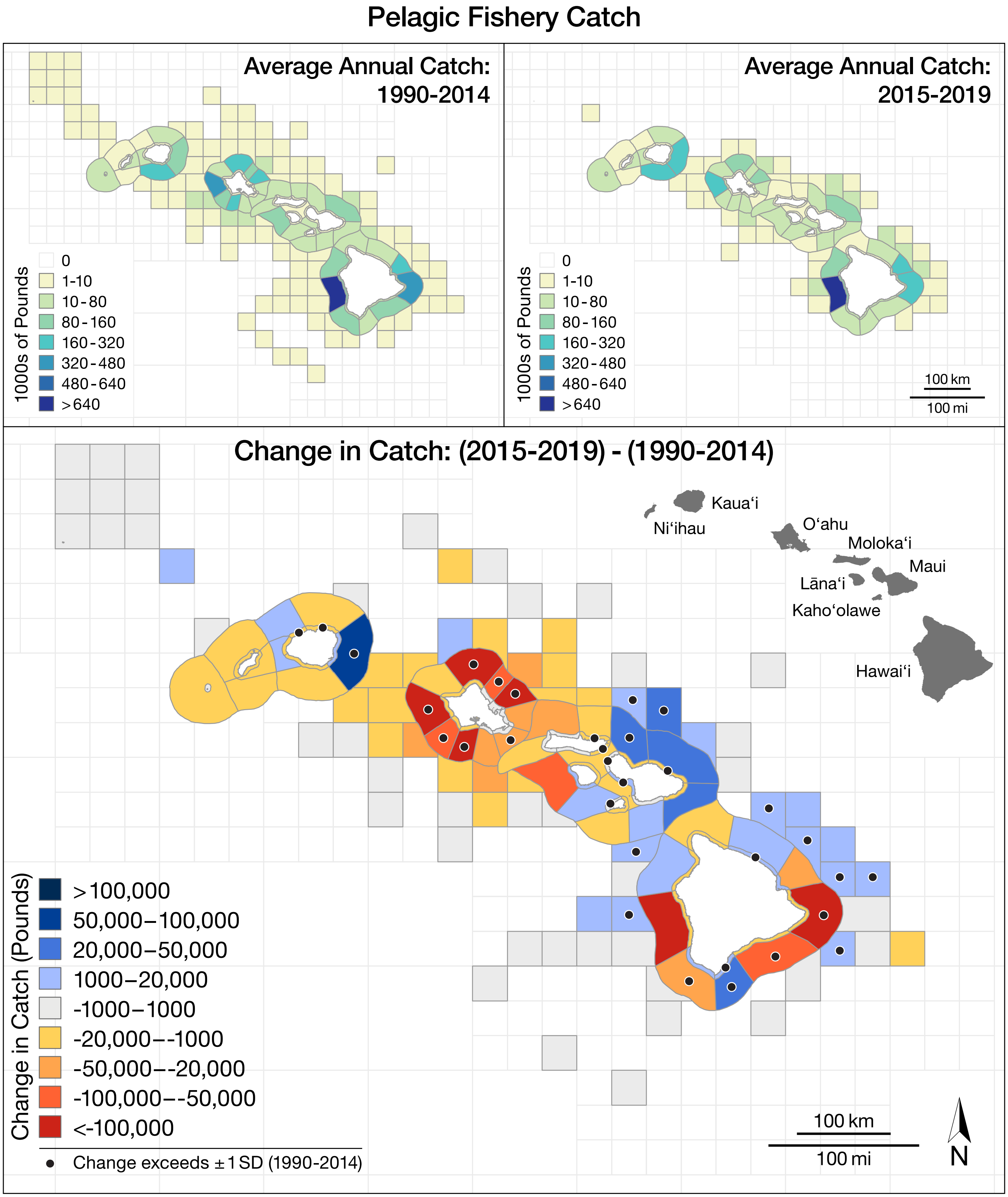


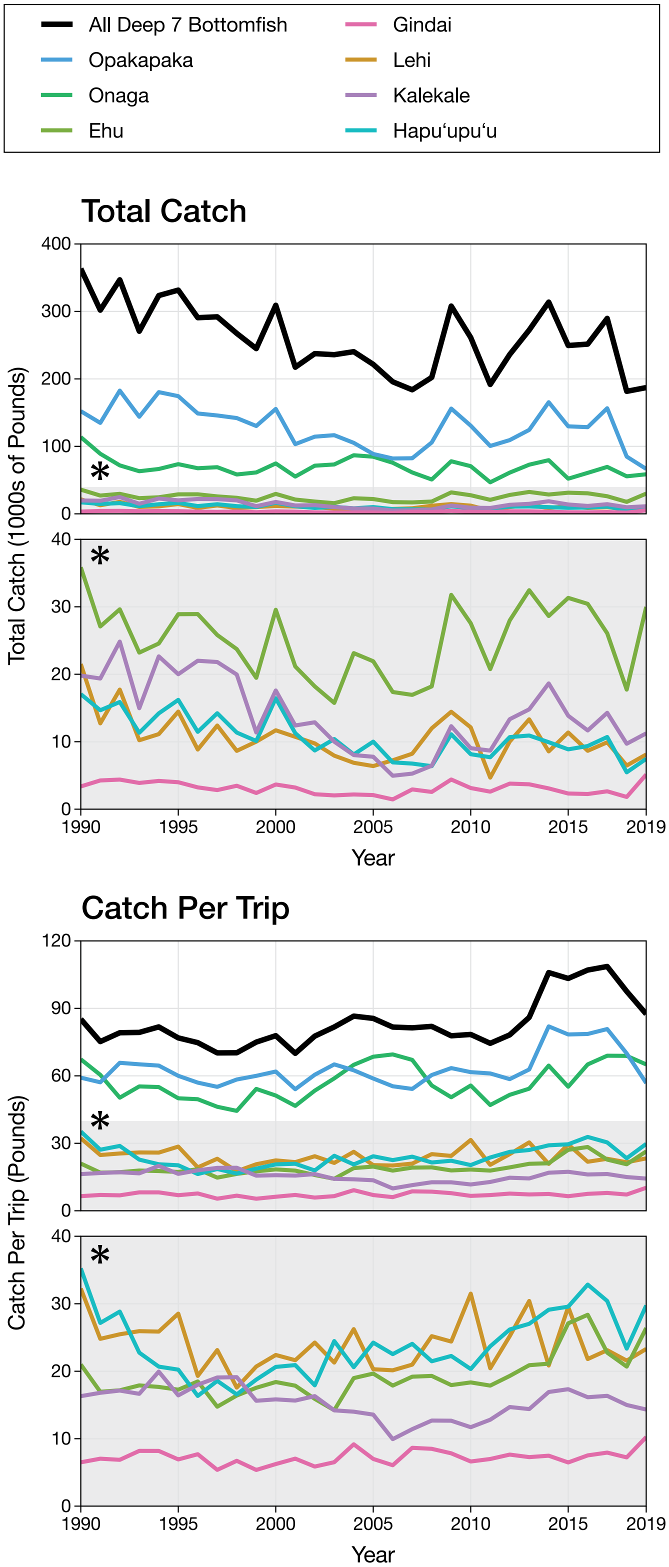
Fig. 2.5. Total commercial catch (pounds) of pelagic fish by small boat commercial fishers for State of Hawai'i fishery reporting blocks for 1990 to 2014 (top left), 2015 to 2019 (top right), and the change between these periods (bottom). Data source: State of Hawai'i and NOAA's Pacific Islands Fisheries Science Center.

Deep 7 Bottomfish Fishery

Total reported catch of Deep 7 Bottomfish steadily declined over the 30-year record, decreasing by 47% from the peak of 360,000 pounds caught in 1990 to approximately 190,000 pounds in 2019 (Fig. 2.6). Catch declines coincided with a decline in the number of fishers reporting commercial catch, which decreased by 47% over the same time period (PIFSC 2022). The change in reported catch were mirrored by changes in the two most dominant of the Deep 7 Bottomfish species caught, ʻōpakapaka and onaga. Despite total catch declines, catch per trip showed either minimal change or an increase for each of the individual bottomfish species and for all species combined. Comparing the spatial distribution in historical catch (1990–2014) with the most recent 5 years (2015–2019) shows some reporting blocks that increased and some that decreased in total catch (Fig. 2.7). Increased catch occurred in the majority of Inshore reporting blocks near Hawaiʻi Island and was greatest in the Coastal reporting blocks near Kawaihae Harbor on Hawaiʻi Island and south of Lānaʻi. However, the majority (25 of 40) of Coastal reporting blocks showed a decline in catch, with the greatest decrease occurring in a single reporting block to the southwest of Molokaʻi (Penguin Bank). Small boat fishers that reported commercial catch of Deep 7 Bottomfish also decreased over time — by 27% between the historical (1990–2014) and most recent (2015–2019) time periods (PIFSC 2022). Such large declines in active fishers presumably contributed to, in part, the declines in total catch and other similar trends in small boat commercial fisheries indicators. For greater detail on the fishery and a more robust assessment of the Deep 7 Bottomfish population status, please refer to the Deep 7 Bottomfish stock assessment (Syslo et al. 2021) and the Annual Stock Assessment and Fishery Evaluation Report for the Hawaiʻi Archipelago Fishery Ecosystem Plan (WPRFMC 2022).

Pink snapper (ʻŌpakapaka), *Pristipomoides filamentosus*, is one of Hawaiʻi's Deep 7 Bottomfish. Ph. David Fleetham | Alamy

Small-Boat Fisheries Catch: Deep 7 Bottomfish



Pink Snapper (Opakapaka)
Pristipomoides filamentosus

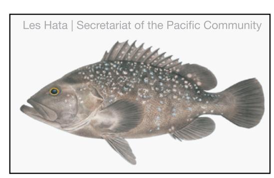
Long-Tail Red Snapper (Onaga)
Etelis coruscans

Ruby Snapper (Ehu)
Etelis carbunculus

Oblique-Banded Snapper (Gindai)
Pristipomoides zonatus

Silver Mouth Snapper (Lehi)
Aphareus rutilans

Von Siebold's Snapper (Kalekale)
Pristipomoides sieboldii



Hawaiian Grouper (Hapu'upu'u)
Hyporthodus quernus

Fig. 2.6. Time series by calendar year of total catch and catch per trip of Deep 7 Bottomfish and individual bottomfish species by small boat commercial fishers between 1990 and 2019. Shaded area and asterisk indicate the time series graphed again with a different y-axis scale to highlight the year-to-year dynamics in bottomfish species with lower levels of total catch and catch per trip. Images represent the species within the Deep 7 Bottomfish stock complex. For greater detail on the fishery and a more robust assessment of the Deep 7 Bottomfish population status, please refer to the Deep 7 Bottomfish stock assessment (Syslo et al. 2021) and the Annual Stock Assessment and Fishery Evaluation Report for the Hawai‘i Archipelago Fishery Ecosystem Plan (WPRFMC 2022). Data source: State of Hawai‘i and NOAA's Pacific Islands Fisheries Science Center.

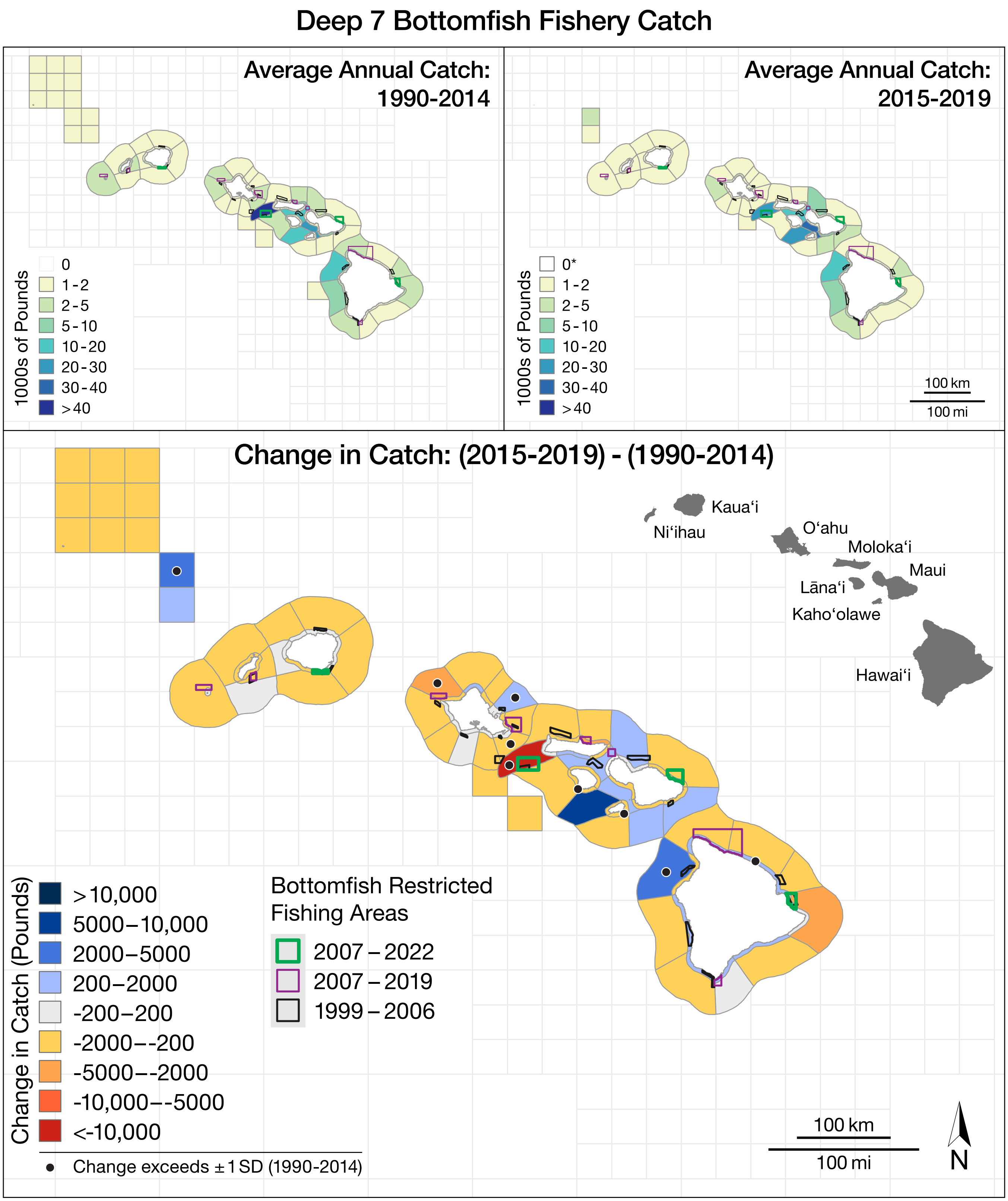


Fig. 2.7. Total commercial catch (pounds) of the Deep 7 Bottomfish by small boat commercial fishers for State of Hawai‘i fishery reporting blocks for 1990 to 2014 (top left), 2015 to 2019 (top right), and the change between these periods (bottom). For greater detail on the fishery and a more robust assessment of the Deep 7 Bottomfish population status, please refer to the Deep 7 Bottomfish stock assessment (Syslo et al. 2021) and the Annual Stock Assessment and Fishery Evaluation Report for the Hawai‘i Archipelago Fishery Ecosystem Plan (WPRFMC 2022). Data source: State of Hawai‘i and NOAA’s Pacific Islands Fisheries Science Center.

Nearshore Fishery

Total reported commercial catch of all nearshore fish increased from 1990 to 1998, then steadily declined by 68%, from 1.9 million pounds in 1998 to 600,000 pounds in 2019 (Fig. 2.8). Catch declines coincided with a decline in the total number of fishers reporting commercial catch, which decreased by 46% over the same time period (PIFSC 2022). The changes in catch over time were largely driven by changes in the catch of scads (ʻōpelu and akule), which comprise upwards of 75% of total nearshore small boat commercial fisher catch. Total catch for all other subgroups (e.g., goatfishes and parrotfishes) was similar between the start and end of the timeseries, but varied considerably within the 30-year record, changing by a factor of 2–3 between the maximum and minimum catch in a given year. Catch per trip showed a general increasing trend from 1990 to 2019 for nearly all nearshore fish subgroups. Catch per trip for scads was nearly identical in 2019 as it was in 1990, but values were considerably higher in 2005 when catch per trip was nearly twice that of the onset or ending of the time series. Comparing the spatial distribution in historical catch (1990–2014) with the most recent 5 years (2015–2019) showed that the majority of Inshore and Coastal reporting blocks across Hawaiʻi decreased in catch (Fig. 2.9). Each of the 4 most populated islands—Hawaiʻi, Maui, Oʻahu, and Kauaʻi—had declines greater than 10,000 lb/year for two or more Inshore reporting blocks. However, a number of Inshore reporting blocks around Oʻahu showed an increase in catch in recent years, which included the largest increase in catch of all Inshore reporting blocks across all islands. Small boat fishers that reported commercial catch of nearshore fish also changed over time, decreasing by 31% between the historical (1990–2014) and most recent (2015–2019) time periods (PIFSC 2022). Such large declines in active fishers presumably contributed to, in part, the declines in total catch and other similar trends in small boat commercial fisheries indicators.

The nearshore fishery includes species such as bigeye scad (Akule), *Selar crumenophthalmus*. Ph. Paul Cox

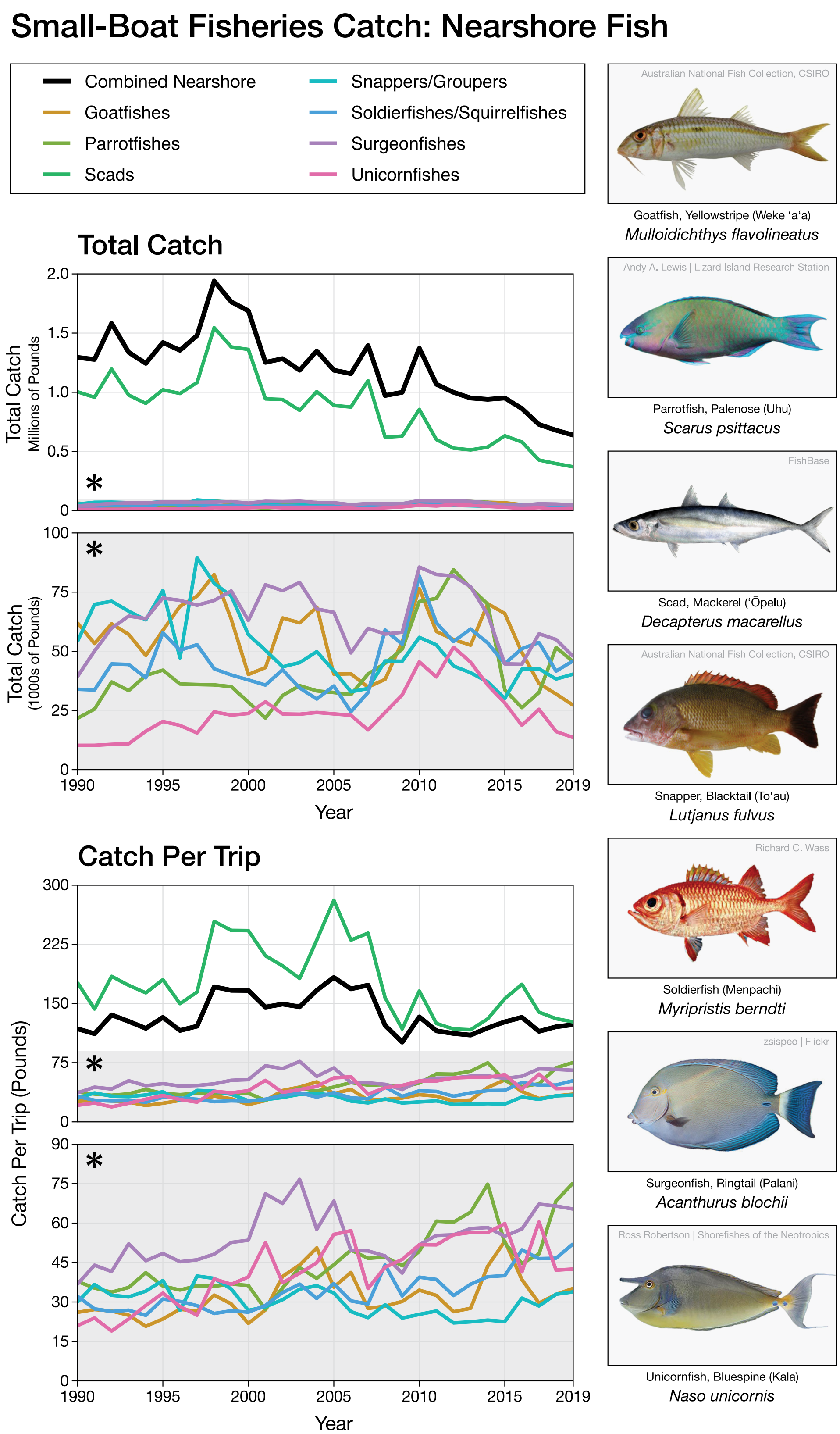


Fig. 2.8. Time series of total catch and catch per trip (in pounds) for nearshore fish and nearshore fish subgroupings by small boat commercial fishers between 1990 and 2019. Shaded area and asterisk indicate the time series graphed again with a different y-axis scale to highlight the year-to-year dynamics in Nearshore Fishery subgroupings with lower levels of total catch and catch per trip. Images represent example fish within each nearshore fish subgrouping. Data source: State of Hawaiʻi and NOAA's Pacific Islands Fisheries Science Center.

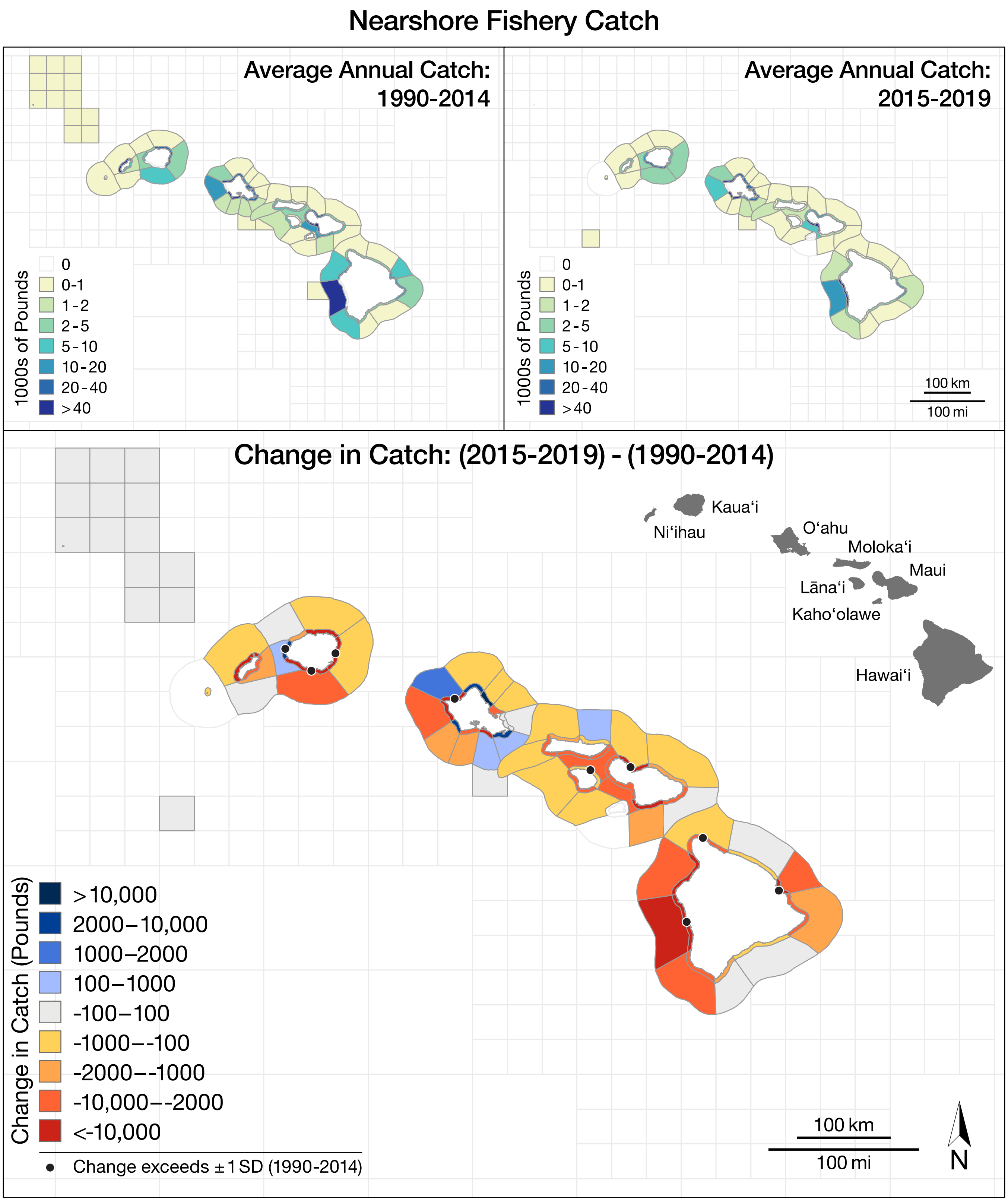


Fig. 2.9. Total commercial nearshore fish catch (pounds) by small boat commercial fishers for State of Hawai'i fishery reporting blocks for 1990 to 2014 (top left), 2015to 2019 (top right), and the change between these periods (bottom). Data source: State of Hawai'i and NOAA's Pacific Islands Fisheries Science Center.

Discussion

Indicators presented are intended to reflect the status and trends in the small boat commercial fishing fleet. There are many potential underlying reasons for the changes observed in each of the indicators, which likely differ in overall impact depending on the fishery. For example, fisher participation within small boat commercial fisheries has changed over the 30-year record based on fisher reports from the State of Hawaiʻi Division of Aquatic Resources. The average number of small boat fishers that reported commercial catch between the historical (1990–2014) and most recent (2015–2019) time periods declined by 16% for the Pelagic Fishery, 27% for the Deep 7 Bottomfish Fishery, and 31% for the Nearshore Fishery (PIFSC 2022). Such large declines in active fishers presumably contributed to, in part, the declines in total catch and other similar trends in small boat commercial fisheries indicators.

Since 1990, changes to fisheries management have likely influenced some of the small boat commercial fishery indicators. The > 50% decrease in total catch for the Deep 7 Bottomfish observed from 2008 to 2009 was due, in part, to the implementation of seasonal closures and catch quotas from 2006 to 2008 (Hospital and Beavers 2011). Further, a series of Bottomfish Restricted Fishing Areas (BRFAs) was created in 1999 and subsequently modified in 2007, which reduced available fishing grounds for bottomfish (see Fig. 2.7). The recent Deep 7 Bottomfish stock assessment indicates the fishery is not overfished nor subject to overfishing (Syslo et al. 2021). While all BRFAs are open to fishing as of 2022, these historical changes to Deep 7 Bottomfish fishing areas may have affected both commercial catch and reporting behavior for commercial fishers. Other factors influencing the status and trends of small boat commercial fisher indicators likely include the rising costs of fishing and living in Hawaiʻi, declines in revenue (Fig. 2.2), and the overall status of some fisheries stocks (Nadon 2017).

Importantly, while total catch declined for the majority of fish groups within each of the Fisheries over the past 3 decades, catch per trip did not show a commensurate drop. Many fish groups showed minimal changes or an increase in catch per trip in recent years compared to 1990. This contrasting trend of declines in reported commercial catch and stable commercial catch per trip, coupled with general overall declines in commercial fishery participants (Hospital and Leong 2021), could implicate changes in fleet composition with fewer, more experienced fishers active in Hawaiʻi fisheries. Ultimately, we do not have a clear understanding of the various socioeconomic, ecological, and environmental drivers that underpin the changes observed. This is an area of active research that we will continue to pursue in the future.

It is also important to note that the time series presented for indicators in this section were intentionally truncated to 2019, prior to the onset of the COVID-19 global pandemic. The COVID-19 pandemic resulted in pervasive and large-scale impacts to U.S. fisheries including supply chain effects and global contraction in seafood demand. Declines in commercial fisheries, catch, revenue, and effort were widespread. These effects were particularly acute in Hawaiʻi, which experienced a 31% decrease in overall commercial landings revenue in 2020 (compared to the 2015–2019 average), the largest decline among all fisheries regions in the U.S. (NMFS 2021). Impacts specific to the small boat fishers include a 35% reduction in revenue and 31% fewer fishers that reported landings. The impacts of the ongoing COVID-19 pandemic to local and national fisheries are being tracked and updated by the National Marine Fisheries Service (NMFS 2021).

3. Coral Reefs and Reef Fish

Summary: *Coral reef ecosystems are productive, biologically diverse, and provide critically important services to local communities in Hawai‘i including cultural practices, livelihoods, food-resources, fisheries, and coastal protection. For all reef areas around the MHI for 2010 through 2019, this section describes: 1) patterns in coral cover, calcifiers cover, and reef-builder ratio and, 2) patterns in total fish biomass, herbivore biomass, and resource fish biomass.*

Introduction

Coral reefs are highly productive and biologically diverse marine ecosystems. Nearly a quarter of reef-associated species found in Hawai‘i occur nowhere else on the planet (Eldredge and Evenhuis 2003; Randall 2007; Kane et al. 2014). Coral reef ecosystems provide critically important services to local communities in Hawai‘i including cultural practices, livelihoods, food-resources, fisheries, and coastal protection (Ingram et al. 2018). However, pressures from pollution, invasive species, overfishing, and climate change (see upcoming report sections) are negatively affecting reefs and undermining the socio-cultural connections that contribute to human well-being in Hawai‘i.

In this section, we present indicators that describe the ecosystem structure, function, and resilience of coral reef benthic and fish communities across the MHI. Reef indicators include percent cover of hard corals, calcified cover, and reef-builder ratio. The level of coral cover influences reef topographic complexity, habitat structure, reef accretion, and the diversity and abundance of coral-dependent fish species (McClanahan et al. 2012). The abundance of calcifying organisms such as coral and crustose coralline algae affects reef development and persistence and drives key ecological processes, including settlement and recruitment of corals and fish (Price 2010; Smith et al. 2016). The reef-builder ratio is the ratio of the combined cover of reef-building hard corals and calcifying algae to the combined cover of fleshy algae. This ratio describes the competition for space on reefs between accreting (reef-building) and non-accreting organisms and indicates benthic community dynamics (Smith et al. 2016).

Reef fish indicators include the total biomass of all reef fish, herbivorous fish biomass (e.g., parrotfish and surgeonfish), and resource fish biomass (e.g., moi, Polydactylus sexfilis; ‘ōpelu, Decapterus macarellus; and ‘ōmilu, Caranx melampygus). Total fish biomass provides a general indication of reef ecosystem health, function, and resilience (Brandl et al. 2019). Herbivores are fish species that principally consume plant material. Herbivory contributes to the capacity of reefs to resist and recover following disturbance and avoid shifting to a reef dominated by fleshy algae (Hughes et al. 2007). Resource fish are targeted for consumption so can be indicative of patterns and levels of fishing pressure (Friedlander et al. 2018).

The benthic and coral reef fish data were collected as part of NOAA's National Coral Reef Monitoring Program (NCRMP), which conducts assessments of biological (benthic and fish), ocean and climate, and socioeconomic indicators of coral reef ecosystems in the U.S. and territories (Towle et al. 2022). Nearshore coral reefs were surveyed at 4 different times between 2010 and 2019 across the MHI. These surveys used a stratified-random sampling design, targeting hard-bottom shallow-water (< 30 m) forereef habitat stratified by depth bin (see Methods). Data were pooled to the sector scale around each island (following Heenan et al. 2017). Sectors around each island were defined according to similarities in historically captured reef composition and geographic and environmental characteristics, such as those within leeward versus windward coastlines.

For all indicators, the current status for each sector was calculated for the most recent survey year, 2019. The status was either relatively 'low,' 'medium,' or 'high' based on whether that sector value was below, within, or above the mean ± 1 standard deviation among all 2019 MHI sectors. Surveys were conducted from April through July 2019, just prior to the coral bleaching and mortality event (see Asner et al. 2022). The direction of change through time was also assessed for each indicator at the sector scale. The direction of change was determined as either 'positive,' 'negative,' or 'not significant' with 95% confidence based on the difference between the most recent time period (2019) and the earlier time period of sampling in the sector (2010–2012 or 2013–2015).

Coral Reef Benthic Communities

Coral reef benthic surveys conducted by NOAA's NCRMP in 2019 included 80% (22 of 28) of sectors within the MHI (Fig. 3.1). Coral cover was greatest in north Lāna'i (39.7%), north Kaho'olawe (27.6%), and southwest Maui (25.5%). The 3 sectors with the lowest coral cover in 2019 were west Ni'ihau (0.4%), northwest Kaua'i (1.3%), and northeast Maui (2.0%). Mean coral cover across each of the sectors surveyed in 2019 was relatively high for 32% (7 of 22 sectors), medium for 14% (3 of 22), and relatively low for 50% (11 of 22). Spatial patterns in relative coral cover, calcifiers cover, and the reef-builder ratio were similar in 2019 (Fig. 3.1). The only exceptions were the sectors along southeast Moloka'i, south Lāna'i, and west Maui had relatively high coral cover but had relative medium calcifiers cover and medium reef-builder ratio.

Direction of change between the earliest (2010–2012 or 2013–2015) and most recent (2019) surveys was calculated for all coral reef benthic indicators for 61% (17 of 28) of sectors in the MHI (Fig. 3.1). The survey data needed to assess change over time were not available for the remaining sectors. Coral cover had a positive direction of change in just 1 sector, north Lāna'i. Direction of change was negative for 30% (5 of 17) of sectors, which included west and east Hawai'i, south Moloka'i, and both sectors on Kaua'i. The remaining 41% (7 of 17) of sectors had no significant direction of change. Direction of change was similar between indicators with the exception of east Kaua'i which had a negative direction of change for calcifiers cover and reef builder ratio, but the direction of change was not significant for coral cover. Additionally, the direction of change was negative for coral cover but not significant for the remaining indicators along southeast Moloka'i.

It is important to note that if direction of change is 'not significant,' this does not necessarily mean that that no change has occurred over time. This designation is a result of uncertainty in the calculated direction of change value such that it could not be considered significantly positive or negative with a high level of confidence (i.e., > 95% confidence).

Coral reef benthic indictors presented in Figure 3.1 represent the sector-level mean among all surveys from 0 to 30 m water depth for each survey year. Coral reef benthic communities can vary considerably across depth gradients (Friedlander and Parrish 1998; Asner et al. 2020). To illustrate depth-based variation, mean 2019 coral cover was calculated for the 3 depth strata—shallow (>0 – 6 m), moderate (>6 – 18 m), deep (>18 – 30 m)—for each island (Fig. 3.2). Coral cover was highest at moderate depth strata and was significantly higher than either the shallow or deep strata for all islands except Maui, which had similar cover across depths. The only island where all 3 strata had significantly different coral cover was Lānaʻi. Coral cover changes over time also varied based on depth. For example, in the west Hawaiʻi sector, coral cover decreased by over 50% (> 95% confidence) between the most recent (2019) and earliest (2010–2012) survey years for the shallow and moderate depth strata (Fig. 3.3). Conversely, coral cover in the deep stratum was not signficiantly different over the same time period.

Shallow coral reef at Molokini.

Ph. Pauline Fiene

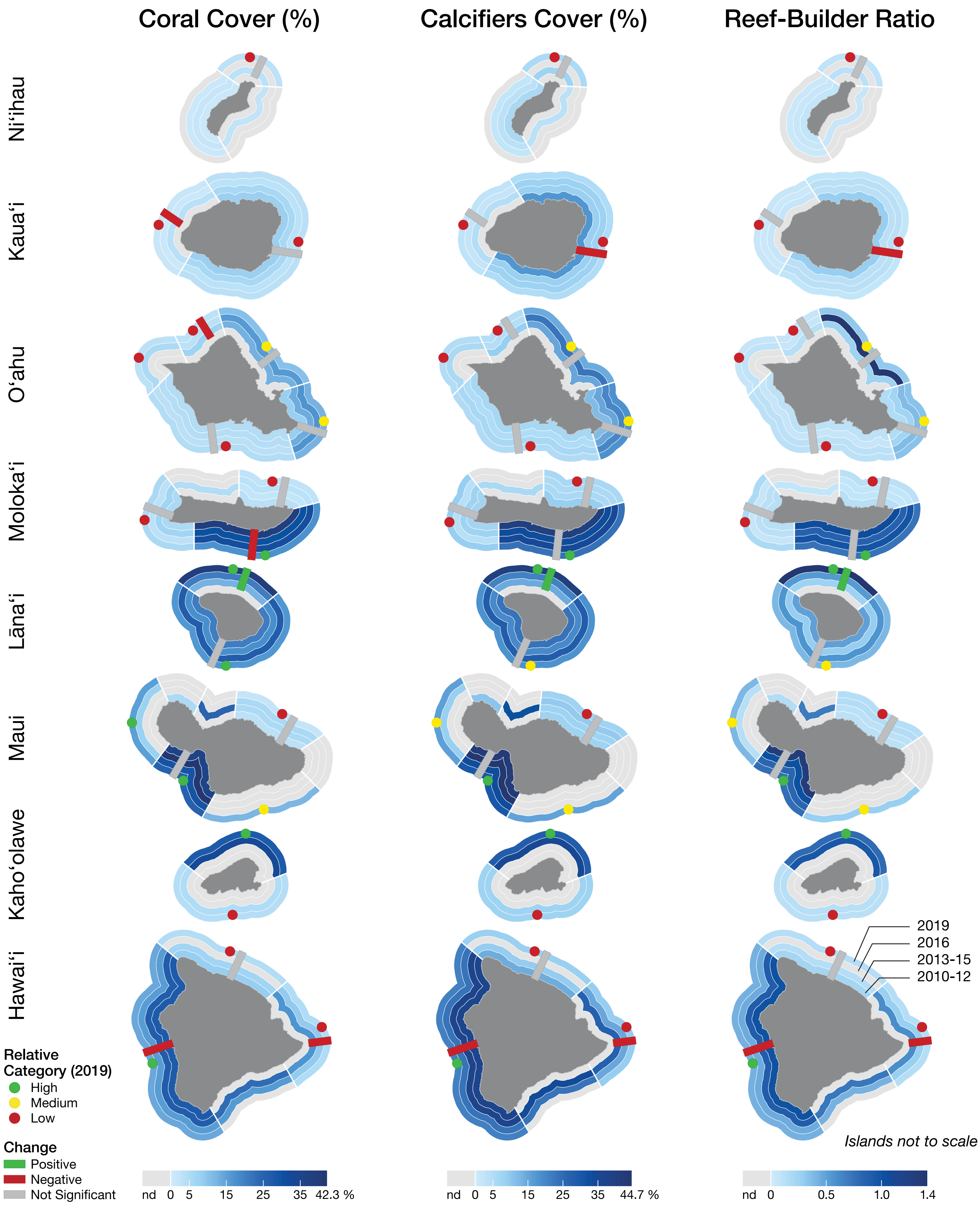


Fig. 3.1. Indicators describing the coral reef benthic environment for surveys conducted by NOAA’s National Coral Reef Monitoring Program between 2010 and 2019. Each ring around islands represents a survey year, with thin white lines separating sampling sectors. Bars spanning survey years indicate direction of change where data were available for 2019 and at least one of 2010 to 2012 or 2013 to 2015. Filled-in circles describe relative category for 2019, which was either low, medium, or high based on whether that sector value was below, within, or above the mean ± 1 standard deviation among all 2019 MHI sectors. Islands are not to scale. Data source – NCRMP.

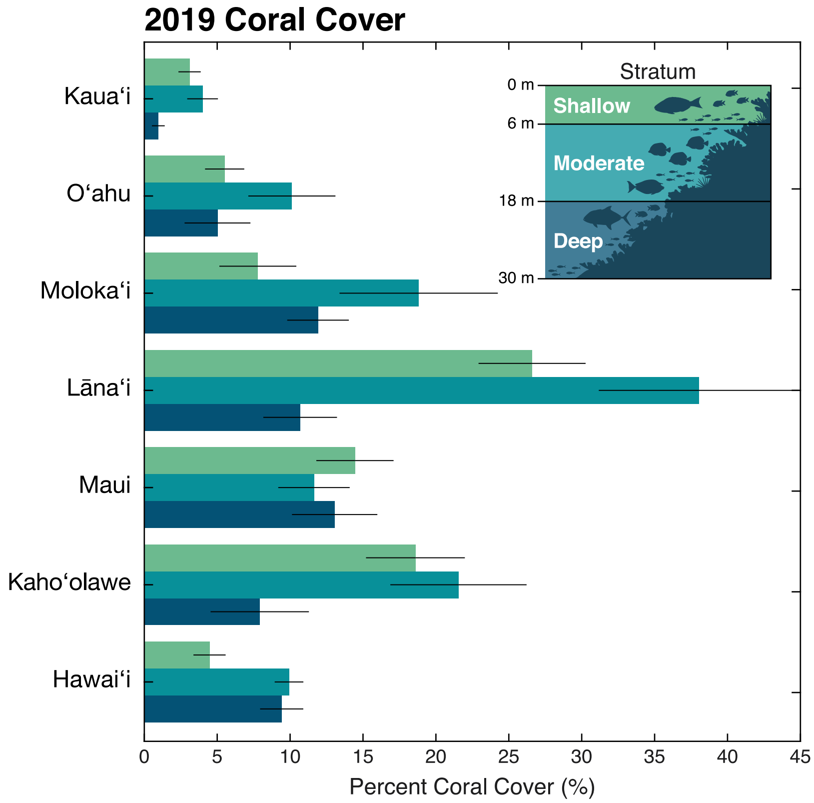


Fig. 3.2. Coral cover (%) for each island in 2019 by depth stratum: shallow (> 0–6 m), moderate (> 6–18 m), deep (>18–30 m) (see inset legend). Error bars represent 95% confidence intervals. Non-overlapping error bars represent significantly different coral cover.

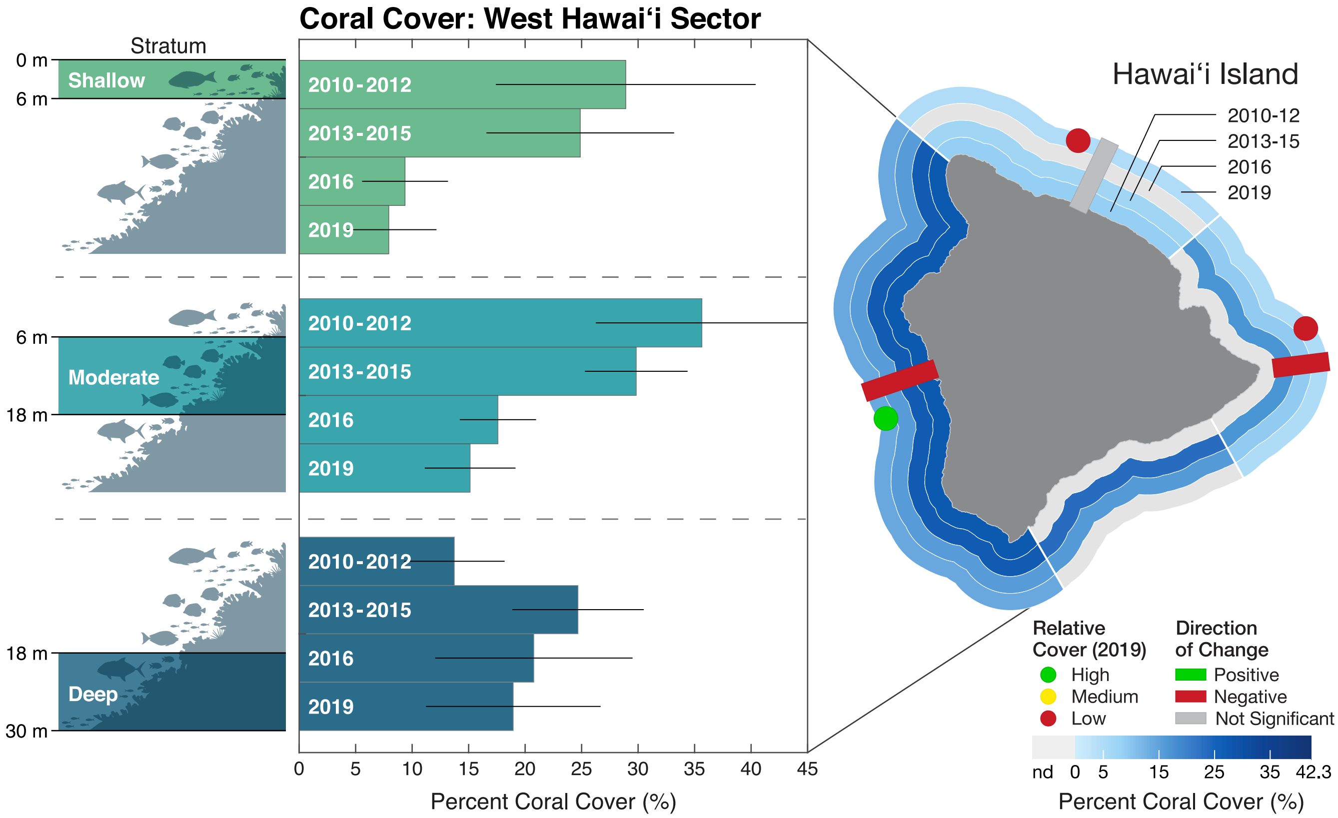


Fig. 3.3. Surveys of coral reef benthic communities were conducted by NOAA's National Coral Reef Monitoring Program (NCRMP) between 2010 and 2019. The left panels show percent hard coral cover (%) by depth stratum—shallow (> 0–6 m), moderate (> 6–18 m), deep (> 18–30 m)—for the west Hawaiʻi sector for each survey year. Error bars represent 95% confidence intervals. Non-overlapping error bars represent significantly different coral cover. The right panel shows coral cover for all sectors for Hawaiʻi Island (from Figure 3.1; see caption for more detail).

Coral Reef Fish Communities

Reef fish surveys conducted by NOAA NCRMP in 2019 included ~65% (18 of 28) of sectors within the MHI (Fig. 3.4). The top 3 sectors with the greatest total fish biomass in 2019 were south Kahoʻolawe (656 kg/ha), northeast Maui (599 kg/ha), and north Kahoʻolawe (530 kg/ha). The 3 sectors with the lowest total fish biomass in 2019 were west Maui (93 kg/ha), west Molokaʻi (118 kg/ha), and northeast Oʻahu (136 kg/ha). When comparing the total fish biomass of individual sectors in 2019 to the overall mean across all the sectors surveyed that year, total fish biomass was relatively high for 39% of sectors (7 of 18 sectors), relatively low for 50% (9 of 18), and only two sectors had a relatively medium level of fish biomass. Spatial patterns in the relative herbivore biomass and resource fish biomass in 2019 were very similar to those of total biomass (Fig. 3.4). The only exceptions were the sectors along east Oʻahu and south Lānaʻi which hadrelatively medium total fish biomass and herbivore biomass but had low resource fish biomass. In addition, west Hawaiʻi had relatively high total fish biomass and herbivore biomass, but medium resource fish biomass.

Direction of change between the earliest (2010–2012 or 2013–2015) and most recent (2019) surveys were calculated for all reef fish indicators for 50% (14 of 28) of the sectors in the MHI (Fig. 3.4). The remaining sectors did not have survey data available to assess change. Total fish biomass had a positive direction of change in 3 of 14 sectors and resource fish biomass had a positive direction of change in 1 sector; all remaining sector-scale indicators of reef fish biomass had no significant direction of change. Direction of change was similar between reef fish indicators with the following exceptions: south Oʻahu and west Hawaiʻi had a positive direction of change for total biomass, but change was not significant for herbivore or resource fish biomass; and northeast Maui had a positive direction of change for total biomass and resource fish biomass, but change was not significant for herbivore biomass.

It is important to note that if direction of change is ʻnot significant,ʼ this does not necessarily mean that that no change has occurred over time. This designation is a result of uncertainty in the calculated direction of change value, such that it could not be considered significantly positive or negative with a high level of confidence (i.e., > 95%).

Coral reef fish indictors presented in Figure 3.4 represent the sector-level mean among all surveys from 0 to 30 m water depth for each survey year. But reef fish biomass can vary considerably across depth gradients (Friedlander and Parrish 1998). To illustrate depth-based variation, total fish biomass at each island in 2019 was parsed into the 3 sampling strata: shallow (> 0–6 m), moderate (> 6–18 m), and deep (> 18–30 m) (Fig. 3.5). Significant differences in total fish biomass between at least two depth strata were apparent at Kauaʻi, Oʻahu, and Maui. With the exception of Kauaʻi, the mean biomass at all other islands was lowest in the shallow depth stratum (note that only for Oʻahu and Maui was this result significant). Shifts in reef fish biomass over time can also vary based on depth. In the west Hawaiʻi sector (Fig. 3.6), for example, temporal variation in total fish biomass was not the same in each stratum, whereby biomass significantly increased (> 95% confidence) between the earliest (2010–2012) and most recent (2019) survey years within the shallow and deep strata. Total fish biomass in the moderate depth stratum was not signficantly different (> 95% confidence) over the same time period.

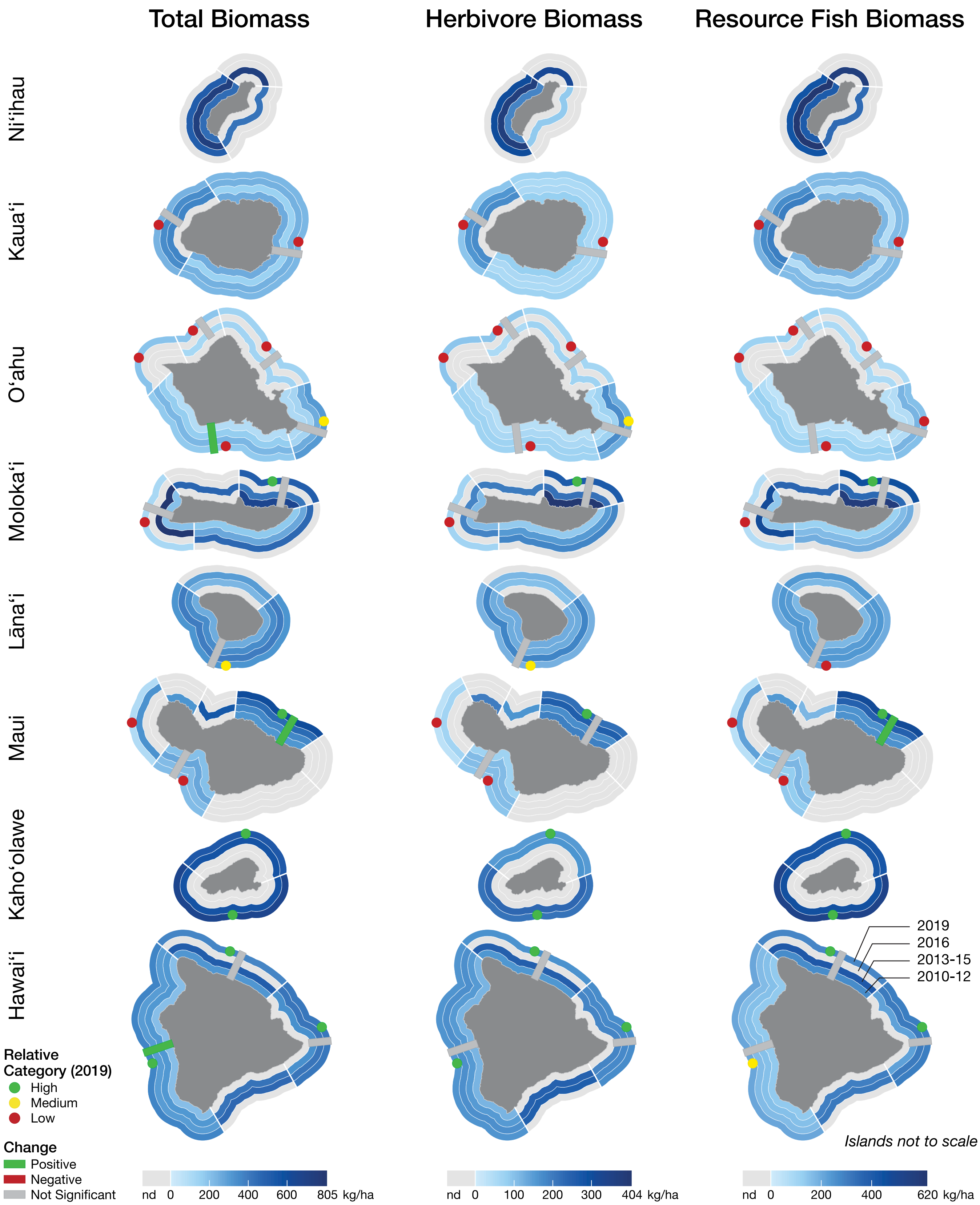


Fig. 3.4. Indicators describing coral reef fish communities from surveys conducted by NOAA's National Coral Reef Monitoring Program between 2010 and 2019. Each ring around islands represents a survey year, with thin white lines separating sampling sectors. Bars spanning survey years indicate change where data were available for 2019 and at least one of 2010 to 2012 or 2013 to 2015. Filled-in circles describe relative category for 2019, which was either low, medium, or high based on whether that sector value was below, within, or above the mean ± 1 standard deviation among all 2019 MHI sectors. Islands are not to scale.

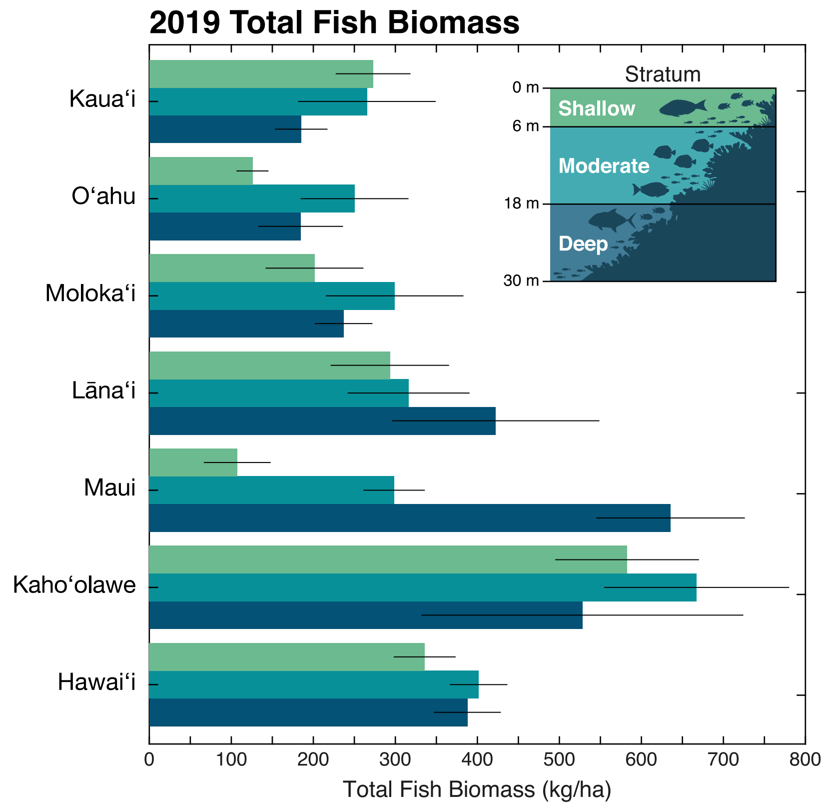


Fig. 3.5. Total fish biomass (kg/ha) for each island in 2019 by depth stratum: shallow (> 0–6 m), moderate (> 6– 18 m), deep (>18–30 m) (see inset legend). Error bars represent 95% confidence intervals. Non-overlapping error bars represent significantly different total fish biomass.

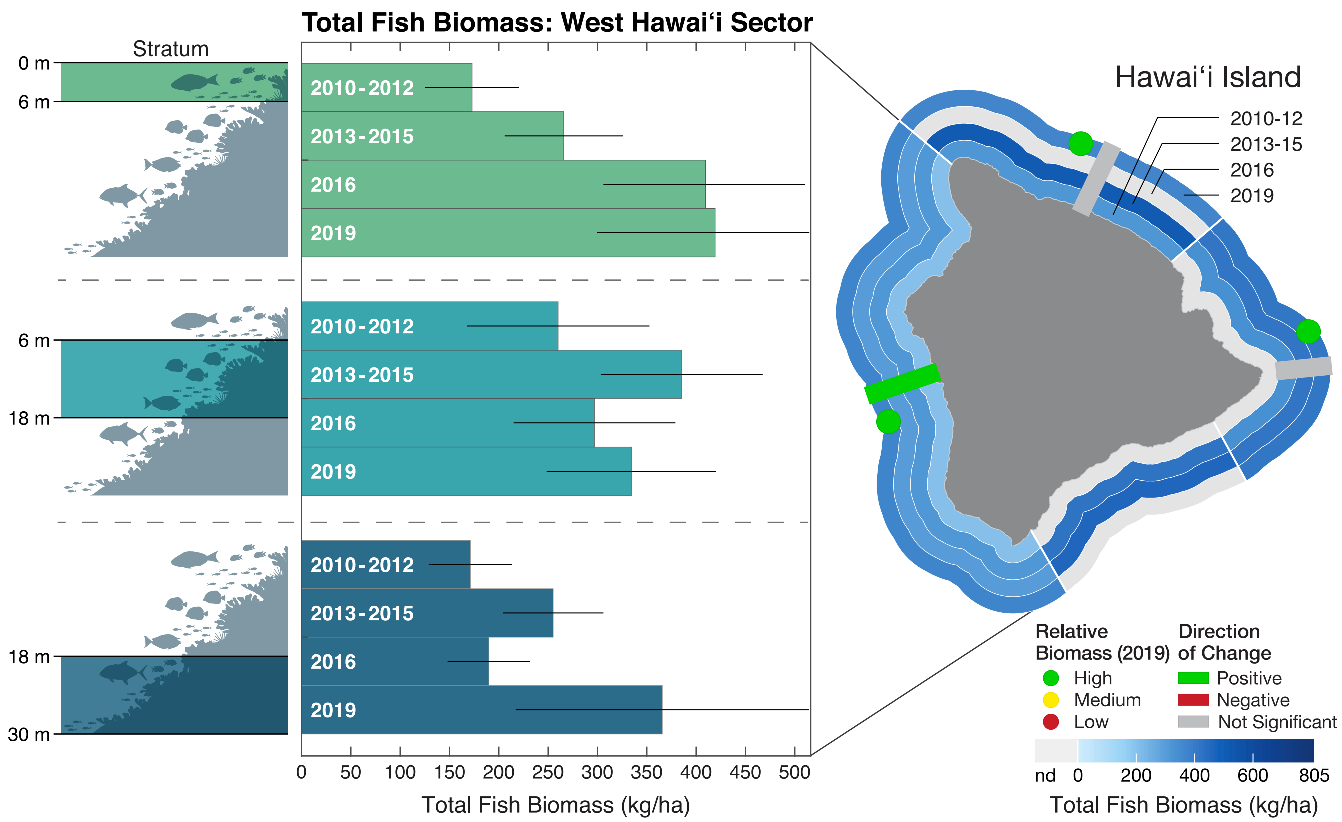


Fig. 3.6. Total fish biomass (kg/ha) by depth stratum (left panel) within the west Hawaiʻi sector for each survey year. Error bars represent 95% confidence intervals. Non-overlapping error bars represent significantly different total fish biomass. The right panel shows coral cover per sector and year for Hawaiʻi Island (from Figure 3.4; see caption for more detail).

Discussion

The NOAA NCRMP team conducted coral reef ecosystem surveys in the Hawaiian Islands from 2010 through 2019. These surveys served as the foundation for coral reef and reef fish indicators used to help describe the structure, function, and resilience of coral reef ecosystems across the MHI. Tracking the current status and recent trends in coral reef indicators can directly inform marine resource planning efforts, support management efficacy evaluation, and assess progress in management objectives over time.

The NCMRP survey sectors in the MHI comprise relatively large areas of coastline (see Fig. 3.1 & 3.4). The status and trends in coral reefs at smaller spatial scales may therefore be different than reported here. Coral reef benthic and fish communities can also vary by depth owing to differences in habitat, food resource availability, and human pressures (Friedlander et al., 2018; Asner et al., 2020). The scale-dependency in coral reef ecosystems highlights the importance of assessing and evaluating ecosystem indictators at spatial and temporal scales relevant to resource management planning efforts. Doing so will be critical for meeting conservation and sustainability goals under climate change.

It is important to keep in mind that changes to reef ecosystem health have been ongoing for decades in the Hawaiian Islands. In Puakō, Hawai‘i Island (located in the west Hawai‘i sector), coral cover declined from 80% in the 1970s to 32% in 2010 (Minton et al. 2012), representing a 50% loss in coral cover prior to this report. Similarly, the current status in reef fish biomass may differ from the estimated natural or historical baseline levels. Hawai‘i Island had relatively high total fish biomass for all sectors surveyed in 2019 (Fig. 3.4), but the estimated historical baseline fish biomass is roughly 2-fold higher (Gorospe 2018). Such historical estimates in reef indicators provide important reference points and context for present-day status and trends in ecosystem health.

The NOAA NCRMP team was unable to consistently survey all sectors across all survey years owing to the combined effects of the substantial geographic area of the MHI, poor weather conditions, and other limiting factors. These factors also influenced the total number of sites surveyed between years. As such, differences (or lack thereof) in coral reef benthic and fish indicators across years may at least in part be attributed to variable sampling effort (Tables A2 – A7 in Appendix).

Finally, this section did not include analyses that identify the underlying drivers of changes in coral reef benthic and reef fish indicators across space or time. There are many potential reasons for the observed directions of change related to the many interacting and cumulative impacts that occur on nearshore ecosystems in Hawai‘i. Please see Section 5. Human Impacts and Section 6. Vulnerability of Coral Reefs to Climate Change for detailed maps on the spatial distribution of cumulative impacts and reef vulnerability to climate change across the Hawaiian Islands.

4. Climate and Ocean

Summary: *Climate and ocean conditions in Hawai‘i are hugely variable across the island chain and through time. Significant climatological changes are predicted to occur in coming decades in Hawai‘i, including changes in rainfall and storm patterns and rising sea levels and sea temperatures. This section describes the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation indices; annual rainfall and peak rainfall events from 1990 to 2021, and the brown water advisories that can follow heavy rainfall; and historical sea level and sea temperature and projected changes over the upcoming 80 years.*

Introduction

Climate and ocean conditions in Hawai‘i are highly variable across the island chain. There are differences in exposure to the trade winds that result in leeward and windward sides of islands, local-scale differences in rainfall due to the mountainous terrain, and great variation in exposure to currents, upwelling, and waves. Further, large-scale climate patterns can directly influence local conditions given the location of the Hawaiian Islands in the middle of the Pacific Ocean basin. Indicators of climate variability and associated environmental changes improve our understanding of ecosystem processes, such as species interactions, food-availability, and ecosystem function. Understanding these linkages is increasingly important given projections of climate change in the coming decades.

This section describes the El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation indices; annual rainfall and peak rainfall events from 1990 to 2021, and the brown water advisories that can follow heavy rainfall; and historical sea level and sea temperature and projected changes over the next century.

El Niño-Southern Oscillation and Pacific Decadal Oscillation

The El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are large-scale climate patterns that can strongly influence ocean conditions, particularly in the central and eastern Pacific. ENSO is an irregular (3–7 years), ocean-atmosphere climate phenomenon. El Niño represents the warm phase of the ENSO cycle, characterized by weakening of the trade winds and warming of equatorial Pacific Ocean temperatures. La Niña represents the cool phase and is associated with stronger than normal trade winds and anomalously cool ocean temperatures in the region (Philander 1990).

The PDO is similar to ENSO but longer in duration. Changes in the PDO are marked by widespread variations in temperature, wind patterns, ocean mixing, and biological productivity (Polovina et al. 1994). The extreme phases of the PDO have been classified as either warm or cool, defined by ocean temperature anomalies in the northeast and tropical Pacific Ocean.

Large departures from normal conditions have occurred when ENSO and PDO are aligned in phase. For example, in 2015, a powerful El Niño occurred alongside a warm phase of the PDO that contributed to the strongest marine heat wave ever recorded in the main Hawaiian Islands and across the Northeast Pacific (Di Lorenzo and Mantua 2016; Gove et al. 2019). At time of publication in 2022, we were experiencing the second year of a La Niña and one of the strongest cool phases in the PDO observed in the past 40 years (Fig. 4.1). The relationships between extremes in ENSO and PDO and ocean-atmosphere conditions experienced in Hawai'i are not well understood and continue to be an active area of scientific research.

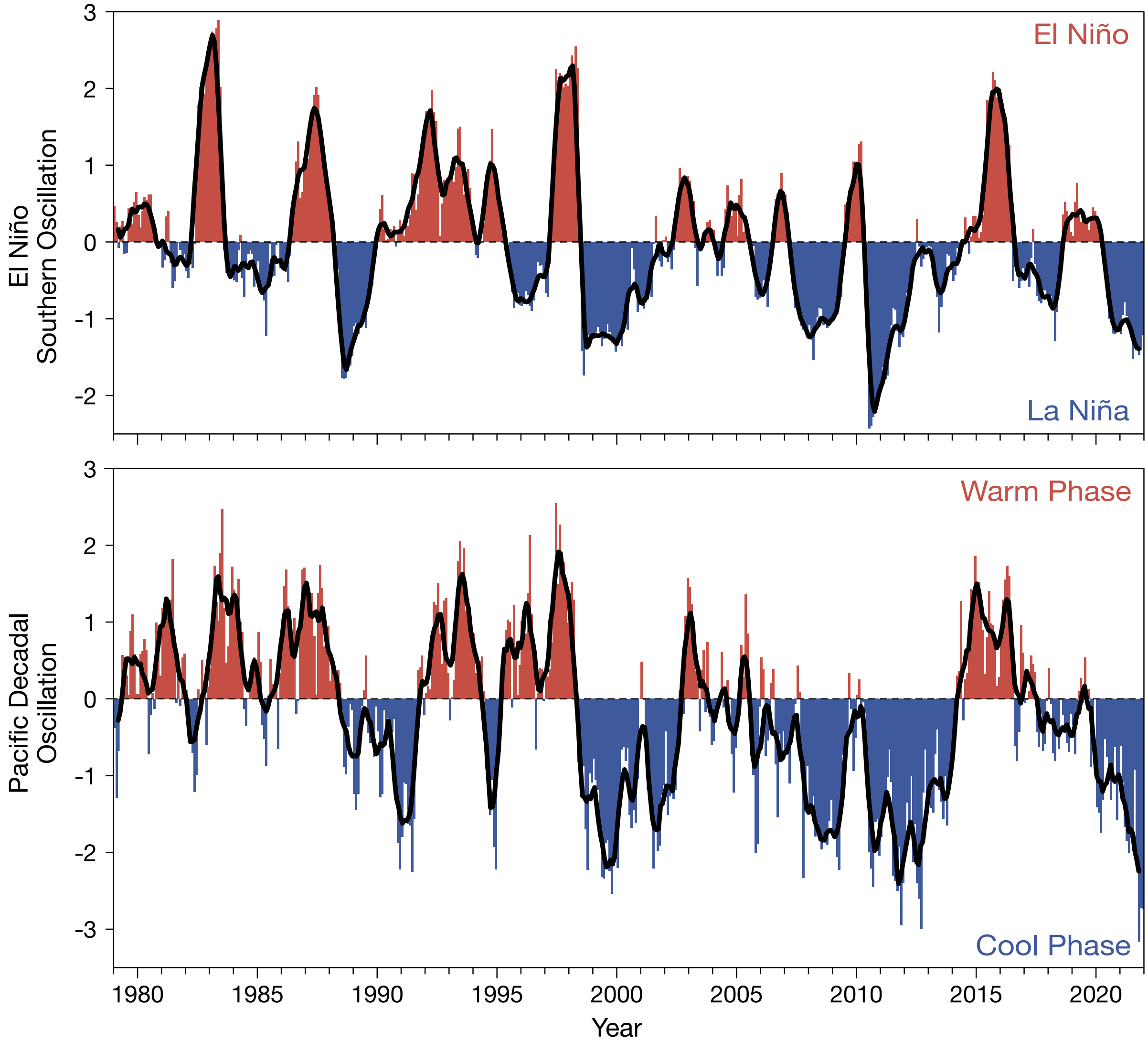


Fig. 4.1. Indices representing the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). The black line represents a 6-month moving average. Data sources: Multivariate ENSO Index was obtained from NOAA's Earth System Research Laboratory (https://www.esrl.noaa.gov/psd/enso/mei). The PDO index was obtained from NOAA's National Centers for Environmental Information (https://www.ncdc.noaa.gov/teleconnections/pdo).

Rainfall Patterns and Brown Water Advisories

The Hawaiian Islands have highly variable and dynamic rainfall patterns. The persistent trade winds, mountainous terrain, and diel heating and cooling of the land interact to produce areas of uplift in distinct spatial patterns associated with the islands' topography. The resulting clouds and rainfall produced by this uplift lead to dramatic differences in rainfall over short geographic distances (Giambelluca et al. 2012). Changes in rainfall influence groundwater and surface water transport to the marine environment, which can impact nearshore salinity and temperature as well as suspended sediment and nutrient concentrations.

In this section, we present indicators of rainfall from 1990 through 2021 for Hilo and Kona (Hawaiʻi), Kahului (Maui), Honolulu (Oʻahu), and Līhuʻe (Kauaʻi) airports. Indicators shown include annual rainfall (mm); peak rainfall, expressed as the percentage of annual rainfall in the top 5 days for each year; and changes in peak events, calculated as the difference in the sum of the rainfall in the top 5 days between the most recent 5 years (2017–2021) and the first 5 years (1990–1994) of the data record.

Over the 32-year record, there were large year-to-year differences in rainfall at all locations (Fig. 4.2). For most locations, the year with the greatest rainfall was between 3 and 6 times greater than the year with the lowest rainfall. However, in Honolulu there was nearly a 9-fold difference among years in lowest and greatest annual rainfall.

While rainfall at Hilo was 3 to 11 times greater than all other locations, it had the lowest rainfall in peak events with an average of just 19.5% of rain occurring within the top 5 days (Fig. 4.2). All other locations had peak rainfall events that averaged between 34% and 47% of annual rainfall over the full time series. The total rainfall during peak events (i.e., sum total rain in the top 5 days for each year) has increased over time at all locations except Hilo (Fig. 4.2). The greatest increase was in Honolulu, where approximately 80% more rainfall occurred during peak events between 2017 and 2021 than in 1990 to 1994.

Rain clouds rolling in over the Na Pali Coast on the island of Kauai.

Ph. gcosoveanu | iStock/Getty

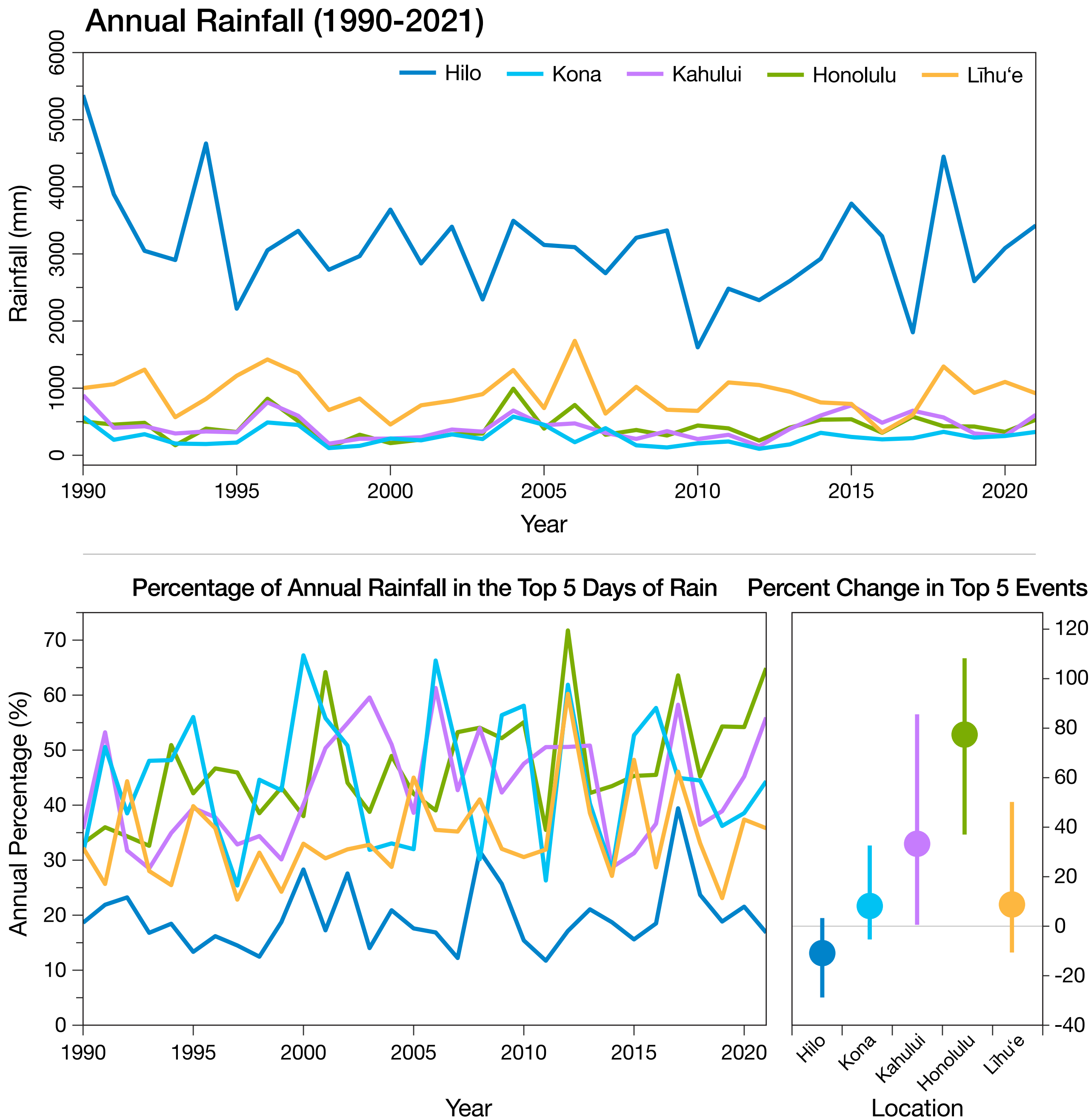
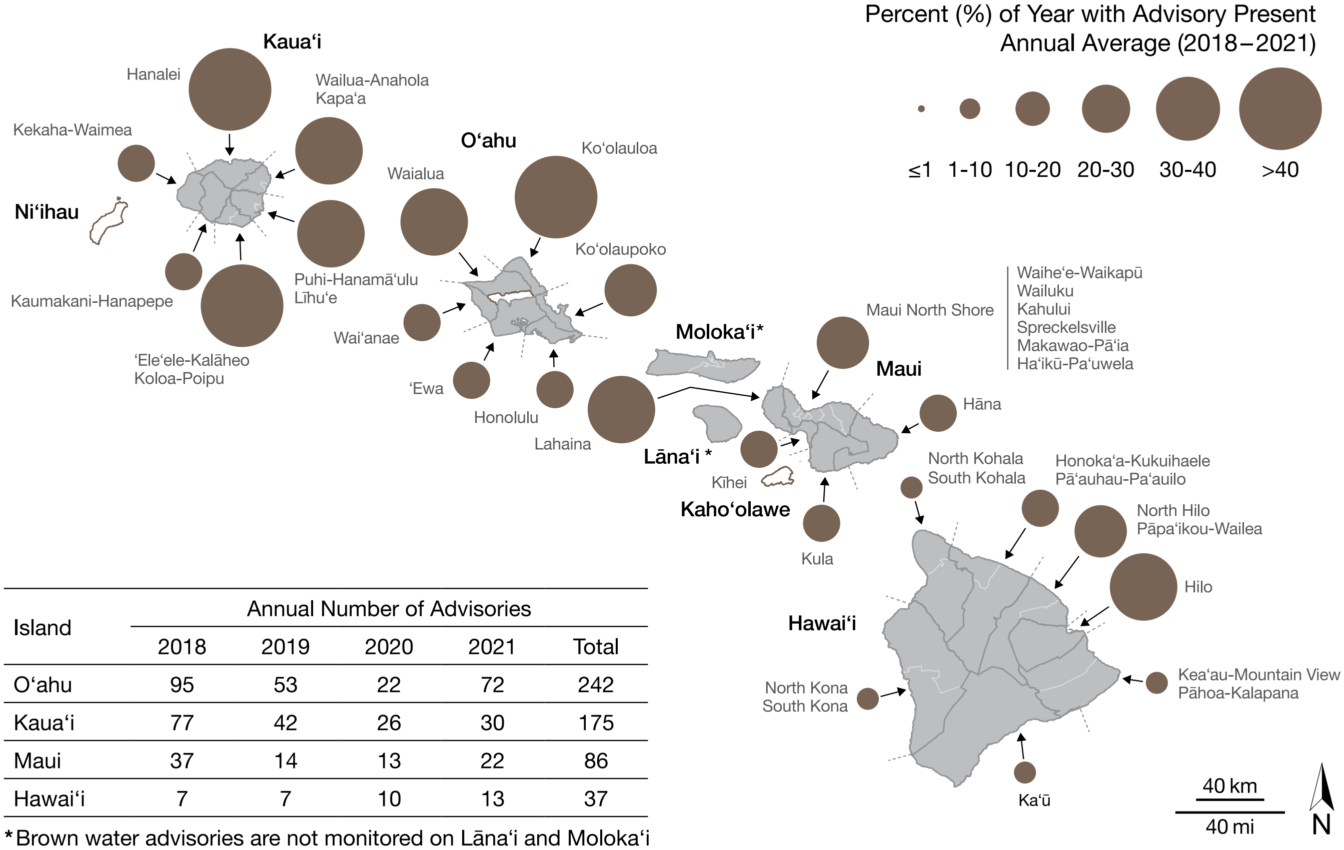


Fig. 4.2. Annual rainfall (mm) for 5 airport locations across Hawai‘i from 1990 through 2021. Peak rainfall, expressed as the percentage (%) of annual rainfall in the top 5 days for each year. Changes in peak events, calculated as the percent difference in peak events (i.e., sum total rain in the top 5 days for each year) between the most recent 5-years (2017–2021) and the first 5 years (1990–1994) of the data record. Upper and lower bars represent the maximum and minimum differences in peak events between these time periods. Data sources: Years 1990–2020, Longman et al., 2020; Years 2020–2021, NOAA's Climate Data Online Portal (https://www.ncdc.noaa.gov).

Rainfall events can cause excessive runoff of water that carries land-based pollution into the ocean. A brown water advisory is issued by the State of Hawai‘i Clean Water Branch (CWB) to advise beach users to use caution when waters are brown, turbid, or cloudy. BWAs are usually issued following heavy rain, high surf, water main breaks, or other events that cause excessive runoff into the ocean. Rain does not need to fall on or near the beach for excessive runoff to occur.

Brown Water Advisories



Island	Annual Number of Advisories				
	2018	2019	2020	2021	Total
O‘ahu	95	53	22	72	242
Kaua‘i	77	42	26	30	175
Maui	37	14	13	22	86
Hawai‘i	7	7	10	13	37

*Brown water advisories are not monitored on Lāna‘i and Moloka‘i

Fig. 4.3. Brown Water Advisory (BWA) information for Hawai‘i from 2018 through 2021. The total number of BWAs by island for each year (table) are shown, and the percent of the year with a BWA present for census county divisions (CCDs) or CCDs grouped into a region or area (e.g., Maui North Shore). Data source: State of Hawai‘i Clean Water Branch.

Rain in the mountains may cause runoff to affect a beach through streams, storm drains, or drainage canals, even on a sunny day at the beach. Runoff can contain pollutants that may be harmful to coastal ecosystems and human health, including water from overflowing cesspools, sewers, and manholes; fertilizers; pesticides; animal fecal matter; dead animals; pathogens; chemicals, heavy metals and toxicants; other pollutants, and debris. In most cases, brown water advisories are issued by the Clean Water Branch at times when the National Weather Service has issued a Flash Flood Warning.

As an indicator of nearshore water quality, we calculated the average number and time (expressed as a percentage of the year that BWAs were present) of brown water advisories issued from 2018 to 2021 (Fig. 4.3). This timeframe spans the period in which BWAs were consistently and reliably reported by the Clean Water Branch. Brown water advisories occurred most frequently on O‘ahu where, on average, 60 were issued per year. Fewer BWAs were issued on Kaua‘i and Maui, where 43 and 21 advisories, respectively, were issued per year on average. At the intra-island scale, regions that had the greatest percent of year with BWAs present were Ko‘olauloa (O‘ahu), Hanalei (Kaua‘i), and the combined area of ‘Ele‘ele-Kalāheo and Kōloa-Po‘ipū (Kaua‘i). These areas had greater than 40% of the year with a BWA in effect.

Sea Level Rise

Long-term sea level rise can lead to chronic coastal erosion, coastal flooding, and drainage problems (HCCMAC 2017). Long-term sea level rise also exacerbates short-term fluctuations in coastal sea level driven by waves, storms, and extreme tides. Tracking the status and trends in sea level is critically important for coastal planning and management of nearshore marine ecosystems.

Long-term sea level measurements (1905–2020) from Honolulu indicate that sea level has increased by 0.30 m (0.89 ft) in the past 120 years (Fig. 4.4). With climate change, sea level is projected to rise between 0.2 and 0.35 m by 2100 (median: 0.27 m; SSP5-8.5; Church et al. 2013). Of all the emissions scenarios, the fossil-fuel-aggressive Shared Socioeconomic Pathway (SSP5-8.5) most closely represents the continuation of our current trajectory based on recent emissions and existing policy as measured at the Mauna Loa observatory on Hawai‘i (from 2015–2022; the first 7 years of the climate model trajectories). In contrast, SSP2-4.5 assumes climate policy rapidly gains momentum and that emissions cuts soon exceed those pledged under the Paris Agreement of 2015 (Riahi et al. 2017). However, differences in projected sea level rise between SSP5-8.5 and SSP2-4.5 are minimal. Under SSP2-4.5, sea level is projected to rise between 0.18 and 0.31 m (median: 0.24 m) (Fig. 4.4).

Over the next 30 to 70 years, properties, infrastructure, and critical habitat located on or near shorelines in Hawai‘i will increasingly be flooded, eroded, or completely lost to the sea (HCCMAC 2017). As sea level continues to rise, low-lying, populated coastal communities will likely experience increased frequency and extent of flooding. Beaches will increasingly be eroded and permanently lost. Places that are economically, culturally, or historically important, many of which are located near the shoreline, will also be severely threatened and potentially lost with continued sea level rise (HCCMAC 2017).

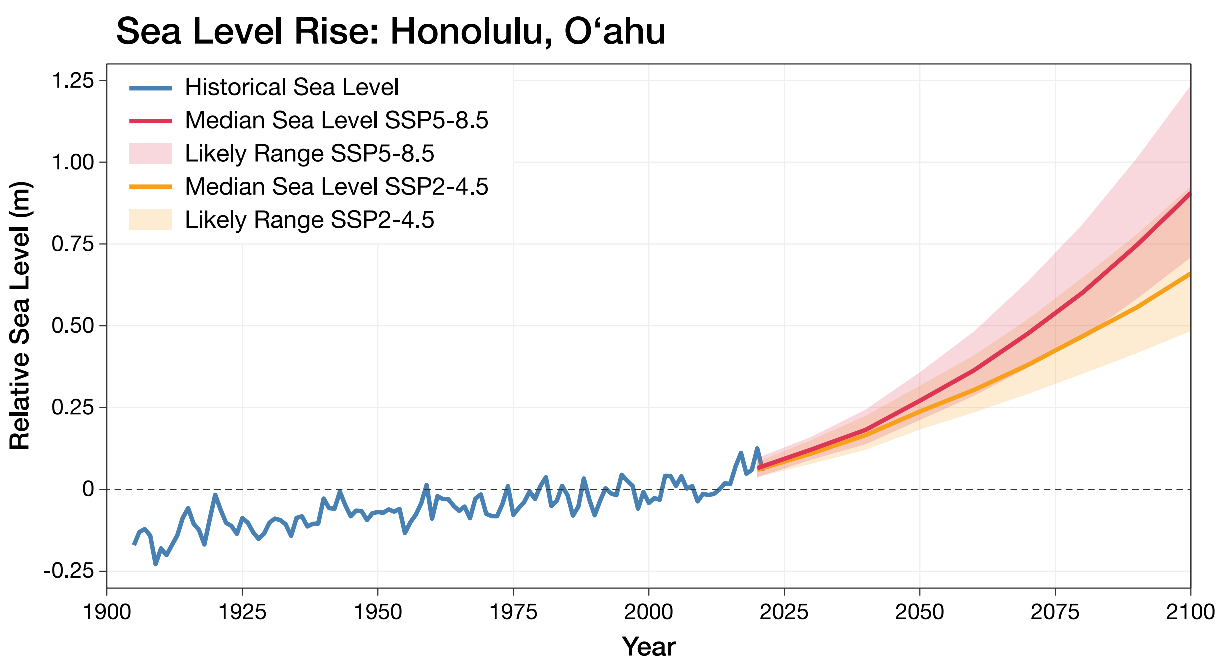
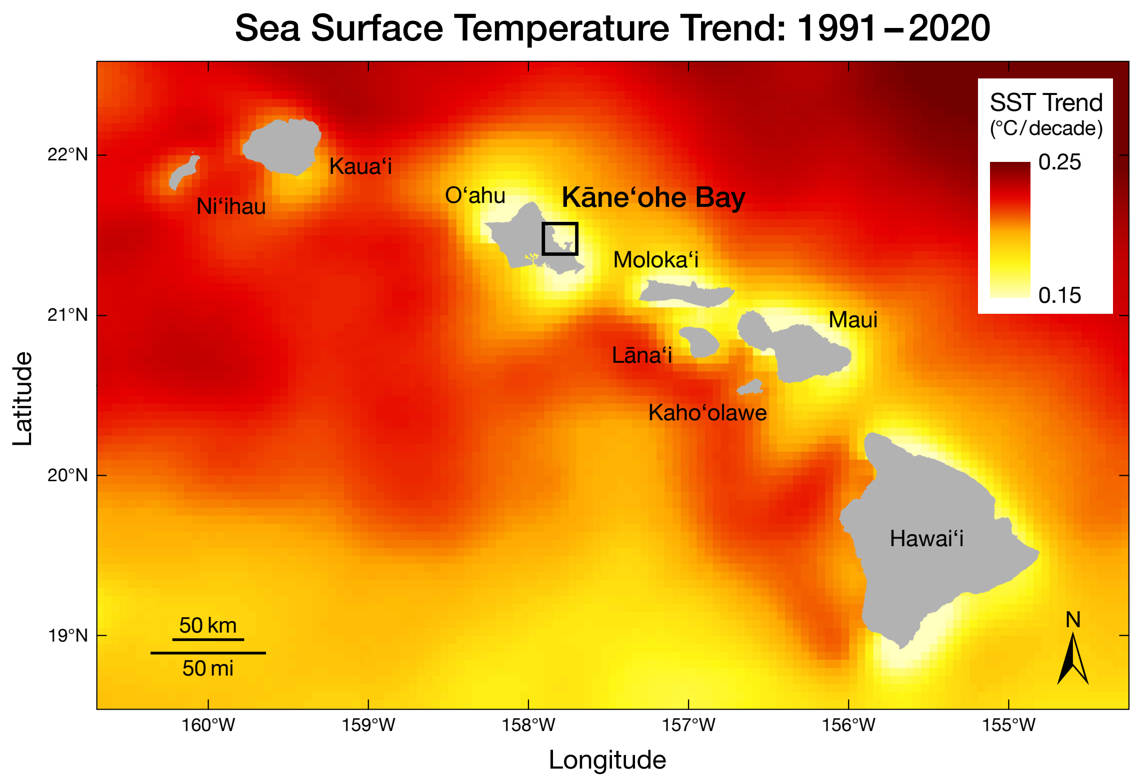


Fig. 4.4. Historical and projected future sea level from Honolulu, O‘ahu for 1905 through 2100. Sea level is shown relative to the 20-year average level between 1990 and 2010. Projected future sea level is shown for the fossil-fuel-aggressive Shared Socioeconomic Pathway (SSP) 5-8.5; and SSP2-4.5, which assumes climate policy rapidly gains momentum and that emissions cuts soon exceed those pledged under the Paris Agreement of 2015. For projected sea level, the median of 20 climate models is shown with the likely range, representing the middle 90% (excludes 5% of model range at top and bottom of range). Historical data are from the University of Hawai‘i Sea Level Center.

Sea Surface Temperature

Surface ocean temperatures in Hawaiʻi can vary over a broad range of temporal scales owing to the oceanic setting and geographic location in the central-northern Pacific. Diel, intra-seasonal (e.g., mesoscale eddies), seasonal, interannual (e.g., ENSO), and decadal (e.g., PDO) forcing as well as fluctuations in the rotational speed of the subtropical gyre all influence ocean temperatures in the main Hawaiian Islands (Gove et al. 2019).



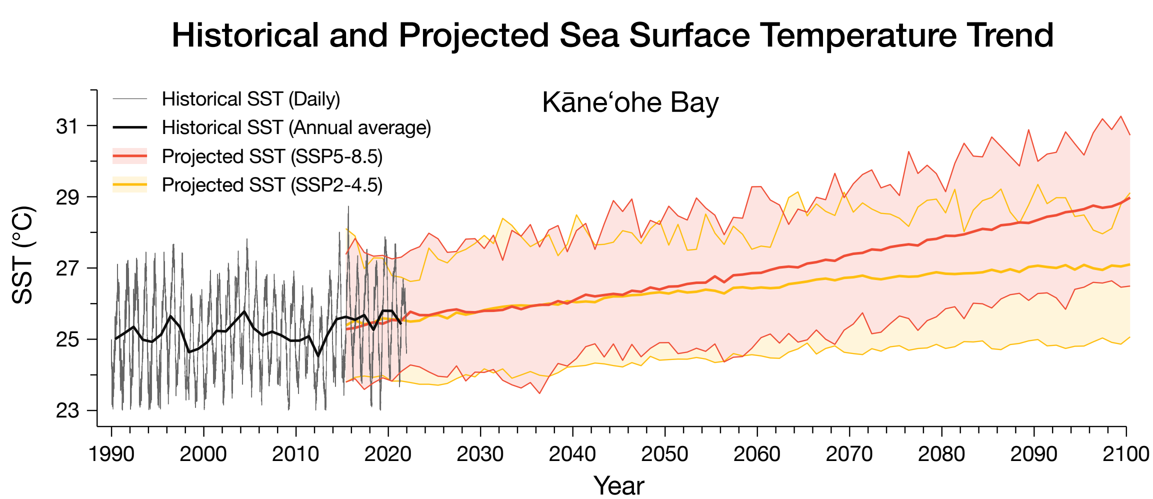


Fig. 4.5. Historical sea surface temperatures for the Hawaiʻi region (top), and historical and projected sea surface temperature for Kāneʻohe Bay, Oʻahu (bottom). Linear trend of SST (°C/month) over the previous 30 years was calculated for each 5-km pixel from 1991 through 2020 using NOAA CRW CoralTemp v3.1 data. Linear trends of mean adjusted multi-model ensemble SSTs from climate models (CMIP6 generation) were calculated from monthly data for each 0.25 degree pixel in the region.

There is seasonal and interannual variability in sea surface temperatures (SST) in the historical record (Fig. 4.5). Seasonally, ocean temperatures are coolest in March (24.8 °C; 76.6 °F, on average) and warmest in September (27 °C; 80.6 °F, on average). This seasonal cycle can be shifted, accentuated, or dampened over longer time scales owing to large-scale ocean-atmosphere climate phenomena. In recent decades (1990–2020), SST has increased between 0.15 and 0.25 °C/decade in the MHI (Fig. 4.5), which is a similar warming trend to that reported by Couch et al. (2017) in the Papahānaumakuākea Marine National Monument (Northwestern Hawaiian Islands). Ocean temperature in 2015 was the warmest on record in Hawaiʻi due to the confluence of local conditions and large-scale processes (see ENSO and PDO sub-section above and Gove et al. 2019).

Under SSP5-8.5, SST is projected to rise nearly 2 °C by 2100, with the rate of change increasing after 2050 (Fig. 4.5). Differences in projected SST between SSP5-8.5 and SSP2-4.5 are minimal up to 2050, with both scenarios projecting an increase of ~0.5 °C. The scenarios quickly diverge after 2050. SST increases after 2050 under SSP5-8.5 are nearly 1.5 °C greater than under SSP2-4.5. Under SSP5-8.5, the extreme ocean temperatures of 2015 that caused severe coral bleaching and mortality are projected to occur annually by 2060.

Rising sea temperatures present a threat to corals (see 6. Vulnerability of Coral Reefs to Climate Change). Ph. Christine Shepard

5. Human Impacts

Summary: *The great majority of human activity in Hawai‘i takes place in and adjacent to the nearshore environment. Land-based impacts like wastewater pollution and sediment input combine with sea-based impacts, such as overfishing. These are cumulative impacts that disrupt natural ecological processes and reduce ecosystem health, function, and resilience. Understanding these cumulative impacts is essential to targeting management and restoration activities. This section presents maps of Hawai‘i that show spatial variation in the severity of cumulative human impacts.*

Introduction

The majority of visitor accommodations, local human population, and infrastructure are along the coastline in Hawai‘i. This high concentration of coastal development and population density results in most human activities taking place in and adjacent to the nearshore environment. Human activities can both negatively and positively influence nearshore marine ecosystem health (see Fig. i). Along the shore, land-based impacts like wastewater pollution and sediment input combine with sea-based impacts, such as overfishing. These are cumulative impacts that disrupt natural ecological processes and reduce ecosystem health, function, and resilience (Crain et al. 2008; Donovan et al. 2021). Understanding these cumulative impacts is essential to targeting management and restoration activities that positively influence ecosystem health and function. Managing sea-based impacts alone, such as fishing, is likely insufficient to mitigate the full spectrum of local human impacts in Hawai‘i. An ecosystem-based approach to management, one that simultaneously addresses human activities on land and sea, best supports ecosystem resilience to current and future impacts (Halpern et al. 2010). Detailed maps of individual stressors caused by human activities are needed, as are maps of cumulative impacts that show variation in impact severity when stressors are combined.

The majority of human activities in Hawai‘i take place in and adjacent to the nearshore environment.

Ph. Pixabay

Efforts to quantify spatial variation in cumulative impacts have been advancing over the past decade. Lecky (2016) developed the first comprehensive spatial database of human stressors and led a panel of experts to determine nearshore habitat vulnerability to each of these stressors. The 3 dominant nearshore marine habitat types in Hawaiʻi are, in order of expert-assessed vulnerability (highest to lowest): coral reefs (coral-dominated hard bottom), rocky areas (other hard bottom), and sandy or muddy areas (soft bottom). Experts individually rated the vulnerability of habitats to each stressor based on 4 vulnerability criteria (frequency, trophic impact, percent change, and recovery time) and determined their certainty for each rating. Among the most highly rated stressors for coral reefs were reef fish fishing, wastewater pollution, and sediment input (see Table A8 for full list of stressors and vulnerability scores). The cumulative impact score for any area (100 m grid cells) is based on the vulnerability-weighted sum of 16 individual stressor intensities for the habitat type present in that area.

The maps presented in this section represent the first-ever assessment of spatial variation in cumulative impacts to nearshore ecosystems for the main Hawaiian Islands. There are many ways these data can support, shape, and target resource management and conservation efforts to support reef and community resilience. The results represent a baseline of comprehensive human impact information for Hawaiʻi and can be updated as new data sets and improved information on nearshore stressors become available. Please see our Hawaiʻi IEA online map viewer to explore in detail the cumulative impact and individual stressor data layers for each of the Hawaiian Islands.

Spatial Patterns of Human Impacts

There is considerable spatial variation in cumulative human impacts across the main Hawaiian Islands (Fig. 5.1). The most impacted area is the highly developed south shore of Oʻahu between Diamond Head and Pearl Harbor. Almost every stressor co-occurred there; many at or near maximum intensity (e.g., direct human impact, fishing, habitat destruction, invasive algae, and urban runoff). While historically this area was likely coral dominated, the south shore of Oʻahu is predominantly a rocky reef habitat (i.e., other hard bottom), which is a relatively low vulnerability habitat type. However, enough stressors overlap with great enough intensity to produce the highest cumulative impact values in the MHI. Additional areas with high cumulative impacts include Hilo Harbor (Hawaiʻi Island) and Kahului (Maui). These locations consist primarily of low vulnerability habitat (i.e., non-coral dominated hardbottom or softbottom) but experience numerous human stressors including shipping activity, habitat destruction, land-based pollution, and fishing. There are also high cumulative impact scores along west Hawaiʻi which provides an interesting contrast to south shore Oʻahu. West Hawaiʻi is almost entirely coral reef, which is the most vulnerable habitat type to human stressors. In south Kohala, for example (see inset maps Fig. 5.1), there were relatively fewer stressors co-occurring with extreme values compared to south Oʻahu. But coral reef habitat is more vulnerable, so the cumulative impact scores are comparable to parts of south Oʻahu.

The west side of Niʻihau, northwest Kauaʻi, west Molokaʻi, west Lānaʻi, and Kahoʻolawe had the lowest cumulative impacts. Sandy bottom areas, such as areas along west Maui, had low cumulative impact scores in part because this habitat type has the lowest vulnerability. The deep reefs offshore of south Maui also had low cumulative impact values, reflecting a general trend of decreasing impact with increased depth and distance from shore.

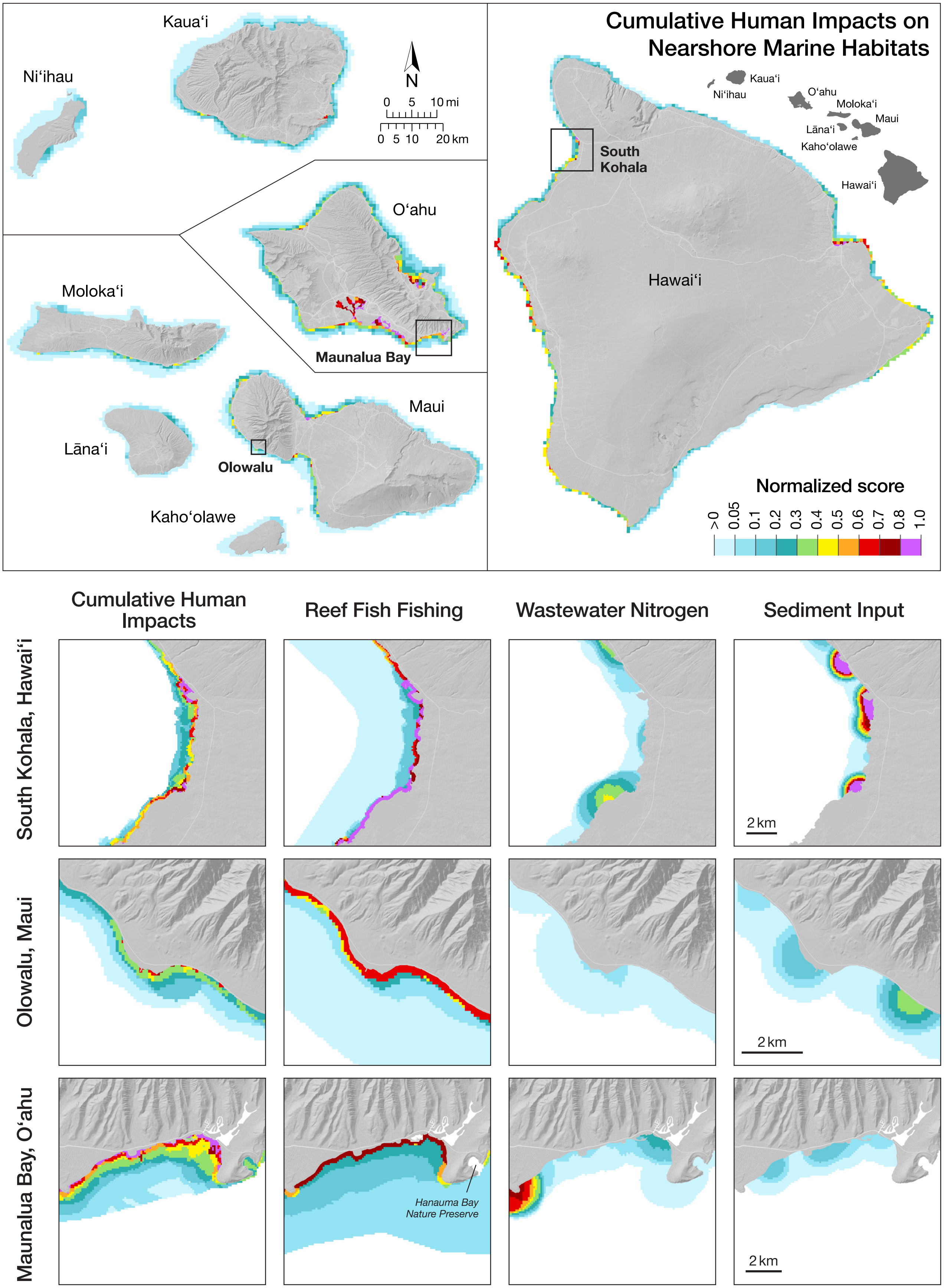


Fig. 5.1. Cumulative human impacts on the nearshore environment across the MHI scaled to 1 km resolution (top map). Maps for 3 special areas of interest showing the high-resolution values for (100 m) cumulative impacts and 3 of the underlying stressors. These focus areas highlight that levels of impact for individual stressors can be very different for areas with similar cumulative impact scores (bottom map).

We selected special geographic areas of interest in consultation with the Hawaiʻi Division of Aquatic Resources to showcase that different areas can have similarly high cumulative impact but very different levels of impact from the underlying individual stressors (Fig. 5.1). The 3 areas of interest—south Kohala (Hawaiʻi), Olowalu (Maui), and Maunalua Bay (Oʻahu)—each had reef fish fishing pressure that was greatest nearshore and decreased further offshore. This inshore-offshore gradient is characteristic of many of the individual stressors underlying the cumulative impact scores.

Impacts from wastewater pollution were greater in South Kohala and western Maunalua Bay compared to Olowalu. This difference is largely due to the high density of cesspools and septic tanks in the community of Puakō in South Kohala, and Black Point in the western end of Maunalua Bay. Cesspool conversion efforts by the state are ongoing with the goal to eliminate all cesspools through upgrades to better performing onsite technologies or connection to sewage systems by 2050.

Sediment input was greater in South Kohala than in Olowalu or Maunalua Bay. The high sediment input to the nearshore marine environment is at least partly due to uncontrolled grazing by feral goats which has decreased native vegetation that would otherwise stabilize sediment. Restoration to mitigate land-based runoff in South Kohala is ongoing, led by a consortium of community, state, and federal agencies known as the South Kohala Coastal Partnership.

Details on the methods, habitat vulnerability scores for each of the underlying human stressors, and the distribution of cumulative impacts can be found in the appendices at the end of this report.

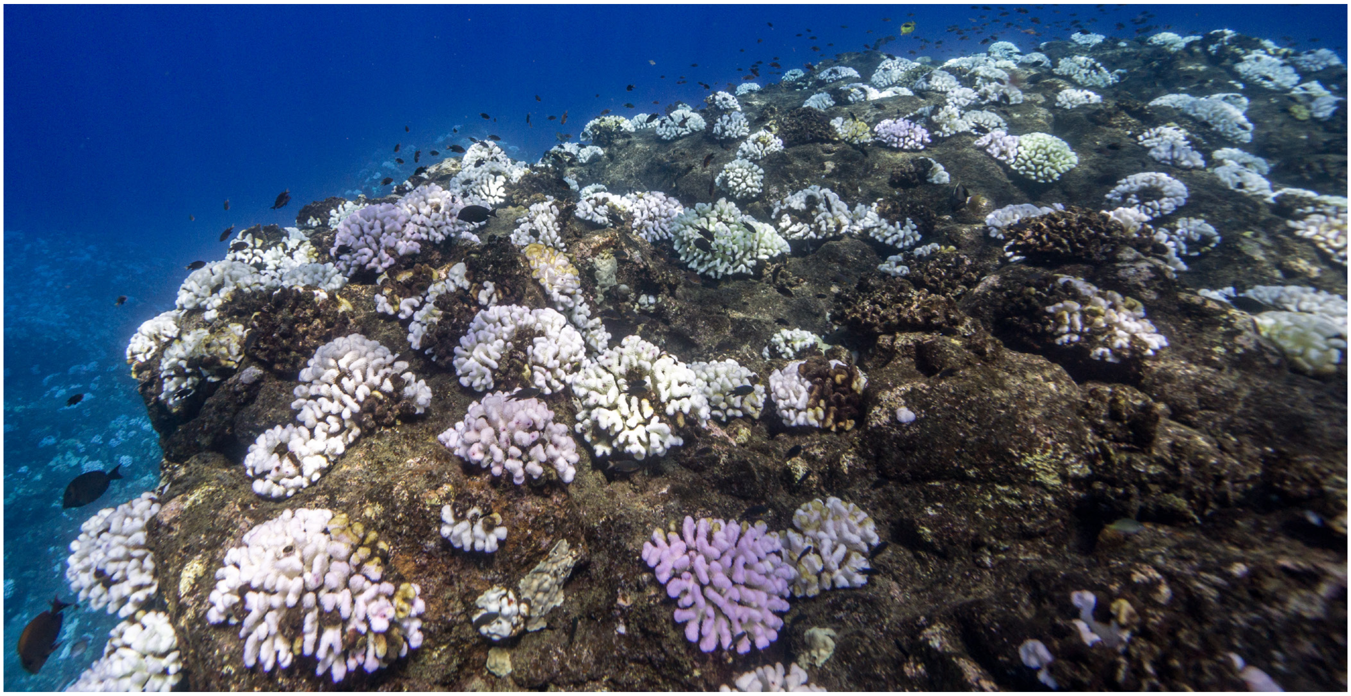
Soil erosion from poorly managaged land is an important source of pollution in South Kohala. Ph. South Kohala Coastal Partnership

6. Vulnerability of Coral Reefs to Climate Change

Summary: *There will be significant spatial variation in climate change impacts to coral reefs, driven by differences within and among reefs in climate vulnerability. Conservation and management actions that account for climate vulnerability can give reefs the best chance to continue to function and provide ecosystem and cultural services. Coral reef vulnerability was assessed for reef sites in the MHI by combining information on human impacts, ecological resilience, and projected future exposure to climate impacts. This section describes climate model projections of future exposure to coral bleaching and the results of inter-island and intra-island assessments of the climate vulnerability of coral reefs.*

Introduction

Climate change poses a critical threat to coral reef ecosystems (Hughes et al. 2018). More severe storms are expected, and the ocean will become more acidic, making it harder for corals and reef calcifiers to grow and keep pace with rising sea levels (van Hooidonk et al. 2014). Climate change is also expected to increase the frequency and severity of coral bleaching events caused by higher-than-normal seawater temperatures (van Hooidonk et al. 2016). Coral bleaching is a stress response caused by the breakdown of the symbiotic relationship between coral and the algae (zooxanthellae) that live in its tissues (Glynn 1993). The loss of the symbiotic algae leaves the coral skeleton visible, giving it a pale or "bleached" appearance. Bleached corals may eventually die if ocean temperatures remain high and the symbiosis is not re-established (Brown 1997).



Coral bleaching occurs when higher-than-normal temperatures cause the loss off colorful symbiotic algae.

Ph. Paul Cox

There will be significant spatial variation in climate impacts to coral reefs, driven by differences within and among reefs in climate vulnerability. Reef areas with lower relative vulnerability are conservation priorities (Maynard et al. 2017). The benefits of management actions could be greater, and management may be more successful in low vulnerability areas than in high-vulnerability areas. Reef restoration is also more likely to be successful in low vulnerability areas since short- and long-term coral survivorship may be greater (Foo and Asner 2019; Shaver et al. 2020). Specific and targeted conservation and management actions that account for climate vulnerability can give reefs the best chance to continue to function and provide ecosystem and cultural services.

The vulnerability of a coral reef to climate change depends on the frequency and severity of climate disturbances, such as marine heatwaves. Vulnerability also depends on sensitivity, which is a combination of coral reef resilience and whether resilience is compromised by human impacts (Turner et al. 2003). This section describes a climate vulnerability assessment for the coral reefs of Hawaiʻi, based on: 1) the cumulative human impacts reviewed in the previous section of this report (Fig. 5.1); 2) an assessment of reef resilience using NOAA NCRMP coral reef and reef fish surveys conducted in 2016 and 2019 (see Figs. 3.1 and 3.4, and the Appendix for resilience assessment results); and 3) climate model projections of future exposure to coral bleaching impacts (Fig. 6.1).

Healthy populations of herbivorous fish can make reefs more resilient to the impacts of climate change.

Ph. Paul Cox

Future Climate Change Impacts to Reefs

A global team supported by the NOAA IEA and United Nations Environment Programme (UNEP) developed projections of future exposure to thermal stress severe enough to cause coral bleaching (global results are presented in van Hooidonk et al. 2020). The current generation (CMIP6) of IPCC climate models was used to project dates when reefs will begin to experience thermal stress severe enough to cause bleaching on an annual basis (referred to here as ‘annual severe coral bleaching’ (ASB) and represents exceedance of eight Degree Heating Weeks). Model-resolution (0.25 degree) results were then downscaled to 5 km. Projections were developed using the fossil-fuel aggressive emissions scenario that characterizes current emissions concentration and growth rates—Shared Socioeconomic Pathway (SSP) 5-8.5. Projected ASB dates for SSP5-8.5 were then compared with projections developed for SSP2-4.5, which assumes climate policy is effective and gains momentum. SSP2-4.5 is considered ambitious but plausible (van Hooidonk et al. 2020).

The MHI-wide average for the projected dates of annual severe bleaching under SSP5-8.5 is 2048. Projected ASB dates range from 2030 to 2066 across the MHI and at each of the islands of Hawaiʻi, Oʻahu, Maui, and Kauaʻi. The roughly 30-year range in the projected timing of ASB indicates there are reefs at each of these islands that have decades more time to adapt and acclimate to climate change than others. Across the MHI, ASB is projected to occur earliest along the windward coastlines such as east Hawaiʻi Island, northeast Oʻahu, and northeast Maui. ASB is projected to occur latest in west Hawaiʻi, southwest Maui, and southwest Oʻahu (Fig. 6.1).

To assess the influence of climate policy on future ocean temperatures projected for the MHI, we compared the emissions scenario that assumes continued and increased fossil fuel use (SSP5-8.5) with the scenario that assumes effective implementation of global climate policy (SSP2-4.5). Differences in emission scenarios for the projected onset of ASB ranged from zero to 28 years across the MHI. Locations where differences between the scenarios are less than 10 years are principally located along windward shorelines, including east Hawaiʻi Island, northeast Oʻahu and Maui, north Molokaʻi, and most of Niʻihau. Locations where differences between the scenarios are greater than 20 years are concentrated mostly along leeward coastlines, such as northwest Hawaiʻi Island, southwest Maui, and southwest Oʻahu.

Differences in ASB timing between the scenarios represent the relative benefits of climate policy that reduces emissions for coral reefs. These results highlight that climate policy benefits some reefs much more greatly than others, in terms of providing additional time to adapt and acclimate to climate change. The projections and scenario comparisons highlight the critical threat of climate change to reefs and that effective policy to reduce emissions is needed and will buy decades of time for some reefs.

Spatial variation in projected ASB dates, with variation in human impacts (Fig. 5.1) and resilience (see Appendix), combine to create great variation among reefs in relative climate vulnerability.

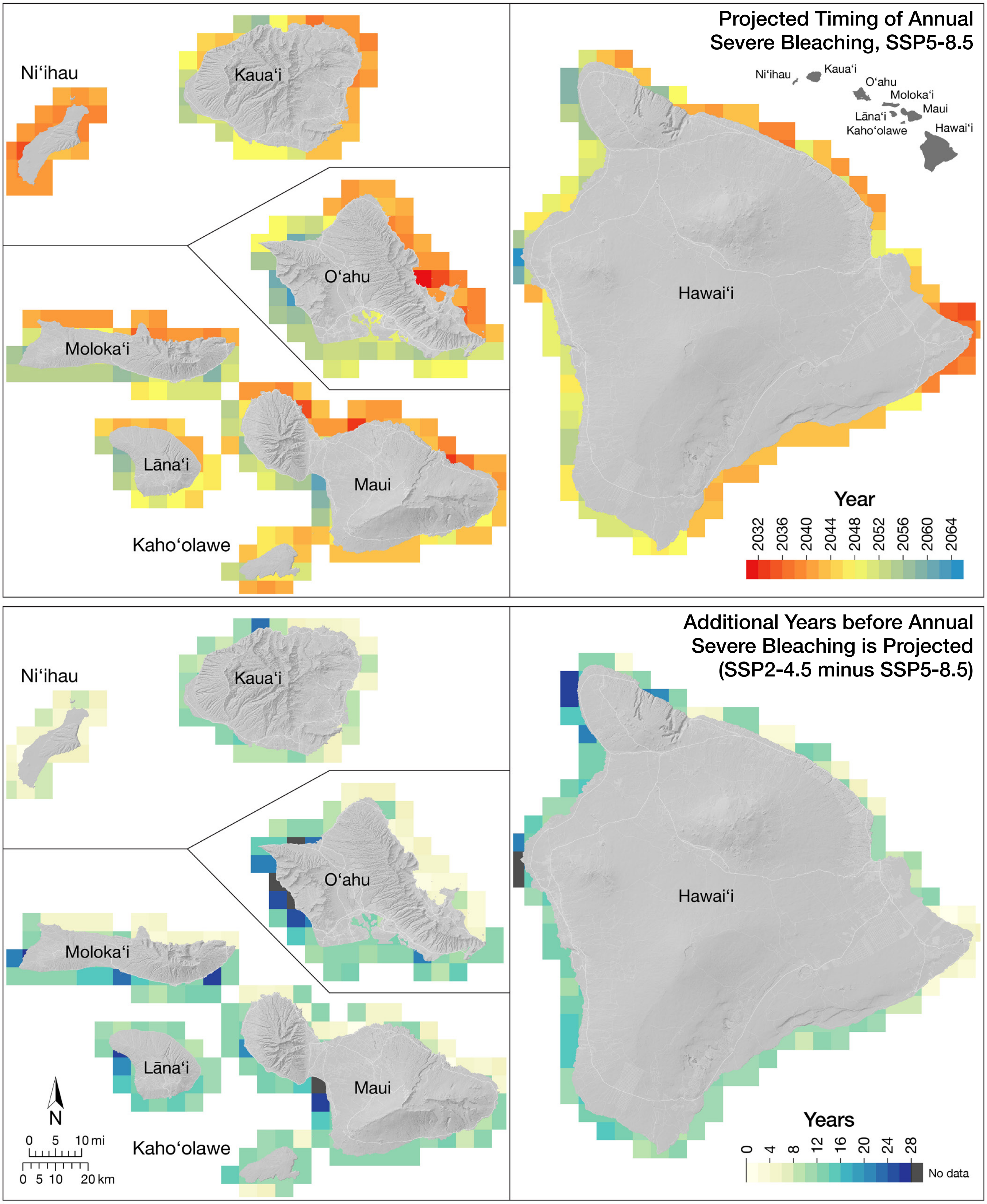


Fig. 6.1. Climate model projections (5-km scale) of the timing of annual severe bleaching (ASB) under the fossil-fuel aggressive emissions scenario SSP5-8.5 (top map). SSP5-8.5 characterizes current emissions concentrations and growth, while SSP2-4.5 assumes climate policy is highly effective and rapidly gains momentum. Projected ASB timing under these two scenarios is compared by subtracting SSP5-8.5 from SSP2-4.5. Comparing the scenarios (bottom map) quantifies the relative benefits of climate policy for reefs in Hawai‘i in terms of increased time to adapt and acclimate to climate change.

Climate Vulnerability

The vulnerability of a coral reef to climate change depends on the frequency and severity of climate disturbances, such as marine heatwaves. Vulnerability also depends on sensitivity, which is a combination of coral reef resilience and whether resilience is compromised by human impacts (Turner et al. 2003). Vulnerability of coral reefs to climate change in the MHI was assessed at the individual island scale and the all-islands (MHI) scale. Scores or values for each of human impacts (Fig. 5.1), ecological resilience (Fig. A2), and projected future exposure to bleaching (Fig. 6.1) were all set to a logical scale where a low score always means lower relative vulnerability. Scores were then averaged and normalized so that the vulnerability of each reef site is assessed as relative to the site with the lowest vulnerability.

We assessed climate vulnerability at 428 individual coral reef sites across the MHI. These sites were surveyed by the NOAA National Coral Reef Monitoring Program in 2019 (see section 3. Coral Reefs and Reef Fish, and Figures 3.1 and 3.4). Vulnerability was assessed relative to all sites in the MHI (the inter-island assessment) and assessed as relative only to sites at an individual island (intra-island assessment). Site numbers for each island are as follows: Kaua‘i (26), Ni‘ihau (21), O‘ahu (75), Moloka‘i (56), Maui (54), Lāna‘i (47), Kaho‘olawe (26), and Hawai‘i Island (123).

Inter-island or ‘all-islands’ assessment

There are low vulnerability sites at all islands except O‘ahu and Ni‘ihau. The greatest percentages of low vulnerability sites are on Lāna‘i, Moloka‘i, and Kaho‘olawe (Fig. 6.2). At these islands, greater than 30% of the sites surveyed had low relative vulnerability. There are low vulnerability sites all around Lāna‘i and Kaho‘olawe. In Moloka‘i, low vulnerability sites are concentrated on the southern side. Roughly 15% of the sites surveyed on Maui (9 of 54) had low relative vulnerability and all are in the southwest near Kīhei and Olowalu. Less than 5% of the sites on Hawai‘i and Kaua‘i had low relative vulnerability (2 of 123 and 1 of 26, respectively).

There are high vulnerability sites at Hawai‘i, Kaua‘i, Ni‘ihau, and O‘ahu. There are no high vulnerability sites on Kaho‘olawe, Lāna‘i, or Moloka‘i. The greatest percentages of high-vulnerability sites are on Hawai‘i Island (25%; 31 of 123), O‘ahu (24%; 18 of 75), and Kaua‘i (20%; 5 of 26).

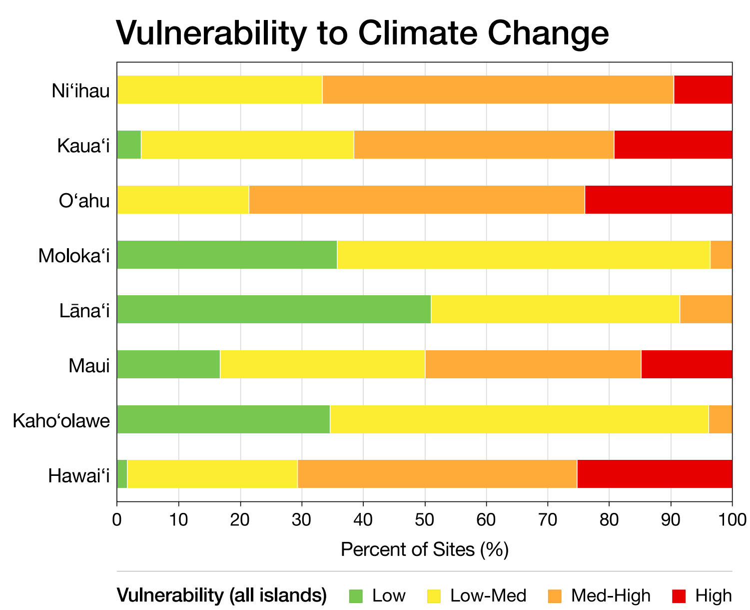


Fig. 6.2. Percent of sites at each island in each of the classes for relative coral reef vulnerability to climate change in the inter-island or ‘all-islands’ assessment (see Fig. 6.3 for map). The greatest percentage of low vulnerability sites is in Lāna‘i (52%), and the greatest percentage of high vulnerability sites is in O‘ahu and Hawai‘i Island (~25%).

High vulnerability sites on Hawai‘i Island are in west Hawai‘i, south of Kailua-Kona and in eastern Hawai‘i near Hilo and Pahoa. There are high vulnerability sites all around O‘ahu. High vulnerability sites on Kaua‘i are in the south and southeast. Between 10 and 15% of the sites surveyed in Ni‘ihau (2 of 21; on the northern side) and Maui (8 of 54; far south and northwest) had high relative vulnerability.

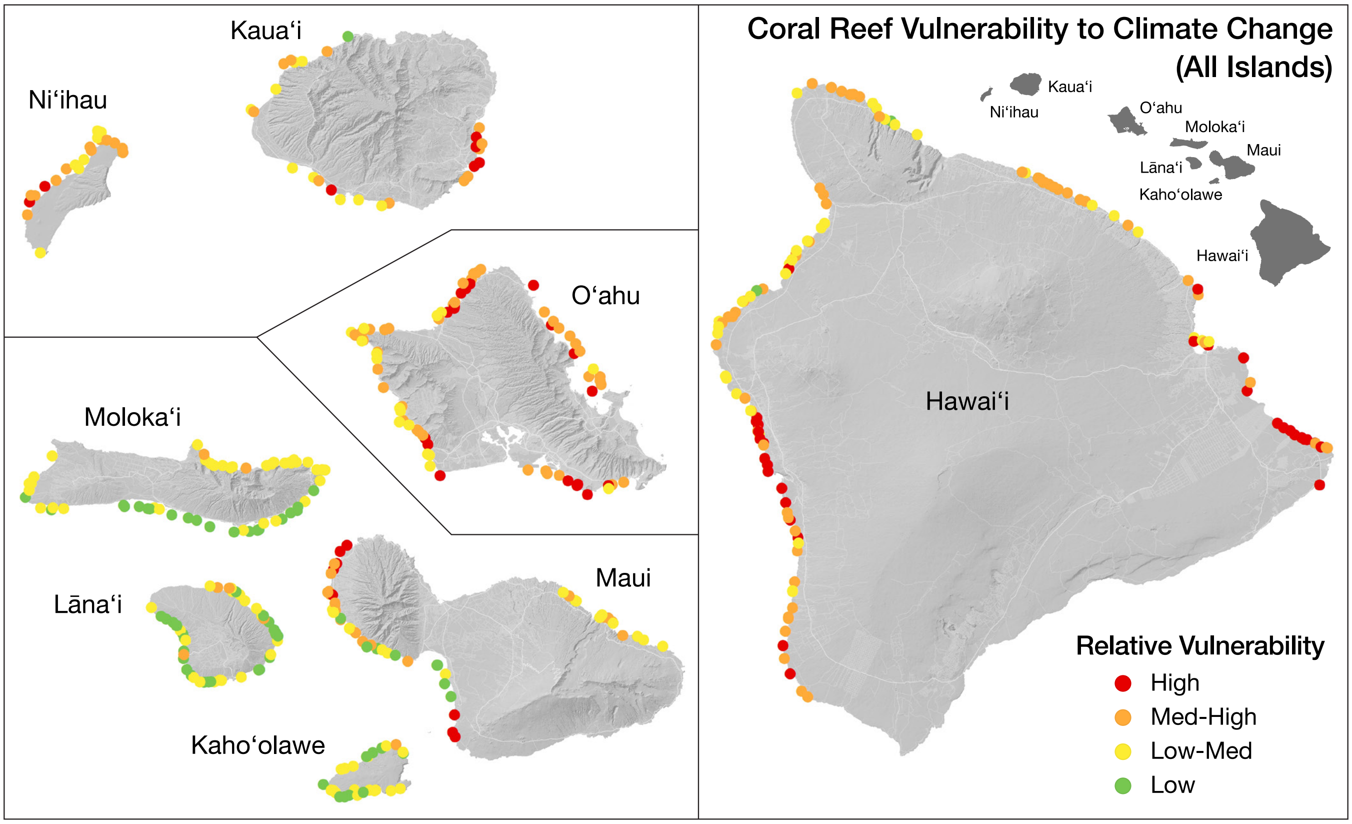
Intra-island assessment

Climate vulnerability varies greatly at the island-scale, highlighting the importance of accounting for vulnerability in island-scale conservation and management decision making. There are sites in each relative category—low, medium-low, medium-high, and high—on all islands in the intra-island assessment.

On Hawai‘i Island, sites with the lowest relative vulnerability are mostly in west Hawai‘i, north of Kailua Kona. Sites with the highest relative vulnerability are south of Kailua Kona in west Hawai‘i and near Hilo in eastern Hawai‘i. On Maui, sites with lower relative vulnerability are in the southwest near Kīhei, and sites with higher relative vulnerability are in the far south and far northwest. On O‘ahu, there are high vulnerability sites everywhere except the far western portion of the island (Kaena Point). On Kaua‘i, sites with lower relative vulnerability are in the northwest and southwest, and sites with higher relative vulnerability are concentrated in the east.

Fringing reef on the south coast of Moloka‘i.

Ph. USGS



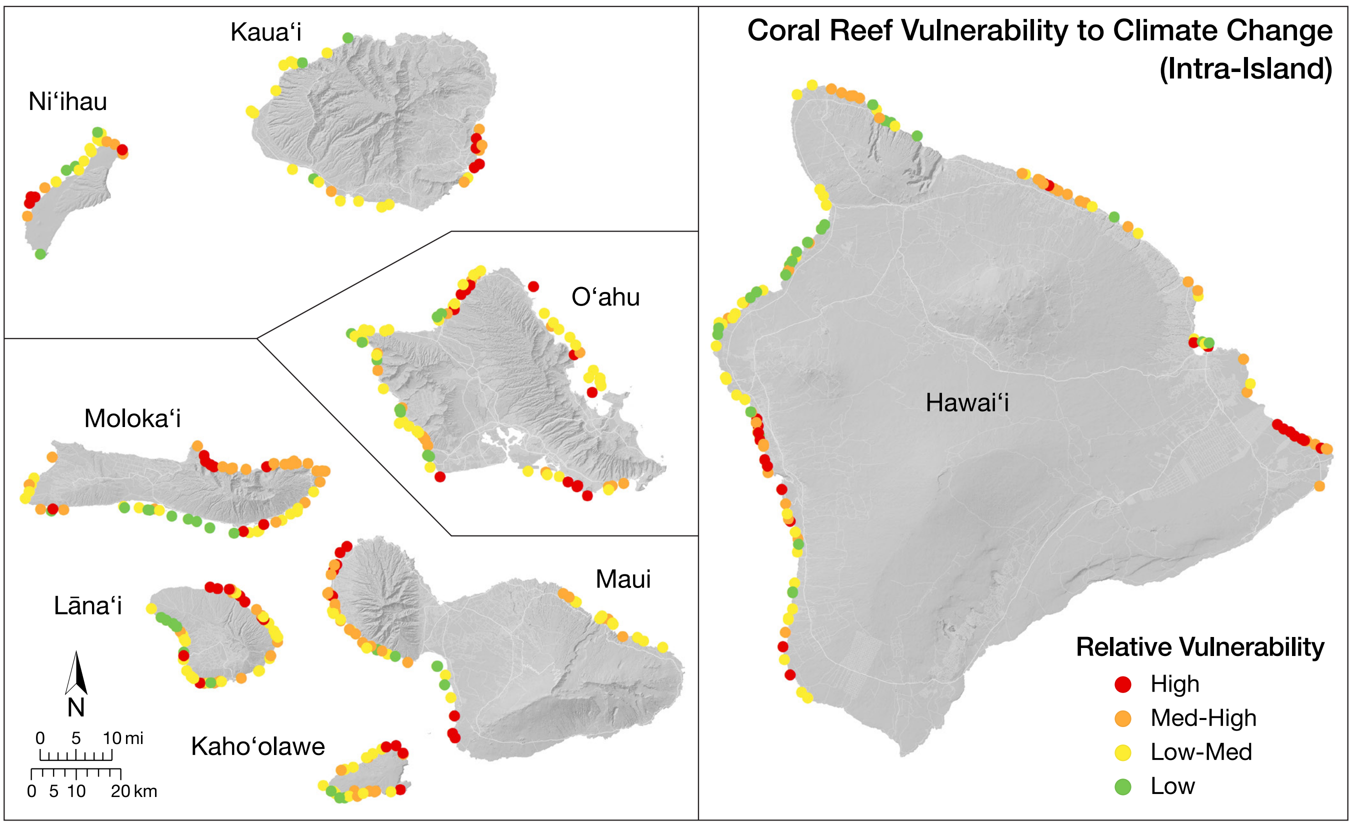


Fig. 6.3. Inter-island (top map) and intra-island (bottom map) assessments of coral reef vulnerability to climate change at 428 sites surveyed in 2019 by NOAA NCRMP. Vulnerability scores were generated by combining scores or values for human impacts (see Fig. 5.1), resilience (see Appendix), and projected future exposure to bleaching impacts (see Fig. 6.1).

Next Steps

The key theme of this report is strong connections; the human-land-sea connections between people and place, climate change and ecological communities, human activities and ecosystem health, and many more. This theme is also relevant for applying and building upon the findings in this report. Strong connections, especially collaborations and partnerships among government, academic, non-governmental organizations and communities, are necessary for setting and achieving effective management and conservation goals. Only through such strong connections can we ensure the ocean environment in Hawaiʻi continues to support human well-being in our changing climate.

All sections of this report contain data and information that can be improved and expanded upon in the coming years. In this sense, the report sections are launching pads for near-future research that can support and inform management and conservation. Research areas likely to be especially promising for improving human well-being and informing management include, from each report section:.

1. Identifying pathways to positively influence cultural values, meanings, and other intangible benefits from ecosystems;
2. Identifying causes and consequences of decline in small boat fisher catch to help mitigate future community level impacts;
3. Developing more detailed understanding of reef and reef fish change across space and through time and the associated effects on human connections that contribute to human well-being in Hawaiʻi;
4. Understanding and mitigating impacts of changing rainfall patterns, rising sea levels, and increasing ocean temperatures on marine ecosystems in Hawaiʻi;
5. Understanding and mitigating the cumulative impacts of land- and sea-based stressors on coastal ecosystems, and developing targeted actions that reduce habitat vulnerability;
6. Expanding climate change vulnerability assessments to include additional ecosystems and marine species and integrating results into management planning efforts.

Acknowledgements

We wish to acknowledge NOAA's National Integrated Ecosystem Assessment (IEA) for funding the development of the 2022 Hawai'i Ecosystem Status Report and for the continued support of the Hawai'i IEA program. We thank the numerous field staff and data contributors to this report, including: the coral reef benthic and fish teams from PIFSC's Ecosystem Sciences Division; the crew and officers of the NOAA Vessels Hi'ialakai and Oscar Elton Sette; the National Coral Reef Monitoring Program socioeconomic field teams; and Bradley Gough and Dios Gonzales of PIFSC's Fisheries Research and Monitoring. We would also like to thank Keali'i Sagum and Anita Tsang for their assistance with Hawaiian names for fish species, and Thomas Oliver and Beth Lumsden for their insightful comments and edits to earlier versions of this report. The National Coral Reef Monitoring Program is funded by NOAA's Coral Reef Conservation Program, project #743. The 2022 Ecosystem Status Report for Hawai'i represents IEA contribution number 2022_6.

References

Allen M, Fleming C, Zito B, Gonyo S, Regan S, Towle E. 2022. National Coral Reef Monitoring Program Socioeconomic Monitoring Component: Summary Findings for Hawaiʻi, 2020 U.S. Dep Commerce, NOAA Tech Memo, NOAA_TM_NOS_CRCP-43 51p + Appendices.

Allen S. 2013. Carving a niche or cutting a broad swath: Subsistence fishing in the western Pacific. Pac Sci. 67 (3):477–488.

Asner GP, Vaughn NR, Martin RE, Foo SA, Heckler J, Neilson BJ, Gove JM. 2022. Mapped coral mortality and refugia in an archipelago-scale marine heat wave. PNAS. 119 (19): e2123331119.

Boggs CH, Ito RY. 1993. Hawaiʻi's Pelagic Fisheries. Mar Fish Rev. 55 (2), 69–82.

Brandl SJ, Rasher DB, Côté IM, Casey JM, Darling ES, Lefcheck JS, Duffy JE. 2019. Coral reef ecosystem functioning: eight core processes and the role of biodiversity. Front Ecol Environ. 17 (8):445–454.

Brown BE. 1997. Coral bleaching: causes and consequences. Coral Reefs 16 (5):S129–S138.

Chan HL, Pan M. 2017. Economic and social characteristics of the Hawaiʻi small boat fishery 2014. NOAA Tech Memo NMFS-PIFSC-63, 107 p.

Couch CS, Burns JHR, Liu G, Steward K, Gutlay TN,.Kenyon J, Eakin CM,. Kosaki RK. 2017. Mass coral bleaching due to unprecedented marine heatwave in Papahānaumokuākea Marine National Monument (Northwestern Hawaiian Islands). Plos One 12 (9): e0185121.

Crain CM, Kroeker K, Halpern BS. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol Lett. 11 (12):1304–1315.

Delaney DG, Teneva LT, Stamoulis KA, Giddens JL, Koike H, Ogawa T, Friedlander AM, Kittinger JN. 2017. Patterns in artisanal coral reef fisheries revealed through local monitoring efforts. PeerJ 5:e4089.

Di Lorenzo E, Mantua N. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nat Clim Change. 6:1042.

Dillard MK,. Goedeke TL, Lovelace S, Orthmeyer A. 2013. Monitoring well-being and changing environmental conditions in coastal communities: development of an assessment method. NOAA Tech Memo NOS NCCOS; 174.

Donovan MK, Burkepile DE, Kratochwill C, Shlesinger T, Sully S, Oliver TA, Hodgson G, Freiwald J, van Woesik R. 2021. Local conditions magnify coral loss after marine heatwaves. Science 372 (6545):977–980.

Eldredge LG, Evenhuis NL. 2003. Hawaii's biodiversity: a detailed assessment of the numbers of species in the Hawaiian Islands. Bishop Museum Honolulu, HI, Bishop Museum Press. ISSN 0893-1348. 76,1–28.

Fabricius KE. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Mar Pollut Bull.50, 125–146.

Falinski KA. 2016. Predicting sediment export into tropical coastal ecosystems to support ridge to reef management, University of Hawaiʻi at Manoa.

Foo SA, Asner GP. 2019. Scaling up coral reef restoration using remote sensing technology. Front Mar Sci. 6 (79).

Friedlander AM, Donovan MK, Stamoulis KA, I. D. Williams ID, Brown EK, Conklin EJ, DeMartini EE, Rodgers KS, Sparks RT, Walsh WJ. 2018. Human-induced gradients of reef fish declines in the Hawaiian Archipelago viewed through the lens of traditional management boundaries. Aquat Conserv. 28 (1):146–157.

Giambelluca TW, Chen Q, Frazier AG, Price JP, Chen Y-L., Chu P-S, Eischeid JK, Delparte DM. 2012. Online rainfall atlas of Hawaiʻi. Bull Am Meteorol Soc. 94 (3):313–316.

Glynn PW. 1993. Coral reef bleaching: ecological perspectives. Coral Reefs 12 (1):1–17.

Gorstein, M, Loerzel J, Levine A., Edwards P, Dillard M. 2018. National Coral Reef Monitoring Program Socioeconomic Monitoring Component: Summary Findings for Hawaiʻi, 2015. U.S. Dep. Commerce, NOAA Tech Memo, NOAA-TM-NOS-CRCP-30, 69 p. + Appendices.

Gove JM, Lecky J, Walsh WJ, Ingram RJ, Leong K, Williams ID, Polovina JJ, Maynard J, Whittier R, Kramer KIL, et al. 2019. West Hawai ʻi Integrated Ecosystem Assessment Ecosystem Status Report. PIFSC Special Publication SP-19-001, 46 p.

Gove JM, Polovina JJ, Walsh WJ, Heenan A, Williams ID, Wedding LM, Ingram RJ, Lecky J, Oleson K, Walecka HR, et al. 2016. West Hawaiʻi Integrated Ecosystem Assessment: Ecosystem Trends and Status Report. PIFSC Special Publication SP-16-004, 47 p.

Gorospe KD, Donahue MJ, Heenan A, Gove JM, Williams ID, Brainard RE. 2018. Local biomass baselines and the recovery potential for Hawaiian coral reef fish communities. Front Mar Sci. 5.

Halpern BS, Lester SE, McLeod KL. 2010. Placing marine protected areas onto the ecosystem-based management seascape. PNAS. 107 (43):18312–18317.

Halpern BS, Selkoe KA, Micheli F, Kappel CV. 2007. Evaluating and ranking the vulnerability of global marine ecosystems to anthropogenic threats. Conserv Biol.21 (5):1301–1315.

Hamel P, Chaplin-Kramer R, Sim S, Mueller C. 2015. A new approach to modeling the sediment retention service (InVEST 3.0): Case study of the Cape Fear catchment, North Carolina, USA. Sci Total Environ. 524–525,166–177. doi:10.1016/j.scitotenv.2015.04.027.

Hawaiʻi Climate Change Mitigation and Adaptation Commission. 2017. Hawaiʻi Sea Level Rise Vulnerability and Adaptation Report. Prepared by Tetra Tech, Inc. and the State of Hawaiʻi. Department of Land and Natural Resources, Office of Conservation and Coastal Lands, under the State of Hawaiʻi Department of Land and Natural Resources Contract No: 64064. https://climateadaptation.hawaii.gov/wp-content/uploads/2017/12/SLR-Report_Dec2017.pdf.

Heenan A, Williams ID, Acoba T, DesRochers A, Kosaki RK, Kanemura T, Nadon MO, Brainard RE. 2017. Long-term monitoring of coral reef fish assemblages in the western central pacific. Sci Data. 4 (1):170176.

Heron SF, Maynard JA van Hooidonk R, Eakin CM. 2016. Warming trends and bleaching stress of the world's coral reefs 1985–2012. Sci Rep. 6 (1):38402.

Hospital J, Beavers C. 2011. Management of the main Hawaiian Islands bottomfish fishery: fishers' attitudes, perceptions, and comments. Pacific Islands Fisheries Science Center Administrative Report H-11-06.

Hospital,J, Leong K. 2021. Community participation in Hawaiʻi commercial fisheries. NOAA Tech Memo NOAA-NMFS-PIFSC-89, 213.

HTA. 2019. Annual Visitor Research Report. Hawaiʻi Tourism Authority. https://www.hawaiitourismauthority.org/media/5062/2019-annual-report-final-for-posting.pdf.

HTA. 2022. Monthly Visitor Statistics. Hawaiʻi Tourism Authority. https://www.hawaiitourismauthority.org/research/monthly-visitor-statistics.

Hughes TP, Kerry JT, Baird AH, Connolly SR, Dietzel A, Eakin CM, Heron SF, Hoey AS, Hoogenboom MO, Liu G. et al. 2018. Global warming transforms coral reef assemblages. Nature 556 (7702):492–496.

Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschaniwskyj N, MS, Steneck RS, Willis B. 2007. Phase shifts, herbivory, and the resilience of coral reefs to climate change. Curr Biol. 17 (4):360–365.

Ingram RJ, Leong KM, Gove J, Wongbusarakum S. 2020. Including human well-being in resource management with cultural ecosystem services. U.S. Dept of Commerce, NOAA Tech Memo NOAA-TM-NMFS-PIFSC-112, 94 p. doi: 10.25923/q8ya-8t22.

Ingram RJ, K. Oleson LL, JM. 2018. Revealing complex social-ecological interactions through participatory modeling to support ecosystem-based management in Hawaiʻi. Mar Pol.94:180–188.

Itano DG. 1999. Hawaiʻi offshore handline fishery: a seamount fishery for juvenile bigeye tuna. 11th Meeting of the Secretariat of the Pacific Community's Standing Committee on Tuna and Billfish. January 1999. https://spccfpstore1.blob.core.windows.net/digitallibrary-docs/files/f4/f47f67cf305e48cd59da173d175848fe.pdf

Ives CD, Abson DJ, von Wehrden H, C. Dorninger, K. Klaniecki, and J. Fischer. 2018. Reconnecting with nature for sustainability. Sustainability Science 13 (5):1389-1397.

Kane C, Kosaki RK, Wagner D. 2014. High levels of mesophotic reef fish endemism in the Northwestern Hawaiian Islands.Bull Mar Sci., 90(2), 693–703.

Kappel CV, Halpern BS, Selkoe KA, Cooke RM. 2012. Eliciting Expert Knowledge of Ecosystem Vulnerability to Human Stressors to Support Comprehensive Ocean Management. In Expert Knowledge and Its Application in Landscape Ecology, edited by A. H. Perera, C. A. Drew, and C. J. Johnson. New York, NY: Springer New York, 253–277.

Kosanic A, Petzold J. 2020. A systematic review of cultural ecosystem services and human wellbeing. Ecosyst Serv. 45:101168.

Lecky J. 2016. Ecosystem vulnerability and mapping cumulative impacts on Hawaiian reefs, University of Hawai'i at Manoa, Honolulu, Hawai'i.

Leong KM, Wongbusarakum S, Ingram RJ, Mawyer A, Poe MR. 2019. Improving representation of human well-being and cultural importance in conceptualizing the west Hawai'i ecosystem. Front Mar Sci.6 (13).

Markrich M, Hawkins C. 2016. Fishing fleets and fishery profiles: management – vessels – gear – economics. Pacific Islands Fishery Monographs. 5 September 2016. Western Pacific Regional Fishery Management Council. Honolulu, Hawai'i. 34 pp.

Maynard J, Conklin EJ, Minton D, Most R, Couch CS, Williams GJ, Gove JM, Tracey DP, Schumacher B, Walsh WA, et al.. 2016. Relative resilience potential and bleaching severity in the West Hawai'i Habitat Focus Area in 2015. NOAA Coral Reef Conservation Program. NOAA Tech Memo CRCP 26, 53 p. doi: 10.7289/V5T43R4Z

Maynard J, Marshall P, Parker B, Mcleod E, Ahmadia G, van Hooidonk R, Planes S, Williams GJ, Raymundo L, Beeden R. 2017. A guide to assessing coral reef resilience for decision support. Nairobi, Kenya: UN Environment.

McClanahanTR, Donner SD, Maynard JA, M. A. MacNeil MA, Graham NAJ, J. Maina J, Baker AC, Alemu I JB, Beger M, Campbell SJ, et al.. 2012. Prioritizing Key Resilience Indicators to Support Coral Reef Management in a Changing Climate. Plos One 7 (8):e42884.

McCoy KS, Williams ID, Friedlander AM, Ma H, Teneva L, Kittinger JN. 2018. Estimating nearshore coral reef-associated fisheries production from the main Hawaiian Islands. Plos One 13 (4):e0195840.

Minton D, Conklin E, Weiant P, Wiggins C. 2012. Forty years of decline on Puako's coral reefs: A review of historical and current data (1970–2010). The Nature Conservancy, 140.

Nadon MO. 2017. Stock assessment of the coral reef fishes of Hawai'i, 2016. NOAA Tech Memo NMFS-PIFSC; 60.

NMFS. 2021. U.S. Seafood industry and for-hire sector impacts from COVID-19: 2020 in perspective. NOAA Tech Memo. NMFS-SPO-221, 88 p.

Pacific Islands Fisheries Science Center (PIFSC). 2022. Hawai'i DAR Fisherman Reporting System Data (Fishers), https://www.fisheries.noaa.gov/inport/item/5609.

Philander SG. 1990. El Niño, La Niña and the Southern Oscillation. New York: Elsevier.

Polovina JJ, Mitchum GT, Graham NE, Craig MP, Demartini EE, Flint EN. 1994. Physical and biological consequences of a climate event in the central North Pacific. Fish Oceanogr. 3 (1):15–21.

Price N. 2010. Habitat selection, facilitation, and biotic settlement cues affect distribution and performance of coral recruits in French Polynesia. Oecologia 163 (3):747–758.

Randall J. 2007. Reef and shore fishes of the Hawaiian Islands: Sea Grant College Program. University of Hawai'i, Honolulu, Hawai'i.

Riahi K, van Vuuren DP, Kriegler E, Edmonds J, O'Neill BC, Fujimori S, Bauer N, Calvin K, Dellink R, Fricko O, et al. 2017. The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob Environ Change. 42:153–168.

Selkoe KA, Halpern BS, Toonen RJ. 2008. Evaluating anthropogenic threats to the Northwestern Hawaiian Islands. Aquat Conserv. 18 (7):1149–1165.

Shaver EC, Courtney CA, West JM, Maynard J, Hein M, Wagner C, Philibotte J, MacGowan P, McLeod I, Böstrom-Einarsson L, et al. 2020. A Manager's Guide to Coral Reef Restoration Planning and Design. NOAA Coral Reef Conservation Program. NOAA Tech Memo CRCP 36, 120 p.

Smith JE, Brainard R, Carter A, Grillo S, Edwards C, Harris J, Lewis L, Obura D, Rohwer F,. Sala E, et al. 2016. Re-evaluating the health of coral reef communities: baselines and evidence for human impacts across the central Pacific. Proceedings of the Royal Society of London B: Biological Sciences 283 (1822).

Syslo J, Brodziak J, Carvalho F. 2021. Stock assessment update for the main Hawaiian Islands Deep 7 Bottomfish Complex in 2021, with catch projections through 2025. NOAA Tech Memo NMFS-PIFSC; 118 p.

Teck SJ, Halpern BS, Kappel CV, Micheli F,. Selkoe KA, Crain CM, Martone R, Shearer C, J. Arvai J, Fischhoff B, et al. 2010. Using expert judgment to estimate marine ecosystem vulnerability in the California Current. Ecol Appl. 20 (5):1402–1416.

Towle EK, Donovan EC, Kelsey H, Allen ME, Barkley H, Blondeau J, Brainard RE, Carew A, Couch CS, Dillard MK, et al. 2022. A national status report on United States coral reefs based on 2012–2018 data from National Oceanic and Atmospheric Administration's National Coral Reef Monitoring Program. Front Mar Sci.8.

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N,. Kasperson JX, A. Luers A, Martello ML, et al. 2003. A framework for vulnerability analysis in sustainability science. PNAS100 (14):8074–8079.

van Hooidonk R, Maynard J, Grimsditch G, Williams G, Tamelander J, Gove J, Koldewey H, Ahmadia G, Tracey D, Hum K, et al. 2020. Projections of future coral bleaching conditions using IPCC CMIP6 Models: climate policy implications, management applications, and regional seas summaries. United Nations Environmental Programme.

van Hooidonk R, Maynard J, Tamelander J, Gove J, Ahmadia G, Raymundo L, Williams G, Heron SF, Planes S. 2016. Local-scale projections of coral reef futures and implications of the Paris Agreement. Sci Rep. 6:39666.

van Hooidonk R, Maynard JA, Manzello D, Planes S. 2014. Opposite latitudinal gradients in projected ocean acidification and bleaching impacts on coral reefs. Glob Change Biol. 20 (1):103–112.

Wedding LM, Lecky J, Walecka HR, Gove JM, Donovan MK, Falinski K, McCoy K, Friedlander AM, Jouffray JB, Kappel CV, et al. 2018. Advancing the integration of spatial data to map human and natural drivers on coral reefs. Plos One 13 (3).

Whittier RB, El-Kadi AI. 2014. Human health and environmental risk of onsite sewage disposal systems for the Hawaiian Islands of Kaua'i, Maui, Moloka'i, and Hawai'i Honolulu, Hawai'i: Hawai'i's Department of Health.

WPRFMC 2020. Annual stock assessment and fishery evaluation report for the Pacific Island Pelagic Fishery Ecosystem Plan 2019. Remington T, Fitchett M, Ishizaki A, DeMello J. (Eds.) Western Pacific Regional Fishery Management Council. Honolulu, Hawai'i 96813 USA. 372 p. + Appendices.

Appendices

Contents

Methods and data sources for each of the 6 main report sections:

Methods and Data Sources

1. Human Connections

Corresponding authors: Mary Allen and Erica Towle of NOAA CRCP/NCRMP; mary.allen@noaa.gov and erica.towle@noaa.gov

Human population density and growth: We quantified human population density using NASA Gridded Population of the World version 4. The dataset is available at 1-km resolution at 5-year intervals from 2000 through 2020 and can be downloaded from: https://sedac.ciesin.columbia.edu/data/collection/gpw-v4.

Resource use and Perceptions of Threats, Status, and Trends: The overall goal of the Socioeconomic Monitoring component of the National Coral Reef Monitoring Program (NCRMP) is to: “track relevant information regarding each jurisdiction’s population, social, and economic structure, the benefits of coral reefs and related habitats, the perceived impacts of society on coral reefs, and the impacts of coral management on communities” (Allen et al. 2022). The history of NCRMP socioeconomic monitoring, including development and refinement of indicators between 2012 and 2020, is described in detail within Allen et al. (2022). This report included data collected in 2020 that was then compared, where possible, to data collected in 2015. A telephone and online web survey of residents aged eighteen and older within the islands of Hawai‘i, Kaua‘i, Maui, and O‘ahu was conducted from March to June of 2020. The survey instrument is included in Appendix A, Figure 1, Section 2 of Allen et al. (2022). Respondents were invited to take an online web survey through mailed invitational letters and reminder post cards with telephone follow-up calls. Respondents could also choose to complete the survey via telephone. All surveys were offered to respondents in English. Of the 23,501 individuals contacted, a total of 2,700 surveys were completed (293 completed telephone surveys and 2,407 completed online web surveys), yielding an overall response rate of 11.5%. Data collection procedures and data weighting and trimming protocols are reviewed in Appendix B1 of Allen et al. (2022).

More information on the survey measures is provided in Appendix A of Allen et al. (2022) and Appendix B of Gorstein et al. (2018). Final results presented in the report include percent of residents participating in various activities on and near coastal ecosystems, familiarity with threats, and perceptions of the status and trends of ecosystem health indicators and crowding of beaches. All results for 2020 and 2015 were directly comparable with the exception of familiarity with threats. To compare familiarity with threats, familiarity was based on the combined 2015 scale values for “familiar” to “very familiar” and the 2020 scale values for “slightly familiar” to “extremely familiar.” Because these two scales were not directly comparable, some measurement error is associated with the familiarity results.

2. Small Boat Commercial Fishers

Corresponding authors: Justin Hospital of NOAA ESD; (justin.hospital@noaa.gov), and Kirsten Leong of NOAA PIFSC/IEA (kirsten.leong@noaa.gov).

This section reported on 3 fisheries (i.e., pelagic, Deep 7 bottomfish, and nearshore fish) and had two sections. Species included within each fishery for each section are listed within Table A1 of this Appendix.

Fishery engagement and regional quotient for revenue: The Fishing Engagement Index (FEI) measures community-level fishery participation (census county divisions (CCDs)) based on pounds landed, revenue, active commercial fishers, and seafood dealers within a community. FEI scores were generated and compared for each community, where scores of 1.0 or greater are defined as highly engaged. Development of the FEI index is described in detail within Hospital and Leong (2021). The Regional Quotient (RQ) reflects a community’s engagement in a fishery or a community’s importance to the fishery. Monitoring the Regional Quotient can provide valuable information outside of the FEI for fishery managers to target outreach and education, particularly in communities that lack elements important to the FEI (e.g., number of dealers or fishers) for them to be considered highly engaged. RQ for revenue values were adjusted for inflation. Development of the RQ index is described in detail within Hospital and Leong (2021).

Fishery Catch and Catch Per Trip: Daily summaries of total catch and number of trips for each fishery and fishery subgrouping were provided by the Pacific Islands Fisheries Science Center, Fisheries Research and Monitoring Division for all years between 1990 and 2021. Catch per trip was calculated as the total catch per fishing trip for each fishery and fishery subgrouping. All daily data were summed over the entire year to get a time series of annual catch and CPUE. Total catch was also provided by reporting blocks, which are classified as inshore, coastal, or offshore (see Figure 2.3 in the report). Annual average catch was calculated for the 1990–2014 and 2015–2019 time periods. Changes in catch were then calculated as 2015–2019 annual average catch –minus 1990–2014 annual average catch; positive values represent increases in catch while negative values represent decreases in catch over this time frame. The map figures (2.5, 2.7, and 2.9) in the report also note for each reporting block whether the annual average total catch from 2015 through 2019 was outside the bounds of the 1990–2014 annual averages +1SD.

3. Coral Reefs and Reef Fish

Corresponding authors: Courtney Couch (courtney.s.couch@noaa.gov) and Tye Kindinger (tye.kindinger@noaa.gov) of PIFSC/ESD.

The benthic and coral reef fish data were collected as part of NOAA's Rapid Assessment and Monitoring Program (2010–2012) and NOAA's National Coral Reef Monitoring Program (NCRMP) (2013–2019), which collects data on biological (e.g., benthic and fish), climatic, and socioeconomic indicators of coral reef ecosystems in U.S. states and territories (NOAA Coral Program, 2021). Coral reefs were surveyed at four different times between 2010 and 2019 across the MHI. A stratified random sampling scheme is used whereby the relative survey effort around each island is proportional to the area of hard-bottom reef habitat stratified by reef zone (all forereef in the MHI) and depth: shallow (> 0–6 m), moderate (> 6–18 m), and deep (> 18–30 m). Collected data were summarized to the stratum-level (habitat type) then pooled to the sector scale by weighting the mean estimates by the proportional stratum area (Heenan et al. 2017). Only sectors that had all 3 depth strata surveyed in all years were included in this analysis.

Sectors around each island were defined according to similarities in historically captured reef composition and geographic and environmental characteristics, such as those within leeward versus windward coastlines. Indicators for reefs include percent cover of hard corals, calcifiers cover, and reef-builder ratio. Indicators for reef fish include the total biomass of all reef fish, herbivorous fish biomass (e.g., parrotfish and surgeonfish), and resource fish biomass (e.g., moi, Polydactylus sexfilis; ʻōpelu, Decapterus macarellus; and ʻōmilu, Caranx melampygus).

The current status of a given indicator for each sector was calculated for the most recent survey year (2019). The status was either relatively 'low,' 'medium,' or 'high' based on whether that sector value was below, within, or above the mean ± 1 standard deviation among all 2019 MHI sectors which were calculated by bootstrapping with replacement (N = 10,000).

The direction of change through time was also assessed for each indicator at the sector scale. The direction of change was determined as either positive, negative, or no change with 95% confidence (mean ± 1.96*standard error) based on the difference between the most recent time period (2019) and whichever was the earliest time period of sampling in the sector (2010–2012 or 2013–2015). Differences in coral reef benthic and reef fish indicators across years may at least in part be attributed to differences in the number of sites and sectors surveyed each year (Table A2-A7 in Appendix for survey effort).

4. Climate and Ocean

Corresponding authors: Jamison Gove of NOAA PIFSC/IEA (jamison.gove@noaa.gov); Ruben van Hooidonnk of NOAA AOML and the University of Miami RSMAS (ruben.van.hooidonk@noaa.gov).

ENSO and PDO: The Multivariate ENSO Index was obtained from NOAA's Earth System Research Laboratory (https://www.esrl.noaa.gov/psd/enso/mei). The PDO index was obtained from NOAA's Centers for Environmental Information (https://www.ncdc.noaa.gov/teleconnections/pdo).

Rainfall patterns and brown water advisories: Daily, gap-filled rainfall (mm) for each airport was obtained from Longman et al. 2020. Daily data were summed over each year to produce an annual rainfall data set from 1990 - 2021. Peak rainfall was calculated as the percentage of annual rain over the 5 rainiest days in each year. Change in peak rainfall was calculated by taking the difference between the mean in drop-one jackknife values between 2017 - 2021 and 1990 - 1994.

Sea level rise: Sea surface height estimates were obtained from an ensemble of CMIP5 models using the RCP8.5 and RCP4.5 emissions scenarios. The twenty models used were: GISS-E2-R, canESM2, NorESM1-M, MPI-ESM-LR, GFDL-ESM2M, MIROC-ESM, HadGEM2-ES, INMCM4, NorESM1-ME, IPSL-CM5A-LR, CSIRO-Mk3-6-0, CNRM-CM5, MIROC-ESM-CHEM, GFDL-ESM2G, MPI-ESM-MR, HadGEM2-CC, IPSL-CM5A-MR, ACCESS1-0, MRI-CGCM3, MIROC5, BCC-CSM1-1. The sea surface height measurements used are reported globally in Church et al. (2013).

Sea surface temperature: Linear trend of sea surface temperature (SST) in °C/month over the last 30 years for each 5-km pixel near the MHI was calculated from 1991 through 2020 CoralTemp v3.1 data using the CDO trend function. CoralTemp daily data were first converted to monthly data using the CDO function monmean. This was done to enable comparison with trends from IPCC CMIP6 climate models. Linear trends of mean adjusted ensemble SSTs from CMIP6 models were calculated using the CDO trend function from monthly data for each 0.25° pixel in the region. Methods to acquire and adjust models are described in van Hooidonk et al. (2020).

5. Human Impacts

Corresponding author: Joey Lecky of NOAA PIFSC/IEA (joey.lecky@noaa.gov)

This report section was derived from research that had 3 major components: (1) ranking ecosystem vulnerability, (2) mapping individual human stressors, and (3) calculating cumulative impacts. The cumulative impact on any given place is a function of the number of stressors exerted on that place, their intensities, and the habitat vulnerability to the stress.

Habitat vulnerability scores: Hawai‘i coral reef experts (all with doctoral degrees in coral reef ecology or similar fields) were surveyed about the vulnerability of 3 Hawaiian nearshore habitats to 48 human stressors: coral reefs (coral-dominated hard bottom), rocky reefs (other hard bottom) and sandy areas (soft bottom). The survey methodology was adapted from previous cumulative impact studies (Halpern et al. 2007; Teck et al. 2010; Selkoe et al. 2008; Kappel et al. 2012). Experts were asked to evaluate 4 vulnerability criteria (frequency, trophic impact, percent change, and recovery time), as well as certainty, for each stressor and habitat. The inclusion of certainty in the vulnerability score calculation was a novel addition to previous cumulative impact studies. Weighting vulnerability scores by expert-provided certainty values was intended to give experts with more knowledge about a particular stressor/habitat more weight in determining the final score. There was no significant relationship between certainty scores and the final vulnerability scores, which means that the certainty scores did not overwhelmingly drive the score calculation. Vulnerability scores were largely consistent with other studies that surveyed experts about threats to coral reefs. Noticeable differences include: LBSP threats were generally ranked somewhat higher in other studies, invasive species were generally ranked much lower in other studies, and military activity was absent from other studies.

Stressor mapping: This effort produced a baseline comprehensive database of spatially explicit anthropogenic stressor data for the main Hawaiian Islands. Of the 48 human stressors included in the survey, 20 had sufficient existing data to produce statewide map layers (16 of which were non-climate change related). Of the top 13 stressors by vulnerability score for coral habitat, 11 of them were mapped. A marked decrease in vulnerability scores occurs after the 13th highest ranked stressor. A majority of the 20 mapped stressors represents the first ever continuous statewide map of that stressor for Hawaiʻi. Maps for individual stressors can be viewed in Lecky (2016). Brief methods for the 3 individual stressors shown in Figure 5.1, are described below. These data layers are also described in Wedding & Lecky et al. (2018) and available for download at: pacioos.org/projects/otp.

Reef fish fishing: This layer represents average annual total catch of reef finfish (2003–2015) for consumption, per unit area. Maps were developed for coral reef fish catch from 9 distinct types of fishing: 3 gear types (line, spear, and net) by 3 modes (shore-based noncommercial, boat-based noncommercial, and commercial). Then all 9 layers were summed to produce the final total reef fish fishing layer. Commercial catch data are reported by commercial fishers to the State of Hawaiʻi in aggregation by large irregular spatial reporting blocks (50–250 km2). Estimates of island-scale non-commercial annual catch of reef fish from survey data (McCoy et al. 2018) were spatially distributed over nearshore reef area based on measures of accessibility (shoreline steepness; proximity to roads and type of road; distance to boat launch/harbor), spatial patterns and footprints unique to each gear type, and spatial fishing regulations (marine managed areas that fully prohibit any or all of the 9 mapped types of fishing and de facto restricted access areas). The final map layer for total reef fish fishing was validated against existing creel survey data from seven sites across the Hawaiian Islands and results showed high correlation ($R2 = 0.64$; $y = 0.99x$) (Wedding and Lecky et al. 2018).

Wastewater nitrogen: This map layer represents nitrogen flux from onsite sewage disposal systems (OSDS; e.g., cesspools and septic tanks) to the nearshore environment. Data on locations and estimated nutrient fluxes into the groundwater of OSDS were obtained from the State of Hawaiʻi Department of Health (Whittier and El-Kadi 2014). For nearshore marine map pixels, we calculated the total nitrogen flux into the ground water from OSDS within a 1.5 km radius (Lecky 2016; Wedding et al. 2018).

Sediment pollution: This map layer represents modeled long term average annual sediment export from land to nearshore waters. Sediment export from the landscape was modeled using the InVEST sediment delivery model (Hamel et al. 2015) which estimates average annual export of sediment from terrestrial map pixels as a function of land use/land cover, soil characteristics, rainfall, slope, geology, and hydrology. Model outputs from the InVEST sediment delivery model (Falinski 2016) were aggregated to coastal pour points (e.g., stream mouths) using sub-watersheds and drainage network line data, then dispersed offshore using a Gaussian kernel decay function that reaches 0 at 1.5 km offshore (Lecky 2016; Wedding et al. 2018).

Cumulative Impacts: Spatial data on human stressors and benthic habitat were combined with vulnerability weighting factors for each stressor-habitat pair to produce maps of cumulative impact for the main Hawaiian Islands. The theoretical maximum cumulative impact score possible was 40.3 (Lecky 2016).

The maximum observed cumulative impact score was 15.8. This reflects the heterogeneity across individual stressor maps and the unique spatial patterns in each stressor. The minimum score observed was 1.4, indicating no single nearshore habitat in the MHI is entirely free of impact. For presentation, data are scaled in the maps within Figure 5.1 from 0–1 using the 99th percentile as the maximum value.

6. Vulnerability of Coral Reefs to Climate Change

Corresponding authors: Ruben van Hooidonk of NOAA/AOML and University of Miami RSMAS (ruben.van.hooidonk@noaa.gov) and Jeffrey Maynard of SymbioSeas (maynardmarine@gmail.com).

Future climate impacts to reefs: The climate model projections were developed following the methods presented within van Hooidonk et al. (2020). Model-resolution projections were then statistically downscaled to 5 km following the methodology in van Hooidonk et al. (2016) using NOAA Coral Reef Watch Coraltemp_v3.1 instead of the Pathfinder v5.2 dataset. The focus in this report and in using the projections to inform management and conservation is on the ASB projections under SSP5-8.5. Current emissions and concentrations are tracking very close to emissions scenario RCP8.5 (forcing for the Shared Socioeconomic Pathway 5-8.5 described in the report). The average CO2 concentration for 2022 is 419 ppm in RCP8.5, and the current observed CO2 concentration as of May 1, 2022 is 419.49 ppm at Mauna Loa. The ASB years projected for SSP5-8.5 were subtracted from SSP2-4.5 to examine climate policy effects. This yielded the amount of additional time coral reefs will have (in most cases) or not (in very rare cases) to adapt or acclimate to increasing temperatures if emissions cuts are made that are in keeping with SSP2-4.5 (i.e., >1.5x greater than were committed to under the Paris Agreement in 2015). The climate model projections make no assumptions as to the depths at which bleaching will occur but are based on bleaching observations data sets that nearly all come from < 30 m (van Hooidonk et al. 2015). Readers should assume that annual severe bleaching means severe bleaching of corals up to and potentially exceeding 30 m in depth. All model output adjustments, projections, data visualizations, and analyses were conducted using the NCAR Command Language Version 6.6.2 (NCL; http://www.ncl.ucar.edu/).

Climate vulnerability: Coral reef climate vulnerability was assessed at the island and all-islands (MHI) scale for 428 sites surveyed by NOAA NCRMP between March and September in 2016 and 2019. Site numbers for each island are Kaua‘i (26), Ni‘ihau (21), O‘ahu (75), Moloka‘i (56), Maui (54), Lāna‘i (47), Kaho‘olawe (26), Hawai‘i (123). First, scores were generated for each of the 3 variables needed to assess climate vulnerability for coral reefs: 1) human impacts (for methods, see Cumulative Impacts section of this Methods appendix), 2) projected future exposure to bleaching (for methods see section just above), and 3) ecological resilience. Resilience was assessed (sensu Maynard et al. 2016; Maynard et al. 2017) using the following indicators (with sources): coral cover (site level - NOAA NCRMP 2019), macroalgae cover (site level - NOAA NCRMP 2019), reef-builder ratio (ratio of the combined cover of reef-building hard corals and calcifying algae to the combined cover of fleshy algae; site level - NOAA NCRMP 2019), herbivore biomass (sector level - NOAA NCRMP 2016 and 2019), rugosity (site level - ASU GAO 2019; average taken for 25-m radius circle centered on the site coordinate), temperature variability (Heron et al. 2016). Scores or values for human impacts, projected future exposure to bleaching, and resilience were all then set to a unidirectional scale where a low score is good (requires inverting resilience). Next, the vulnerability to climate change is assessed at each site for the MHI-wide inter-island or all-islands assessment, and for the intra-island assessment, as follows: scores for the three input variables were summed and normalized to a scale of 0–1 by dividing by the maximum value (at each island for the intra-island assessment). Sites were set into relative classes as follows: low (< avg-1sd), medium-low (> avg-1sd and < avg), medium-high (> avg and < avg+1sd), and high (> avg+1sd).

Fisheries Species Tables

Table A1. Fish species included within the 3 fisheries—Pelagic, Deep 7 Bottomfish, and Nearshore—reported on in the Small-Boat Commercial Fishers section. Some species included as part of each fishery for the Fishery Engagement section differ from the fish included for each fishery in the Catch section, and vice versa. Note that sharks subgrouping under Pelagic is not reported in the main text and only occurs in this table. The Hawaiian names of the fishes may have been corrected from what was originally reported to include correct spelling as represented in the Hawaiian Dictionary by Pukui and Elbert (1986).

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
PELAGIC					
Pelagic – Tunas	*Katsuwonus pelamis*	Skipjack	Aku, Otado, Otaru	X	X
Pelagic – Tunas	*Thunnus albacares*	Yellowfin Tuna	'Ahi Y, Koshibi, Shibiko	X	X
Pelagic – Tunas	*Thunnus alalunga*	Albacore	'Ahi Palaha, Tombo	X	X
Pelagic – Tunas	*Thunnus thynnus*	Bluefin Tuna	Bluefin tuna, Maguro, Ahi	X	X
Pelagic – Tunas	*Thunnus obesus*	Bigeye Tuna	Ahi, 'Ahi po'o nui, Daruma	X	X
Pelagic – Tunas	*Euthynnus affinis*	Bonito, Mackerel Tuna, Wavyback Skipjack	Kawa, Kawakawa	X	X
Pelagic – Tunas	*Auxis thazard thazard*	Frigate Mackeral	'Oi'oi, Keokeo	X	X
Pelagic – Tunas	*Sarda orientalis*	Dogtooth Tuna, Oriental Bonito, Striped Bonito	Hagasu, Hagatsuo		X
Pelagic – Billfishes	Istiophoridae (family) or Xiphiidae (family)	Billfish (Misc.)	Mitsukuri	X	X
Pelagic – Billfishes	*Kajikia audax*	Striped Marlin	A'u, Naragi	X	X
Pelagic – Billfishes	*Makaira mazara* or *Makaira nigricans*	Blue Marlin	A'u B, Kajiki	X	X
Pelagic – Billfishes	*Xiphias gladius*	Swordfish	A'u ku, Shutome	X	X
Pelagic – Billfishes	*Istiophorus platypterus*	Sailfish	A'u lepe, A'u s	X	X
Pelagic – Billfishes	*Tetrapturus angustirostris*	Shortbill Spearfish	A'u, A'u I, Hebi	X	X
Pelagic – Billfishes	*Istiompax indica*	Black Marlin, Silver Marlin, White Marlin	A'u, Hida	X	X
Pelagic – Other Pelagics	*Coryphaena hippurus*	Dolphinfish, Dorado	Mahimahi	X	X
Pelagic – Other Pelagics	*Acanthocybium solandri*	Wahoo	Ono, Wahoo	X	X
Pelagic – Other Pelagics	Exocoetidae (family)	Flying Fish	Mālolo		X
Pelagic – Other Pelagics	*Ruvettus pretiosus*	Hawaiian Butterfish, Oilfish	Walu	X	X
Pelagic – Other Pelagics	*Lampris guttatus*	Moonfish	Manendai, Opah	X	X
Pelagic – Other Pelagics	*Taractichthys steindachneri* or *Eumegistus illustris*	Pomfret	Monchong, Yohando	X	X

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
PELAGIC					
Pelagic – Sharks	*Squalus* spp.	Spiny Dogfish Shark	Gray Reef, Green Eye, Mano (Misc.)		X
Pelagic – Sharks	*Sphyrna* spp.	Hammerhead Shark	Bay Shark, Manō Kihikihi		X
Pelagic – Sharks	*Isurus oxyrinchus*	Mako Shark	Mako Shark	X	X
Pelagic – Sharks	*Alopias vulpinus*	Thresher Shark	Manō'ula	X	X
Pelagic – Sharks	*Galeocerdo cuvier*	Tiger Shark	Niuhi		X
Pelagic – Sharks	*Triaenodon obesus*	Whitetip Reef Shark	Manō lālā kea		X
Pelagic – Sharks	*Isurus* spp.	Mako shark (unspecified, fins)	Mako shark (unspecified, fins)	X	X
Pelagic – Sharks	*Alopias vulpinus* – fins	Thresher Shark – fins	Thresher Shark – fins	X	X
Pelagic – Sharks	*Prionace glauca* – fins	Blue shark – fins	Blue shark – fins	X	X
Pelagic – Sharks	*Carcharhinus longimanus*	Oceanic whitetip shark – fins	Oceanic whitetip shark – fins	X	X
Pelagic – Sharks	Selachii (infraclass) – fins	Shark – fins (Misc.)	Sharks (misc.)		X
Pelagic – Sharks	*Sphyrna* spp. – fins	Hammerhead Shark – fins	Hammerhead Shark – fins		X

BOTTOMFISH					
Bottomfish Deep 7	*Hyporthodus quernus*	Hawaiian Black Grouper, Hawaiian Grouper, Sea Bass	Hāpu'u, Hāpu'upu'u, Shapon	X	X
Bottomfish Deep 7	*Pristipomoides sieboldii*	Pink Snapper (Kalekale)	Kalekale, Kalikali, Lavender jobfish	X	X
Bottomfish Deep 7	*Pristipomoides filamentosus*	Pink Snapper	'Opakapaka	X	X
Bottomfish Deep 7	*Etelis carbunculus*	Red Snapper (Ehu)	Ehu, 'Ula'ula	X	X
Bottomfish Deep 7	*Etelis coruscans*	Longtail Red Snapper	Onaga, Ulaula, Ulu, Buninas, Taighulupegh, Longtail snapper	X	X
Bottomfish Deep 7	*Aphareus rutilans*	Silverjaw Snapper	Lehi	X	X
Bottomfish Deep 7	*Pristipomoides zonatus*	Oblique-banded Snapper	'Ukikiki, Gindai, Tai	X	X

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
NEARSHORE					
Nearshore – Barracudas	*Sphyraena barracuda*	Great Barracuda	Kākū	X	X
Nearshore – Barracudas	*Sphyraena helleri*	Heller's Barracuda, Japanese Barracuda	Kamasu, Kawale'ā	X	X
Nearshore – Eels	Muraenidae (family)	Moray Eel (Misc.)	Puhi	X	X
Nearshore – Eels	*Gymnothorax* spp.	Moray Eel (Gymnothorax spp.)	Puhi, Puhi (Black/Brown), Puhi Paka	X	X
Nearshore – Eels	Congridae (family)	Conger Eel, Garden Eel, White Eel	Puhi, Tohei	X	X
Nearshore – Goatfishes	*Mulloidichthys pfluegeri*	Orange Goatfish, Pfluger's Goatfish	Aka Weke, Moilua, Weke 'Ula, Weke Moelua, Weke Nono	X	X
Nearshore – Goatfishes	*Parupeneus porphyreus*	White Saddle Goatfish	Kūmū	X	X
Nearshore – Goatfishes	*Parupeneus* spp.	Goatfish	Moana, Moana Maru, Moano	X	X
Nearshore – Goatfishes	Mullidae (family)	Goatfish (Misc.)	Green Weke, Oama, Sand Weke, Weke, Weke (Misc.)	X	X
Nearshore – Goatfishes	*Parupeneus pleurostigma*	Sidespot Goatfish	Malu, Maru, Moano	X	X
Nearshore – Goatfishes	*Parupeneus trifasciatus*	Doublebar Goatfish	Joe Louis, Munu	X	X
Nearshore – Goatfishes	*Upeneus taeniopterus*	Bandtail Goatfish	Nightmare Weke, Obake Weke, Weke Pueo	X	X
Nearshore – Goatfishes	*Mulloidichthys vanicolensis*	Yellowfin Goatfish	Red Stripe Goatfish, Red Weke, Weke 'Ula	X	X
Nearshore – Goatfishes	*Mulloidichthys flavolineatus*	Square-Spot Goatfish, Yellowstripe Goatfish	Sand Weke, Weke a'a, Weke'ā, White Weke	X	X
Nearshore – Goatfishes	*Parupeneus cyclostomus*	Blue Goatfish, Yellowsaddle Goatfish	Anahuli, Aoweke, Moana Kea, Moana Pāpā, Moano Kea, Moano Ukali Ulua	X	X
Nearshore – Mullets	*Mugil cephalus*	Flathead Grey Mullet, Striped Mullet	'Ama'ama, Pua	X	X
Nearshore – Mullets	*Osteomugil engeli*, *Moolgarda engeli*	Australian Mullet, Summer Mullet	Kanda	X	X
Nearshore – Mullets	*Neomyxus leuciscus*	False Mullet, Sharpnose Mullet	False 'Ama'ama, Uouoa	X	X
Nearshore – Other	Belonidae (family)	Needlefish	'Aha, 'Aha Mele, 'Aha'aha, Bluebone, Dasu	X	X
Nearshore – Other	*Kuhlia sandvicensis*	Hawaiian Flagtail, Mountainbass, Perch	Āholehole	X	X
Nearshore – Other	*Chanos chanos*	Milkfish	Awa, Bangos	X	X
Nearshore – Other	*Elops hawaiensis*	Hawaiian Ladyfish	'Awa 'awa, Awa 'aua, Hawaiian Tarpon, Hawaiian Tenpounder	X	X
Nearshore – Other	*Heteropriacanthus cruentatus*	Glasseye Snapper, Hawaiian Bigeye	Āweoweo, 'Āweoweo (Nearshore), Big Eye	X	X

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
NEARSHORE					
Nearshore – Other	Dasyatidae (family)	Eagle Ray, Sting Ray	Hīhīmanu	X	X
Nearshore – Other	Balistidae (family)	Triggerfish	Humuhumu	X	X
Nearshore – Other	*Atherinomorus insularum*	Hawaiian Silverside	'Iao	X	X
Nearshore – Other	Hemiramphidae (family)	Halfbeak	Iheihe, Sayori	X	X
Nearshore – Other	*Zanclus cornutus*	Moorish Idol	Kihikihi	X	X
Nearshore – Other	*Abudefduf sordidus*	Blackspot Sergeant, Damselfish	Kūpīpī	X	X
Nearshore – Other	*Chaetodon miliaris*	Millet Butterflyfish	Lauwiliwili	X	X
Nearshore – Other	*Abudefduf abdominalis*	Hawaiian Sergeant, Sergeant Major	Ma'o Ma'o, Mamo	X	X
Nearshore – Other	*Etrumeus micropus*	Sardine	Makiawa	X	X
Nearshore – Other	*Polydactylus sexfilis*	Threadfin	Moi, Moi-li'i	X	X
Nearshore – Other	*Monotaxis grandoculis*	Bigeye Emperor	Big Eye, Medai, Mū, Porgy	X	X
Nearshore – Other	*Encrasicholina purpurea*	Anchovy	Nehu	X	X
Nearshore – Other	*Kyphosus bigibbus* or *Kyphosus cinerascens*	Chub, Rudderfish	Enenue, Nenue	X	X
Nearshore – Other	*Scorpaenopsis* spp.	Scorpionfish	Nohu, Okoze	X	X
Nearshore – Other	*Aulostomus chinensis*	Cornetfish, Stickfish, Trumpetfish	Nūnū	X	X
Nearshore – Other	Monacanthidae (family)	Filefish	'Ō'ili, 'Ō'ili Lepa, Broomtail, Hage, Loulu	X	X
Nearshore – Other	*Albula glossodonta*	Bonefish	'Ō'io	X	X
Nearshore – Other	*Mesoplodon* spp.	Balloonfish, Porcupinefish, Pufferfish	'O'opu Hue, Fugu, Kōkala	X	X
Nearshore – Other	*Bothus* spp.	Flatfish, Flounder	Pāki'i	X	X
Nearshore – Other	*Spratelloides delicatulus*	Delicate Roundherring	Piha	X	X
Nearshore – Other	*Pristiapogon kallopterus*	Cardinalfish	'Upāpalu, Moonlight Annie	X	X
Nearshore – Other	*Mola mola*	Ocean Sunfish, Slender Sunfish	Mola mola	X	X
Nearshore – Other	*Scomber japonicus*	Japanese Mackerel	Saba	X	X
Nearshore – Other	*Tilapia* sp.	Tilapia	Cichlid, Tilapia	X	X
Nearshore – Other	*Cirrhitus* spp.	Hawkfish	Po'opa'a	X	X
Nearshore – Other	*Oplegnathus punctatus*	Spotted Knifejaw	Ishigakidai, Jabberjaw		X
Nearshore – Other	*Oplegnathus fasciatus*	Barred Knifejaw	Ishidai, Jabberjaw		X
Nearshore – Other	*Herklotsichthys quadrimaculatus*	Gold-spot Herring	Gold spot herring	X	X
Nearshore – Parrotfishes	*Calotomus carolinus*	Stareye Parrotfish	Panuhunuhu, Sleeping Uhu, Uhu	X	X

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
NEARSHORE					
Nearshore – Parrotfishes	*Scarus psittacus*	Palenose Parrotfish	Panunu, Uhu	X	X
Nearshore – Parrotfishes	Scaridae (family)	Parrotfish (Misc.)	Fuga, Uhu, Uhu (Misc.)	X	X
Nearshore – Scads	*Selar crumenophthalmus*	Bigeye Scad	Akule, Hahalalu (juvenile), Bigeye Scad	X	X
Nearshore – Scads	*Decapterus macarellus*	Mackerel Scad	'Ōpelu, Muroaji	X	X
Nearshore – Scads	*Sphyraena barracuda* or *Decapterus macarellus*	Butternose	'Ōpelu Māmā	X	X
Nearshore – Snappers/Groupers	*Aphareus furca*	Forktail Snapper	Gurutsu, Hanui, Joey Brown, Wahanui		X
Nearshore – Snappers/Groupers	*Lutjanus kasmira*	Bluestripe Snapper	Ta'ape	X	X
Nearshore – Snappers/Groupers	*Lutjanus fulvus*	Blacktail Snapper, Golden Perch	To'au	X	X
Nearshore – Snappers/Groupers	*Cephalopholis argus*	Peacock Grouper, Royal Sea Bass	Roi	X	X
Nearshore – Snappers/Groupers	*Aphareus furca*	Forktail Snapper	Gurutsu, Hanui, Joey Brown, Wahanui	X	X
Nearshore – Squirrelfishes	*Sargocentron xantherythrum*	Hawaiian Squirrelfish, Indianfish	'Ala'ihi	X	X
Nearshore – Squirrelfishes	Holocentrinae (subfamily)	Squirrelfish (Holocentridae)	'Ala'ihi, Pauu	X	X
Nearshore – Squirrelfishes	*Myripristis* spp.	Squirrelfish (Myripristis spp.)	'Ū'ū, Menpachi	X	X
Nearshore – Squirrelfishes	*Sargocentron spiniferum*	Longjaw Squirrelfish	'Ala'ihi, Uukanipo	X	X
Nearshore – Surgeonfishes	*Ctenochaetus strigosus*	Goldring Surgeonfish	Kole, Yellow Eye Kole	X	X
Nearshore – Surgeonfishes	*Acanthurus nigrofuscus*	Brown Surgeonfish, Lavendar Tang	Alibangbang, Fork Tail, Ma'i'i'i, Maiil	X	X
Nearshore – Surgeonfishes	*Acanthurus nigroris*	Blueline Surgeonfish	Maiko	X	X
Nearshore – Surgeonfishes	*Acanthurus leucopareius*	Whitebar Surgeonfish	Māikoiko	X	X
Nearshore – Surgeonfishes	*Acanthurus triostegus*	Convict Tang	Manini	X	X
Nearshore – Surgeonfishes	*Acanthurus olivaceus*	Olive Tang, Orangeband Surgeonfish	Na'ena'e	X	X
Nearshore – Surgeonfishes	*Zebrasoma flavescens*	Yellow Tang	Lau'īpala, Yellow Manini	X	X
Nearshore – Surgeonfishes	*Acanthurus achilles*	Achilles Tang	Pāku'iku'i	X	X
Nearshore – Surgeonfishes	*Acanthurus dussumieri*	Eyestripe Surgeonfish	Palani, Pone	X	X

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
NEARSHORE					
Nearshore – Surgeonfishes	*Acanthurus blochii* or *Acanthurus xanthopterus*	Ringtail Surgeonfish (Acanthurus blochii), Yellowfin Surgeonfish (Acanthurus xanthopterus)	Pualu (Acanthurus xanthopterus)	X	X
Nearshore – Surgeonfishes	*Acanthurus guttatus*	Whitespotted Surgeonfish	'Api, Mustard Tang	X	X
Nearshore – Surgeonfishes	*Ctenochaetus hawaiiensis*	Black Surgeonfish	Black Kole	X	X
Nearshore – Unicornfishes	*Naso annulatus*, *Naso Brevirostris*, or *Naso Unicornis*	Unicornfish	Kala	X	X
Nearshore – Unicornfishes	*Naso hexacanthus*	Sleek Unicornfish	'Ōpelu Kala, Kala Holo, Six Spined Surgeon	X	X
Nearshore – Unicornfishes	*Naso lituratus*	Naso Tang, Orangespine Unicornfish	Clown Tang, Kalalei, Orange Lip Surgeon, Umauma lei	X	X
Nearshore – Wrasses	*Bodianus bilunulatus*	Hawaiian Hogfish, Tableboss	A'awa, Hawaiian hogfish, Table boss, Bodai, Aia, Aeea	X	X
Nearshore – Wrasses	Labridae (family)	Wrasse (Misc.)	Ea (Misc.), Hīnālea	X	X
Nearshore – Wrasses	*Coris flavovittata*	Blackstripe Coris Wrasse	Hilu	X	X
Nearshore – Wrasses	*Thalassoma* spp.	Wrasse	Hīnālea	X	X
Nearshore – Wrasses	*Cheilio inermis*	Cigar Wrasse, Mongoose Fish	Alligator Wrasse, Banana Wrasse, Kūpou, Kūpoupou, Mongoose Wrasse	X	X
Nearshore – Wrasses	*Iniistius pavo*	Peacock Razorfish	Laenihi, Nabeta, Razorback Wrasse, Razorfin Wrasse	X	X
Nearshore – Wrasses	*Anampses cuvier*	Pearl Wrasse	'Opule, Snowflake Wrasse	X	X
Nearshore – Wrasses	*Cheilinus undulatus*	Humphead Wrasse, Napoleon Wrasse	Malatea, Maratea	X	X
Nearshore – Wrasses	*Oxycheilinus unifasciatus*	Ringtail Wrasse	Po'ou	X	X
Nearshore	*Caranx melampygus*	Bluefin Trevally	'Ōmilu, Hoshi Ulua, Nukumomi, Star Ulua	X	
Nearshore	Carangidae (family)	Ulua (Misc.)	Pāpio, Ulua	X	
Nearshore	*Gempylus serpens*	Hauliuli	Snake Mackerel, Hauliuli	X	
Nearshore	*Elagatis bipinnulata*	Hawaiian Salmon, Rainbow Runner, Spanish Jack	Kamanu	X	
Nearshore	*Scomberoides lysan*	Leatherback, Queenfish	Lai	X	
Nearshore	Exocoetidae (family)	Flying Fish	Mālolo	X	
Nearshore	*Sphyrna* and *Squalus* spp.	Nearshore Sharks	Sharks (misc.)	X	

Fishery and **Subcategory**	**Scientific Name**	**Common Name**	**Local Name**	**Fishery Engagement** and **Regional Quotient for revenue**	**Small-Boat Commercial Fishing**
NEARSHORE					
Nearshore	*Albula* spp.	Oio	Oio, Bonefish, Ola (unspecified)	X	X
Nearshore	*Atule mate*	Yellowtail Scad	'Omaka	X	
Nearshore	*Gnathanodon speciosus*	Golden Trevally, Yellow Ulua	Pa'opa'o, Striped Ulua	X	
Nearshore	*Alectis ciliaris*	Pompano	Kagami, Ulua Kihikihi	X	
Nearshore	*Uraspis helvola*	Whitetongue Jack	Dobe Ulua, Dusky	X	
Nearshore	*Caranx sexfasciatus*	Bigeye Jack, Bigeye Trevally	Pake Ulua, Sasa	X	
Nearshore	*Carangoides orthogrammus*	Island Jack	Pāpā, Ulua	X	
Nearshore	*Randallichthys filamentosu*	Randall's Snapper	Randall's snapper; Bake-akamutsu	X	
Nearshore	*Erythrocles schlegelii*, *Erythrocles scintillans*	Golden Kali	Golden kale, Schlegel's boga fish, Yanaginomai	X	
Nearshore	*Carangoides equula*	Whitefin Trevally	No-Bite, Schleger's Jack	X	
Nearshore	*Carangoides ferdau*	Barred Jack	Ulua	X	
Nearshore	*Pontinus macrocephalus*	Large-Headed Scorpionfish	Hogo	X	
Nearshore	*Carpilius maculatus*	Crab (Misc.)	7–11 crab, Stone crab	X	
Nearshore	*Portunus sanguinolentus hawaiiensis*	Kuahonu Crab	Kuahonu/White/Koha/ Swimming crab	X	
Nearshore	*Podophthalmus vigil*	Hawaiian Crab	Hawaiian red crab, Long-eyed swimming crab, Moala	X	
Nearshore	*Scylla serrata*	Samoan Crab	Samoan/Mangrove crab	X	
Nearshore	*Macrobrachium lar*	Misc. Shrimp/Prawn	Tahitian/Freshwater prawn, black shrimp	X	
Nearshore	*Grapsus tenuicrustatus*	A'Ama	Aama/Black crab	X	
Nearshore	*Thalamita crenata*	Blue Pincher Crab	Blue pincher crab, Swimming crab	X	
Nearshore	*Halocaridina rubra*	Opae Ula	Opae ula, Red shrimp	X	
Nearshore	*Metabetaeus lohena*	Metabetaeus Lohena	Opae lolo	X	
Nearshore	*Tellina palatum*	Olepe	Hawaiian clam, Olepe	X	
Nearshore	*Octopus* spp.	Octopus	Tako, Octopus, He'e, Fe'e, He'e mauli, He'e puloa, Makoko	X	
Nearshore	*Nerita* spp.	Pupu	Nerita snail	X	
Nearshore	Synaptidae (family)	Namako	Sea cucumber, Loli/Lole, Namako	X	
Nearshore	Numerous	Ha'Uke'Uke, Hawae, Wana, etc.	Sea urchins, Ha'uke'uke, Flat urchins	X	
Nearshore	Numerous	Limu	Lemu, Limu, Seaweed	X	

Data Tables for Coral Reef Benthic and Fish Communities

Summary that applies to all tables (Tables A2 to A7) in this section:

Table of sector level means and standard error (in parenthesis) by survey year (bottom summary table). The current status of a given indicator for each sector was calculated for the most recent survey year (2019) as either low, medium, or high based on whether that sector value was below, within, or above the mean ±1 standard deviation among all 2019 MHI sectors. The direction of change through time for each sector is also shown as positive, negative, or not significant. Direction of change was calculated based on whether the 2019 sector mean was above (positive), below (negative), or within (no change) the 95% confidence interval of sector values from either 2010–2012 or 2013–2015 (whichever was the earliest sampling year for that sector). Change was significant if the two time periods had non-overlapping 95% confidence intervals, calculated as standard error multiplied by 1.96. Not all sectors were surveyed during each survey year owing to weather and other factors. 'NA' values indicate years that a given sector was not sampled.

Coral Cover

Table A2.

CORAL COVER (%)							
Island	Sector	2010-12 (N=262)	2013-15 (N=688)	2016 (N=390)	2019 (N=465)	Relative Cover 2019	Change Over Time
HAW	HAW_HAMAKUA	8.5 (2.3)	6.8 (0.9)	NA	4.6 (0.6)	L	Not Significant
HAW	HAW_KONA	27.6 (2.8)	26.9 (1.8)	15.8 (1.5)	13.9 (1.5)	H	Negative
HAW	HAW_PUNA	NA	16.9 (2.7)	9.0 (2.3)	5.0 (0.9)	L	Negative
HAW	HAW_SE	NA	23.3 (3.5)	16.2 (2.2)	NA	-	-
KAH	KAH_NORTH	NA	NA	32.7 (4.4)	27.6 (4.4)	H	-
KAH	KAH_SOUTH	NA	NA	5.0 (0.7)	4.4 (0.9)	L	-
KAU	KAU_EAST	8.0 (2.0)	6.1 (1.0)	3.2 (0.6)	3.4 (0.7)	L	Not Significant
KAU	KAU_NAPALI	NA	3.6 (0.6)	0.9 (0.2)	1.3 (0.5)	L	Negative
LAN	LAN_NORTH	NA	12.6 (3.0)	20.6 (6.6)	39.1 (5.5)	H	Positive
LAN	LAN_SOUTH	20.6 (2.9)	17.6 (1.7)	26.7 (3.2)	16.4 (2.5)	H	Not Significant
MAI	MAI_KAHULUI	NA	25.2 (4.6)	NA	NA	-	-
MAI	MAI_KIHEI	36.1 (4.7)	42.3 (2.6)	29.5 (3.2)	25.5 (4.5)	H	Not Significant
MAI	MAI_LAHAINA	NA	NA	7.9 (2.4)	15.5 (4.2)	H	-
MAI	MAI_NE	3.0 (0.7)	5.4 (1.2)	5.6 (1.8)	2.0 (0.3)	L	Not Significant
MAI	MAI_NW	5.3 (1.2)	NA	NA	NA	-	-
MAI	MAI_SE	NA	NA	NA	11.9 (2.9)	M	-
MOL	MOL_NW	NA	4.7 (1.2)	NA	NA	-	-
MOL	MOL_PALI	3.6 (1.0)	2.0 (0.7)	3.2 (2.0)	2.5 (0.6)	L	Not Significant
MOL	MOL_SOUTH	38.1 (6.0)	30.5 (4.2)	31.2 (9.3)	17.4 (3.0)	H	Negative
MOL	MOL_WEST	5.3 (2.9)	7.0 (2.5)	3.1 (1.8)	5.8 (3.9)	L	Not Significant
NII	NII_EAST	NA	2.4 (0.4)	NA	NA	-	-
NII	NII_LEHUA	NA	3.2 (0.8)	NA	2.7 (1.0)	L	Not Significant
NII	NII_WEST	1.0 (0.3)	1.4 (0.4)	0.8 (0.4)	NA	-	-
OAH	OAH_EAST	8.3 (2.2)	13.5 (2.2)	17.1 (2.3)	12.6 (3.3)	M	Not Significant
OAH	OAH_KAENA	NA	NA	5.3 (1.9)	2.9 (0.5)	L	-
OAH	OAH_NE	NA	12.9 (2.3)	16.1 (3.5)	10.4 (3.7)	M	Not Significant
OAH	OAH_NORTH	NA	7.6 (1.3)	2.9 (1.0)	2.8 (1.0)	L	Negative
OAH	OAH_SOUTH	4.6 (0.9)	4.4 (0.7)	3.4 (0.7)	4.5 (2.0)	L	Not Significant

Total Calcified Cover

Table A3.

TOTAL CALCIFIED COVER (%)							
Island	Sector	2010-12 (N=262)	2013-15 (N=688)	2016 (N=390)	2019 (N=465)	Relative Cover 2019	Change Over Time
HAW	HAW_HAMAKUA	14.4 (2.3)	9.3 (1.0)	NA	8.5 (1.0)	L	Not Significant
HAW	HAW_KONA	36.6 (3.1)	36.8 (1.9)	23.5 (1.9)	21.3 (1.9)	H	Negative
HAW	HAW_PUNA	NA	26.8 (3.3)	15.0 (2.6)	9.3 (1.1)	L	Negative
HAW	HAW_SE	NA	33.9 (5.2)	23.5 (2.6)	NA	-	-
KAH	KAH_NORTH	NA	NA	35.0 (4.3)	28.6 (4.4)	H	-
KAH	KAH_SOUTH	NA	NA	7.7 (0.9)	8.0 (1.4)	L	-
KAU	KAU_EAST	17.8 (2.8)	8.6 (1.1)	8.2 (1.1)	5.3 (0.9)	L	Negative
KAU	KAU_NAPALI	NA	4.7 (0.8)	2.2 (0.5)	2.7 (0.7)	L	Not Significant
LAN	LAN_NORTH	NA	14.6 (3.3)	21.0 (6.7)	39.9 (5.5)	H	Positive
LAN	LAN_SOUTH	23.8 (3.0)	19.5 (1.7)	28.3 (3.2)	18.3 (2.6)	H	Not Significant
MAI	MAI_KAHULUI	NA	32.0 (4.3)	NA	NA	-	-
MAI	MAI_KIHEI	42.5 (5.0)	44.7 (2.6)	33.3 (3.4)	29.6 (4.8)	H	Not Significant
MAI	MAI_LAHAINA	NA	NA	8.7 (2.9)	16.3 (4.4)	H	-
MAI	MAI_NE	8.1 (1.2)	7.6 (1.6)	9.6 (2.6)	7.8 (1.5)	L	Not Significant
MAI	MAI_NW	10.4 (1.1)	NA	NA	NA	-	-
MAI	MAI_SE	NA	NA	NA	15.6 (2.9)	M	-
MOL	MOL_NW	NA	5.8 (1.4)	NA	NA	-	-
MOL	MOL_PALI	9.1 (1.3)	5.9 (1.2)	5.6 (1.6)	6.6 (1.1)	L	Not Significant
MOL	MOL_SOUTH	40.2 (6.2)	33.3 (4.1)	34.4 (9.8)	24.1 (4.0)	H	Not Significant
MOL	MOL_WEST	6.9 (2.9)	7.8 (2.5)	4.0 (1.8)	9.1 (4.1)	L	Not Significant
NII	NII_EAST	NA	3.2 (0.5)	NA	NA	-	-
NII	NII_LEHUA	NA	7.8 (1.6)	NA	5.6 (2.0)	L	Not Significant
NII	NII_WEST	5.8 (0.6)	3.2 (0.7)	2.2 (0.6)	NA	-	-
OAH	OAH_EAST	11.8 (2.4)	15.1 (2.4)	19.8 (2.5)	18.4 (3.3)	H	Not Significant
OAH	OAH_KAENA	NA	NA	6.0 (1.9)	4.9 (0.6)	L	-
OAH	OAH_NE	NA	15.3 (2.4)	23.2 (3.7)	14.5 (3.5)	M	Not Significant
OAH	OAH_NORTH	NA	9.1 (1.3)	4.4 (1.5)	4.3 (1.7)	L	Not Significant
OAH	OAH_SOUTH	6.8 (1.2)	5.3 (0.8)	6.6 (1.4)	5.2 (2.2)	L	Not Significant

Reef Builder Ratio

Table A4.

REEF-BUILDER RATIO							
Island	Sector	2010-12 (N=262)	2013-15 (N=688)	2016 (N=390)	2019 (N=465)	Relative Cover 2019	Change Over Time
HAW	HAW_HAMAKUA	0.22 (0.05)	0.13 (0.02)	NA	0.13 (0.02)	L	Not Significant
HAW	HAW_KONA	0.99 (0.14)	0.90 (0.08)	0.45 (0.05)	0.43 (0.05)	H	Negative
HAW	HAW_PUNA	NA	0.59 (0.16)	0.27 (0.08)	0.14 (0.02)	L	Negative
HAW	HAW_SE	NA	0.72 (0.16)	0.42 (0.08)	NA	-	-
KAH	KAH_NORTH	NA	NA	0.93 (0.18)	0.79 (0.18)	H	-
KAH	KAH_SOUTH	NA	NA	0.10 (0.01)	0.12 (0.03)	L	-
KAU	KAU_EAST	0.28 (0.06)	0.11 (0.01)	0.11 (0.02)	0.07 (0.01)	L	Negative
KAU	KAU_NAPALI	NA	0.05 (0.01)	0.03 (0.01)	0.04 (0.01)	L	Not Significant
LAN	LAN_NORTH	NA	0.26 (0.07)	0.53 (0.25)	1.40 (0.34)	H	Positive
LAN	LAN_SOUTH	0.50 (0.11)	0.29 (0.03)	0.56 (0.09)	0.39 (0.08)	M	Not Significant
MAI	MAI_KAHULUI	NA	0.70 (0.18)	NA	NA	-	-
MAI	MAI_KIHEI	1.32 (0.20)	1.01 (0.10)	0.82 (0.11)	0.77 (0.16)	H	Not Significant
MAI	MAI_LAHAINA	NA	NA	0.12 (0.04)	0.39 (0.14)	M	-
MAI	MAI_NE	0.10 (0.02)	0.10 (0.02)	0.15 (0.05)	0.14 (0.04)	L	Not Significant
MAI	MAI_NW	0.15 (0.02)	NA	NA	NA	-	-
MAI	MAI_SE	NA	NA	NA	0.27 (0.06)	M	-
MOL	MOL_NW	NA	0.07 (0.02)	NA	NA	-	-
MOL	MOL_PALI	0.12 (0.02)	0.07 (0.02)	0.07 (0.02)	0.11 (0.03)	L	Not Significant
MOL	MOL_SOUTH	1.04 (0.18)	0.85 (0.13)	0.98 (0.30)	0.73 (0.17)	H	Not Significant
MOL	MOL_WEST	0.12 (0.08)	0.11 (0.04)	0.05 (0.03)	0.18 (0.10)	L	Not Significant
NII	NII_EAST	NA	0.04 (0.01)	NA	NA	-	-
NII	NII_LEHUA	NA	0.10 (0.02)	NA	0.08 (0.03)	L	Not Significant
NII	NII_WEST	0.07 (0.01)	0.04 (0.01)	0.03 (0.01)	NA	-	-
OAH	OAH_EAST	0.17 (0.04)	0.23 (0.04)	0.37 (0.07)	0.34 (0.07)	M	Not Significant
OAH	OAH_KAENA	NA	NA	0.08 (0.02)	0.06 (0.01)	L	-
OAH	OAH_NE	NA	0.24 (0.05)	1.38 (0.60)	0.31 (0.11)	M	Not Significant
OAH	OAH_NORTH	NA	0.12 (0.02)	0.06 (0.02)	0.06 (0.03)	L	Not Significant
OAH	OAH_SOUTH	0.09 (0.02)	0.06 (0.01)	0.10 (0.02)	0.10 (0.05)	L	Not Significant

Total Fish Biomass

Table A5.

		TOTAL BIOMASS (kg/ha)					
Island	Sector	2010-12 (N=264)	2013-15 (N=563)	2016 (N=219)	2019 (N=254)	Relative Biomass 2019	Change Over Time
HAW	HAW_HAMAKUA	320 (49)	512 (49)	NA	364 (37)	H	Not Significant
HAW	HAW_KONA	208 (22)	312 (21)	304 (25)	370 (34)	H	Positive
HAW	HAW_PUNA	NA	333 (45)	418 (74)	413 (45)	H	Not Significant
HAW	HAW_SE	NA	423 (58)	467 (33)	NA	-	-
KAH	KAH_NORTH	NA	NA	568 (103)	530 (107)	H	-
KAH	KAH_SOUTH	NA	NA	560 (110)	655 (122)	H	-
KAU	KAU_EAST	258 (48)	151 (21)	246 (101)	231 (47)	L	Not Significant
KAU	KAU_NAPALI	NA	370 (99)	343 (63)	241 (64)	L	Not Significant
LAN	LAN_NORTH	NA	227 (56)	304 (116)	NA	-	-
LAN	LAN_SOUTH	255 (25)	344 (55)	397 (47)	322 (49)	M	Not Significant
MAI	MAI_KAHULUI	NA	546 (224)	NA	NA	-	-
MAI	MAI_KIHEI	202 (37)	269 (55)	217 (31)	211 (68)	L	Not Significant
MAI	MAI_LAHAINA	NA	NA	331 (49)	93 (31)	L	-
MAI	MAI_NE	318 (56)	357 (61)	456 (45)	599 (56)	H	Positive
MAI	MAI_NW	322 (103)	NA	NA	NA	-	-
MOL	MOL_NW	NA	472 (58)	NA	NA	-	-
MOL	MOL_PALI	649 (204)	419 (93)	NA	512 (60)	H	Not Significant
MOL	MOL_SOUTH	175 (36)	267 (27)	462 (194)	NA	-	-
MOL	MOL_WEST	198 (46)	805 (296)	NA	118 (45)	L	Not Significant
NII	NII_EAST	NA	420 (87)	NA	NA	-	-
NII	NII_LEHUA	NA	720 (72)	NA	NA	-	-
NII	NII_WEST	447 (75)	727 (92)	516 (122)	NA	-	-
OAH	OAH_EAST	98 (14)	124 (23)	256 (45)	305 (125)	M	Not Significant
OAH	OAH_KAENA	NA	NA	NA	194 (96)	L	-
OAH	OAH_NE	NA	134 (32)	NA	136 (54)	L	Not Significant
OAH	OAH_NORTH	NA	121 (28)	NA	186 (70)	L	Not Significant
OAH	OAH_SOUTH	91 (14)	165 (19)	228 (64)	177 (29)	L	Positive

Herbivore Biomass

Table A6.

HERBIVORE BIOMASS (kg/ha)							
Island	Sector	2010-12 (N=264)	2013-15 (N=563)	2016 (N=219)	2019 (N=254)	Relative Biomass 2019	Change Over Time
HAW	HAW_HAMAKUA	160 (31)	253 (34)	NA	166 (23)	H	Not Significant
HAW	HAW_KONA	120 (11)	154 (13)	169 (13)	161 (12)	H	Not Significant
HAW	HAW_PUNA	NA	183 (28)	177 (41)	171 (30)	H	Not Significant
HAW	HAW_SE	NA	243 (30)	255 (23)	NA	-	-
KAH	KAH_NORTH	NA	NA	164 (36)	156 (28)	H	-
KAH	KAH_SOUTH	NA	NA	234 (48)	215 (64)	H	-
KAU	KAU_EAST	79 (19)	58 (13)	52 (12)	73 (24)	L	Not Significant
KAU	KAU_NAPALI	NA	171 (50)	161 (59)	94 (35)	L	Not Significant
LAN	LAN_NORTH	NA	103 (25)	115 (40)	NA	-	-
LAN	LAN_SOUTH	127 (17)	129 (20)	186 (30)	125 (26)	M	Not Significant
MAI	MAI_KAHULUI	NA	162 (38)	NA	NA	-	-
MAI	MAI_KIHEI	72 (11)	109 (20)	106 (21)	95 (20)	L	Not Significant
MAI	MAI_LAHAINA	NA	NA	65 (20)	32 (9)	L	-
MAI	MAI_NE	192 (52)	171 (31)	252 (72)	220 (35)	H	Not Significant
MAI	MAI_NW	199 (107)	NA	NA	NA	-	-
MOL	MOL_NW	NA	200 (32)	NA	NA	-	-
MOL	MOL_PALI	404 (183)	216 (76)	NA	263 (47)	H	Not Significant
MOL	MOL_SOUTH	86 (16)	153 (21)	184 (93)	NA	-	-
MOL	MOL_WEST	109 (36)	186 (74)	NA	65 (36)	L	Not Significant
NII	NII_EAST	NA	89 (19)	NA	NA	-	-
NII	NII_LEHUA	NA	315 (67)	NA	NA	-	-
NII	NII_WEST	185 (35)	373 (68)	305 (77)	NA	-	-
OAH	OAH_EAST	49 (11)	70 (17)	175 (39)	127 (37)	M	Not Significant
OAH	OAH_KAENA	NA	NA	NA	93 (60)	L	-
OAH	OAH_NE	NA	71 (22)	NA	63 (29)	L	Not Significant
OAH	OAH_NORTH	NA	51 (18)	NA	95 (46)	L	Not Significant
OAH	OAH_SOUTH	35 (9)	57 (9)	72 (16)	71 (17)	L	Not Significant

Resource Fish Biomass

Table A7.

RESOURCE FISH BIOMASS (kg/ha)							
Island	Sector	2010-12 (N=264)	2013-15 (N=563)	2016 (N=219)	2019 (N=254)	Relative Biomass 2019	Change Over Time
HAW	HAW_HAMAKUA	266 (48)	408 (41)	NA	277 (34)	H	Not Significant
HAW	HAW_KONA	139 (19)	158 (15)	166 (18)	208 (24)	M	Not Significant
HAW	HAW_PUNA	NA	219 (41)	311 (78)	304 (38)	H	Not Significant
HAW	HAW_SE	NA	297 (37)	313 (29)	NA	-	-
KAH	KAH_NORTH	NA	NA	409 (93)	421 (108)	H	-
KAH	KAH_SOUTH	NA	NA	443 (105)	527 (111)	H	-
KAU	KAU_EAST	177 (38)	70 (14)	169 (92)	163 (36)	L	Not Significant
KAU	KAU_NAPALI	NA	301 (96)	266 (46)	188 (60)	L	Not Significant
LAN	LAN_NORTH	NA	172 (51)	242 (105)	NA	-	-
LAN	LAN_SOUTH	173 (19)	233 (50)	241 (42)	195 (38)	L	Not Significant
MAI	MAI_KAHULUI	NA	177 (41)	NA	NA	-	-
MAI	MAI_KIHEI	134 (35)	178 (53)	131 (27)	140 (62)	L	Not Significant
MAI	MAI_LAHAINA	NA	NA	221 (58)	51 (22)	L	-
MAI	MAI_NE	256 (53)	256 (57)	372 (32)	471 (52)	H	Positive
MAI	MAI_NW	241 (117)	NA	NA	NA	-	-
MOL	MOL_NW	NA	362 (50)	NA	NA	-	-
MOL	MOL_PALI	579 (199)	355 (90)	NA	451 (58)	H	Not Significant
MOL	MOL_SOUTH	116 (32)	166 (23)	193 (71)	NA	-	-
MOL	MOL_WEST	140 (42)	473 (234)	NA	70 (38)	L	Not Significant
NII	NII_EAST	NA	350 (80)	NA	NA	-	-
NII	NII_LEHUA	NA	570 (82)	NA	NA	-	-
NII	NII_WEST	406 (75)	620 (81)	430 (116)	NA	-	-
OAH	OAH_EAST	57 (9)	68 (19)	184 (47)	158 (72)	L	Not Significant
OAH	OAH_KAENA	NA	NA	NA	113 (73)	L	-
OAH	OAH_NE	NA	79 (26)	NA	78 (43)	L	Not Significant
OAH	OAH_NORTH	NA	64 (23)	NA	123 (55)	L	Not Significant
OAH	OAH_SOUTH	35 (12)	75 (14)	121 (49)	99 (21)	L	Not Significant

Impacts Data Tables and Histograms

Table A8.

Vulnerability scores for 48 human stressors and 3 habitat types, derived from expert knowledge elicitation. Values indicate the relative vulnerability of a habitat to a given stressor when it occurs at high intensity. These values were combined with spatial data layers to calculate cumulative impact maps. The maximum possible vulnerability score was 4. Stressor names in bold above the dotted lines were mapped statewide in Lecky (2016). Four climate change related stressors had sufficient data to be mapped but are excluded from this report and Fig. 5.1 (as indicated in the "Climate*" section in the middle of the table). Scores are the average of multiple expert survey responses for each stressor and habitat (n), and darker shading indicates a larger n. The maximum n was 9; smaller numbers indicate experts gave "don't know" responses. The standard deviation across expert responses is also shown (std) with light to dark green shading for highest to lowest standard deviation, respectively. The "Not Mapped" section of the table (bottom) shows stressors that were included in the expert surveys but did not have sufficient available data to produce statewide maps suitable for inclusion in cumulative impact mapping.

			Coral Dominated			Other Hard Bottom			Soft Bottom		
	Category	**Stressor**	Vulnerability	n	std	Vulnerability	n	std	Vulnerability	n	std
Mapped	**Fishing**	**Reef Fish Fishing**	3.11	9	0.35	2.70	8	0.66	1.91	8	0.64
Mapped	**Species**	**Invasive Aliens**	2.87	8	0.90	2.32	7	0.74	2.59	5	1.02
Mapped	**Ship-Based Effects**	**Shipwrecks/Groundings**	2.74	9	0.85	2.20	8	0.77	1.85	8	1.01
Mapped	**Land-Based Pollution**	**Sediment Increase**	2.63	9	0.82	2.18	8	0.71	1.51	8	0.98
Mapped	**Tourism & Recreation**	**Direct Human Impact**	2.59	9	1.12	1.84	8	0.88	1.67	8	0.91
Mapped	**Land-Based Pollution**	**Nutrient Input (OSDS)**	2.59	8	0.78	1.94	7	0.39	1.66	6	0.47
Mapped	**Land-Based Pollution**	**Agricultural Runoff**	2.51	8	0.74	1.84	7	0.28	1.62	8	0.41
Mapped	**Habitat Destruction**	**Dredging**	2.49	8	0.77	2.48	7	0.71	2.49	7	0.84
Mapped	**Habitat Destruction**	**Coastal engineering**	2.46	8	0.78	2.44	7	0.76	2.10	7	0.77
Mapped	**Habitat Destruction**	**Benthic Structures**	2.27	8	0.99	2.22	7	0.97	2.04	7	0.86
Mapped	**Fishing**	**Aquarium Collection**	1.79	8	0.64	1.26	7	0.47	0.42	7	0.53
Mapped	**Marine Debris**	**Marine Debris**	1.79	9	1.03	1.69	8	0.98	1.84	7	0.75
Mapped	**Land-Based Pollution**	**Urban Runoff**	1.73	6	0.22	1.65	6	0.25	1.46	7	0.38
Mapped	**Aquaculture**	**Aquaculture: Terrestrial**	1.37	6	0.73	1.31	6	0.72	1.08	6	0.70
Mapped	**Ship-Based Effects**	**Shipping**	1.03	8	0.78	1.14	7	0.70	1.13	7	0.69
Mapped	**Aquaculture**	**Aquaculture: Open Ocean**	0.99	9	0.91	1.09	8	0.87	1.58	8	0.82
Climate*	**Climate Change**	**Thermal Stress (Ocean Warming)**	2.30	9	0.59	1.75	7	0.39	1.23	7	0.95
Climate*	**Climate Change**	**Ocean Acidification**	1.29	8	1.00	1.32	7	0.72	1.21	5	0.78
Climate*	**Climate Change**	**Sea Level Rise**	1.01	9	0.83	1.08	8	0.78	0.87	7	0.92
Climate*	**Climate Change**	**Ultra Violet Radiation Increase**	0.73	5	0.73	0.88	4	0.66	0.71	4	0.74
Not Mapped	Military	Military Activity	2.77	3	0.23	2.53	2	0.54	2.33	2	0.69
Not Mapped	Land-Based Pollution	Freshwater Input: Increase	2.24	8	1.08	1.58	7	0.42	1.34	7	0.43
Not Mapped	Land-Based Pollution	Other Chemical Pollution	1.70	5	0.59	1.62	5	0.49	1.58	5	0.51
Not Mapped	Tourism & Recreation	Thrill Craft	1.50	7	1.02	1.49	7	1.02	1.35	7	1.02
Not Mapped	Species	Invasive Native Pests	1.48	8	0.75	1.16	7	1.12	1.10	6	1.29
Not Mapped	Fishing	Shoreline Gathering	1.44	9	0.75	1.57	8	0.75	1.41	8	0.79
Not Mapped	Species	Non-Invasive Aliens	1.43	9	0.78	1.52	8	0.67	1.55	5	0.51
Not Mapped	Science	Scientific Research	1.32	9	0.76	1.22	8	0.75	1.10	8	0.75
Not Mapped	Tourism & Recreation	Recreational Boating	1.28	9	0.93	1.32	8	0.98	1.19	8	0.94
Not Mapped	Tourism & Recreation	SCUBA Diving	1.27	9	0.65	1.21	8	0.64	0.70	8	0.74
Not Mapped	Land-Based Pollution	Power Plants	1.23	5	0.63	0.99	6	0.72	0.96	6	0.71
Not Mapped	Climate Change	Increasing Storm Frequency/Strength	1.14	8	0.82	1.21	7	0.68	1.12	7	0.68
Not Mapped	Land-Based Pollution	Freshwater Input: Decrease	1.11	6	1.03	1.55	4	0.71	1.07	5	0.90
Not Mapped	Aquaculture	Aquaculture: Fishponds	1.10	8	1.28	1.51	7	1.20	1.46	7	1.19
Not Mapped	Other	Atmospheric Pollution Input	0.99	4	0.58	0.99	4	0.58	0.91	4	0.50
Not Mapped	Ship-Based Effects	Vessel Strikes	0.93	7	0.30	0.94	7	0.31	0.79	7	0.35
Not Mapped	Fishing	Trap Fishing	0.93	7	0.86	1.06	6	0.80	0.91	5	0.86
Not Mapped	Fishing	Pelagic Fishing (Except Longline)	0.91	9	0.96	0.99	8	0.96	1.01	8	0.96
Not Mapped	Climate Change	Increased PAR	0.88	5	0.94	1.06	4	0.86	0.75	4	0.81
Not Mapped	Tourism & Recreation	Human-Powered Vessels	0.84	9	0.74	0.93	8	0.71	0.87	8	0.64
Not Mapped	Land-Based Pollution	Sediment Decrease	0.79	4	1.07	1.04	3	1.14	1.08	4	1.05
Not Mapped	Tourism & Recreation	Surfing	0.75	9	0.79	0.80	8	0.77	0.77	8	0.71
Not Mapped	Climate Change	Changing Precipitation Patterns	0.75	7	0.53	0.82	6	0.44	0.78	5	0.51
Not Mapped	Fishing	Bottomfish Fishing	0.66	9	0.64	0.70	8	0.60	0.41	8	0.59
Not Mapped	Land-Based Pollution	Light Pollution	0.51	7	0.54	0.56	6	0.57	0.67	6	0.50
Not Mapped	Fishing	Commercial Longline	0.44	9	0.87	0.46	8	0.86	0.42	8	0.78
Not Mapped	Land-Based Pollution	Noise Pollution	0.33	7	0.57	0.38	6	0.60	0.38	6	0.60
Not Mapped	Climate Change	Increasing Thermal Stratification	0.33	7	0.45	0.38	6	0.47	0.45	6	0.61

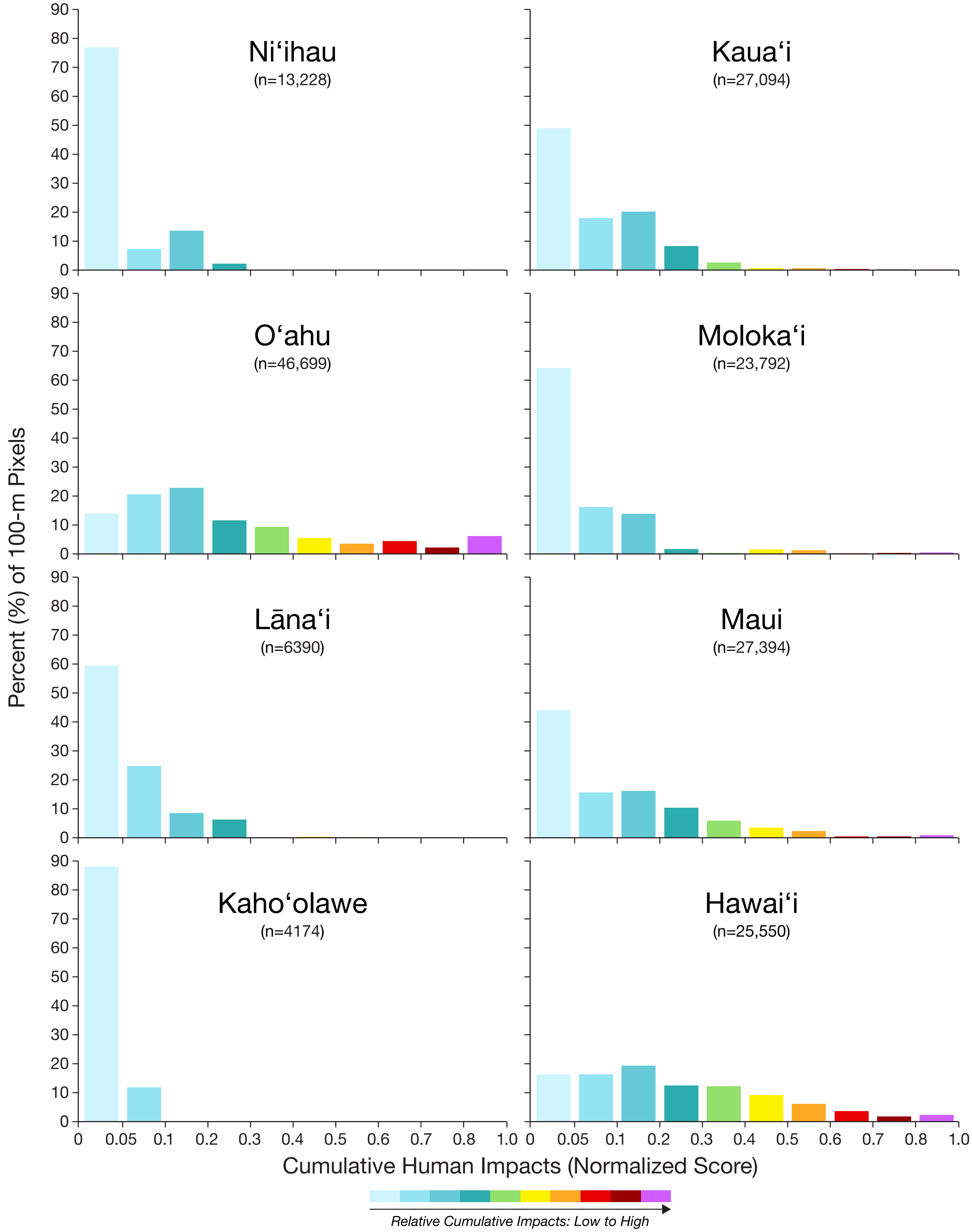


Fig. A1. Histograms of cumulative impact by island. Y axes are percent of 100 x 100 m pixels. The total number of pixels per island (i.e., area in hectares) is shown below each island name (n). Break values on the x-axis and color coding correspond to map symbology in Fig. 5.1. The upper- and lower-most bins are not the same width as the rest of the bins.

Coral Reef Resilience to Climate Change

Results of inter-island (or 'all islands') and intra-island assessments of relative coral reef resilience to climate change.

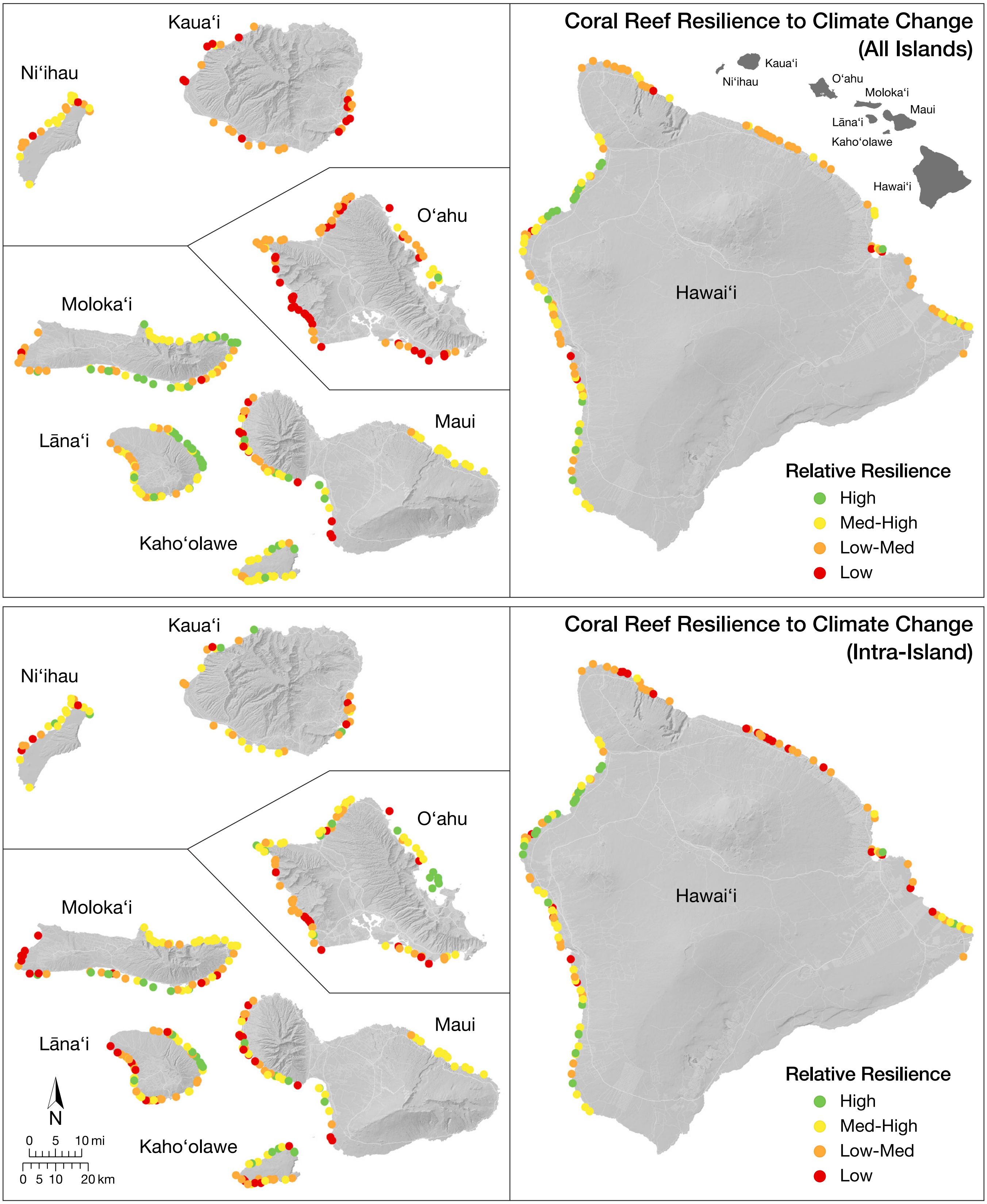


Fig. A2. (Previous page). Inter-island and intra-island assessments of relative resilience to climate change. Ecological resilience is one of the 3 input layers to climate vulnerability (Figure 6.3 in the report), along with projected impacts to reefs from bleaching and cumulative human impacts. Resilience was assessed following methods presented in Maynard et al. (2015) and this Guide for Managers, using these indicators (with sources): coral cover (site level—NOAA NCRMP 2019), macroalgae cover (site level - NOAA NCRMP 2019), reef builder ratio (site level - NOAA NCRMP 2019), herbivore biomass (sector level—NOAA NCRMP 2016 and 2019), rugosity (site level—ASU CGDCS; average taken for 25-m radius circle centered on the site coordinate), temperature variability (Heron et al. 2016). Scores for all indicators are set to a uni-directional scale of 0–1 where a high score is a good score (for high resilience; this involves taking inverse of macroalgae cover). Scores are then averaged and re-normalized to 0–1 by dividing by the highest score, setting scores as relative to the site with the highest (assessed) resilience. Relative classes for resilience are set as follows: low (< avg-1sd), medium-low (> avg-1sd and <avg), medium-high (> avg and < avg+1sd), and high (> avg+1sd).