2018 HAWAI'I OCEAN HEALTH INDEX

CONSERVATION INTERNATIONAL Hawai'i

IEA

HAWAIIAN AIRLINES.

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Full data repository and report can be found at ohi-science.org/mhi

Summary

The Hawai'i Ocean Health Index is a scientifically robust index that measures ocean health for Hawai'i that is supported by local stakeholders that integrates policy initiatives to support sustainable ocean management. The Ocean Health Index framework allows for repeatable assessments of the index goals overtime to measure progress toward a common vision for a healthy ocean and sustainable ocean management for Hawai'i. The 2018 assessment of the Hawai'i Ocean Health Index provides an opportunity to assess the opportunities for strengthening ocean resource management by priority area and county region. Seven goals or priorities were assessed in the 2018 Hawai'i Ocean Health Index: Food Provision (Wild Caught Fisheries and Mariculture), Coastal Protection, Biodiversity (Habitats and Species), Economies & Livelihoods, Artisanal Fishing Opportunities, Sustainable Tourism, and Sense of Place (Lasting Special Places and Connection to Place). The Main Hawaiian Islands received a score of 70, with Hawai'i Island having the highest regional Ocean Health Index score (74), followed by Maui Nui (72), Kaua'i (72), and O'ahu (61). Ocean Livelihoods & Economies received the highest score, with Hawaii's ocean economy providing 16% of Hawaii's jobs and 6 billion annually in revenue. Goals that incorporated ocean and coastal habitat health or protection tended to score the lowest, highlighting the need to protect or restore these habitats ensure the benefits that these goals provide will sustain into the future. These goals are Biodiversity, Coastal Protection, Sustainable Tourism, and Sense of Place. Protecting and restoring these habitats is essential to sustaining our community and economy now and into the future.

Background

The Ocean Health Index is the first integrated assessment framework that scientifically combines key biological, physical, economic, and social elements of the ocean's health. Overall Index scores are a combination of components, or 'goals', of ocean health. These scores are calculated using the best available data and indicators at the scale of the assessment. Scores reflect how well coastal regions optimize their potential ocean benefits and services in a *sustainable way relative to a reference point* (target), on a scale of 0-100.

Methods for calculating the Ocean Health Index were developed at a global scale, combining dozens of data sets to produce annual Index scores for coastal nations and territories (Halpern et al., 2012). As a result, for the first time, we are able to assess and compare global performance in managing our relationship with the Earth's greatest resource—the Ocean. Using the same framework, independent assessments (OHI+) allow for exploration of variables influencing ocean health at the smaller scales where policy and management decisions are made. Targets for goals are created using stakeholder input, higher resolution data, indicators, and priorities, which produce scores that better reflect local priorities. This enables communities, managers, policy makers, scientists to better and more holistically understand, track, and communicate the status of local marine ecosystems, and to design strategic management actions to improve overall ocean health.

Adapting the Index for Hawaiʻi

Hawaiians have a long history of sustainable management and resource use. They recognized that their wellbeing and health relied on the status or availability of their resource. Today, the same is true; the health of our island communities and our environment is intertwined. Healthy communities are more equipped to be stewards of their environment and a healthy environment supports community wellbeing. This strong sense of place and mālama ʻāina (care for the land and ocean) drives community conservation in Hawaiʻi and is a model for the rest of the world. These social and cultural values are the foundation for the development of the Hawaiʻi Ocean Health Idex. The index was developed by a diverse group of stakeholders including community members, non-profit groups, private industries, state and federal agencies to communicate the status of our ocean resources and create a shared vision for the future of our oceans.

Methods

OHI Framework

Ocean Health was defined as an ocean that can provide benefits and services for people now and into the future. Furthermore, health was defined as a state of being that is pono (sustainable/respectful); where functions and processes can exist, perpetuate, and evolve, including the presence and role of humans. Our common vision for ocean health in Hawaiʻi is a resilient and productive system that provides services and resources to sustain Hawaii's residents and economy now and into the future.

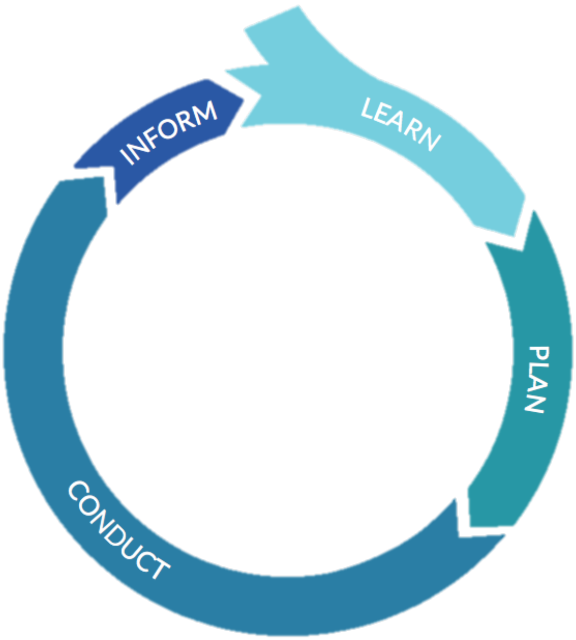
The global Ocean Health Index developed 10 goals that encompass ocean health: Food Provision, Natural Products, Clean Water, Coastal Protection, Carbon Storage, Biodiversity, Tourism & Recreation, Livelihoods & Economies, Artisanal Fishing Opportunities, and Sense of Place. These goals were adapted from the global framework and transformed into seven goals for the Hawaiʻi OHI: Food Provision, Coastal Protection, Biodiversity, Economies & Livelihoods, Artisanal Fishing Opportunities, Sustainable Tourism, and Sense of Place (Table 1).

Table 1. Locally defined goals for the Hawai‘i Ocean Health Index.

Goal	Subgoal	Definition
Food Provision (FP)	Fisheries (FIS) Mariculture (MAR)	Sustainably harvested or cultured seafood. Measured by the amount of wild-caught seafood from pelagic, bottomfish, coastal pelagic, and nearshore fisheries that can be sustainably harvested and the sustainable production of seafood from contemporary mariculture and customary Hawaiian fishponds (loko i‘a).
Artisanal Fishing Opportunities (AO)		The opportunity for fishers to supply seafood for themselves, families, and community.
Sense of Place (SP)	Lasting Special Places (LSP) Connection to Place (CON)	Sense of Place incorperates the relationships between people and ‘āina (land and ocean). Lasting Special Places tracks the protection of marine and coastal areas and Connection to Place measures the participation on ocean and coastal activities that occur in each place.
Sustainable Tourism (ST)		Balanced economic growth through tourism with management and preservation of natural resources and Hawaiian culture.
Biodiversity (BD)	Habitats (HAB) Species (SPP)	The value of coastal and ocean species and habitats. Habitats measures the extent and condition of reefs, wetlands, soft-bottom habitats, and beaches. Species measures the population status of Hawai‘i species based on reef fish biomass and the risk of extinction of marine mammals, turtles and birds, and coastal beach and sand dune plants.
Coastal Protection (CP)		Extent and condition of habitats (beaches, coral reefs, wetlands) that provide coastal protection from inundation and erosion.
Livelihoods & Economies (LE)	Livelihoods (LIV) Economies (ECO)	Coastal and ocean-dependent jobs and productive coastal economies from the revenue from marine related industries including tourism, fishing, shipbuilding, and transportation. Livelihoods tracks the number of jobs and the quality of wages (wage/livable wage) of marine sectors and economies tracks the revenue generated from productive coastal economies.

Process for Developing the Hawai‘i OHI

The OHI+ framework was developed for Hawai‘i through the following process:



Learn about the Ocean Health Index and its applications

Plan the assessment to achieve local objectives and involve stakeholders

Conduct assessment with adapted framework and local data on status, pressures, and resilience.

Repeat assessment process incorporating updated science and policies to track progress towards a healthy ocean.

Plan the assessment to achieve local objectives and involve stakeholders

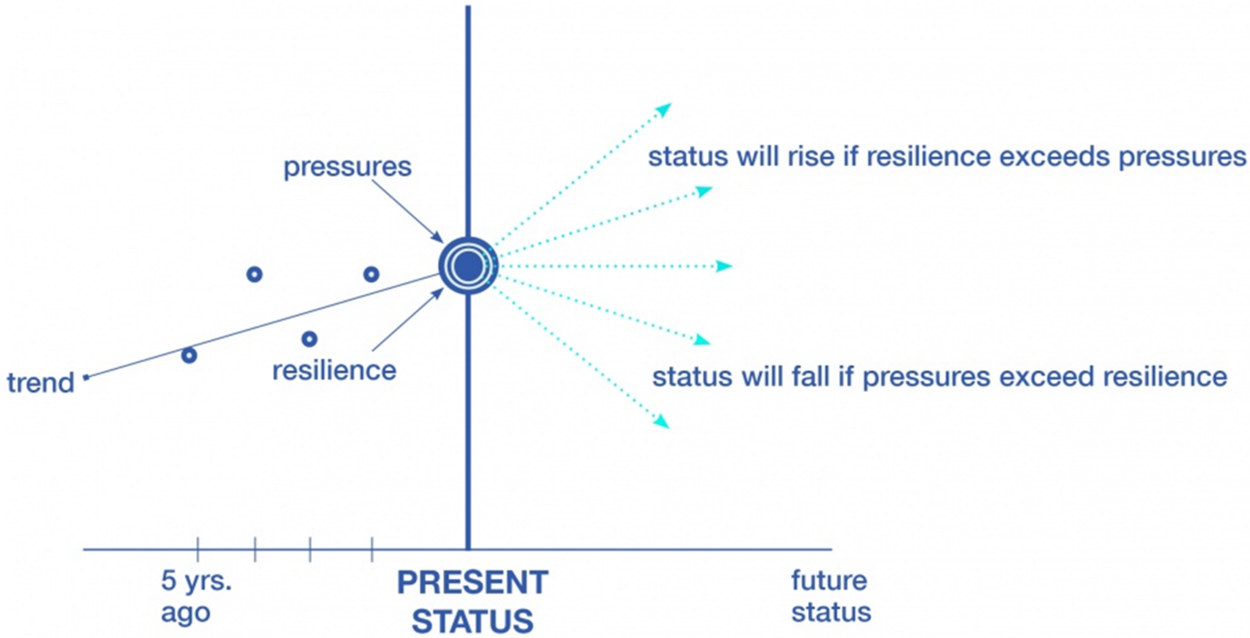
Inform testing management options, support sustainable actions, and increase collaboration/communication

The Ocean Health Index was developed for Hawai‘i through the support of local experts, stakeholder surveys, working groups, workshops, and meetings. A coalition for sustainable ocean management was built through bringing together management agencies, stakeholders, and organizations to support sustainable ocean management through a clear vision of ocean health and a united common goal of assessing and tracking ocean health in Hawai‘i. The conceptual framework of the Hawai‘i OHI assessment was adapted from the global OHI framework to meet Hawaii’s unique ecological, social, economic, and cultural aspects.

Synergies with Existing Regional and Statewide Ocean Sustainability Initiatives

The Hawai‘i Ocean Health Index supports the *Aloha+ Challenge* targets through measuring ocean health under the Natural Resources target on the Governor’s Dashboard. The *Aloha+ Challenge* is a joint leadership commitment to sustainability for the State of Hawai‘i that was launched by Hawaii’s Governor, its four mayors, and the Office of Hawaiian Affairs in July 2014. The *Aloha+ Challenge* sets six statewide sustainability targets to be achieved by 2030 – in clean energy transformation, local food production, natural resource management, solid waste reduction (discarded resource recovery), smart sustainable communities, climate resilience, green job creation, and education. The purpose of these targets is to provide a shared framework to set priorities, take action, and track progress toward a more sustainable and resilient Hawai‘i

Calculating the Index



Index, Regional, and Goal Scores

The index (I) score is the sum of the regional scores (I_{region}). All regions were given equal weight in the index (α_i).

$$I = \sum_{i=1}^{N} \alpha_i I_{region,i}$$

The regional scores (I_{region}) are the sum of all the individual goal scores (G_i). All goals were given equal weight in the index (α_i).

$$I_{region} = \sum_{i=1}^{N} \alpha_i G_i$$

The goal score (G_i) is the average of current status (50% of the goal score) and probable future state (50% of the goal score).

$$G = \frac{x + x_f}{2}$$

The goal current status (x) is calculated using available indicators in relation to a stakeholder set reference point (see goal models below for specific models for each goal). The probable future status (x_f) measures the cumulative pressures (negative impacts on a goal score), cumulative resilience (positive impacts on a goal score) and trend (projected goal status in five years). The future status score is the near future score projection of a goal calculated as the current goal status multiplied by the 5 year status trend (*T*) and the difference in the resilience (*r*) and pressure (*p*) applied to that goal (Halpern et al., 2012).

$$x_{i,f} = [1+\beta T_i+(1-\beta)(r_i-p_i)]X_i$$

The tend is given a higher weight ($\beta = 0.67$) than the pressure/resilience component. This value was choosen based on the assumption that trend is a better indicator of the near future condition than indirect measures of pressure and resilience (Halpern et al., 2012). All pressure and resilience values are scaled from 0 to 1 and trend is constrained to -1.0 to +1.0.

Pressures and Resilience

Cummulative pressures acting on each goal are calculated as the sum of ecological (p_E) and social pressures (p_S):

$$p = \gamma * p_E + (1-\gamma) * p_S$$

Where γ is the relative weight for ecological vs. social pressures, set as equal (0.5).

Each pressure layer is assigned to an ecological or social category, with ecological pressures further assigned to one of five subcategories (pollution, alien species, habitat destruction, fishing pressure, and climate change). Each ecological pressure layer is then applied to relevant goals and assigned a rank sensitivity or the weight of the pressure on that goal from 1 to 3 with 1 being low impact, 2 being medium impact, and 3 being high impact. Ecological pressures are then calculated as the wieghted average of the pressure scores for each category for each goal (see Halpern et al. 2012). Social pressures are unweighted and the social pressure exerted on a goal is calculated as the average of the all the social pressures applied to that goal (Halpern et al. 2012).

Resilience layers are assigned to three categories: ecological integrity, regulatory efforts, and social integrity. Ecological integrity and regulatory effort resilience scores address ecological pressures and therefore are averaged together and added to the social integrity resilience scores for each goal (Halpern et al. 2012).

The pressure and resilience layers help capture the complex interactions social and ecological interactions that are exerted on each goal. For example, increased visitors can support Livelihoods & Economies but can exert a pressure on habitat health and therefore reduce Biodiversity. These interactions are captured in the Ocean Health Index through pressure and resilience layers that are scored and applied to each goal. See the section on Data Layers for a full list of the pressures and resilience layers that are applied to each goal.

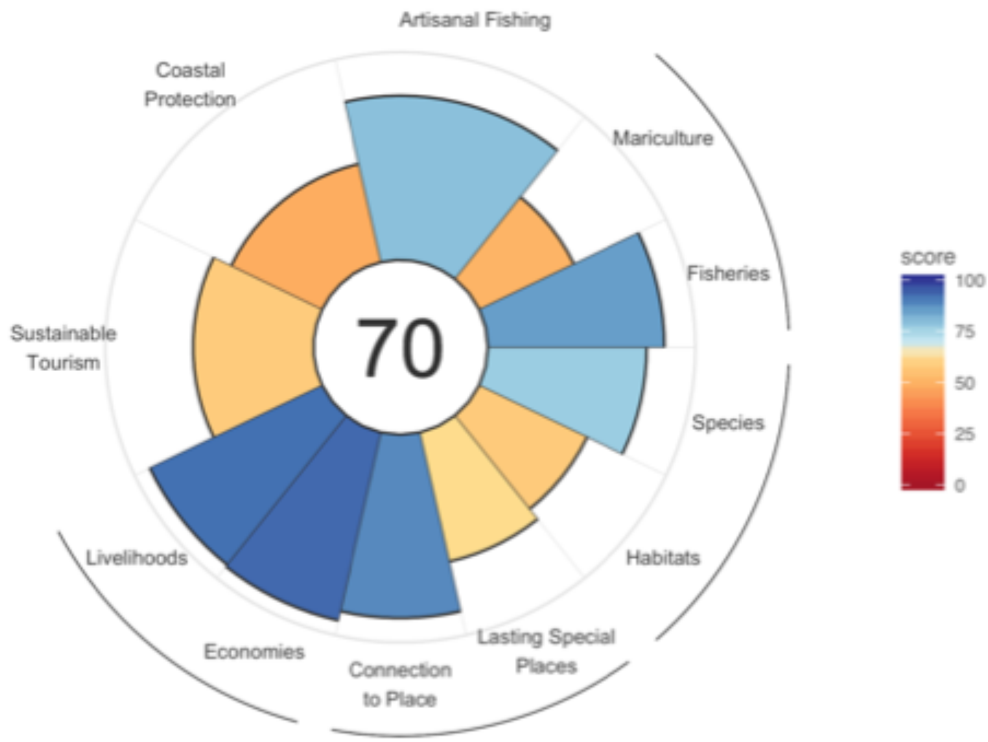
Spatial Extent

The Hawai‘i OHI was a statewide assessment for the Main Hawaiian Islands. The assessment was done at the county scale (Hawai‘i, Maui Nui, O‘ahu, and Kaua‘i) and averaged to produce the overall Hawai‘i Ocean Health Index score. The OHI focus is on the entire EEZ, however, some goals are assessed on the nearshore (3 nm scale) (Table 2).

Table 2. Spatial extent of goal models.

Goal	Sub-Goal	Primary Scale of Goal
Food Provision	Fisheries	EEZ
	Mariculture	Nearshore
Artisanal Fishing Opportunities		Nearshore
Sense of Place		Nearshore
Sustainable Tourism		Nearshore
Biodiversity	Species	EEZ
	Habitats	EEZ
Coastal Protection		Nearshore
Livelihoods & Economies		EEZ

Results

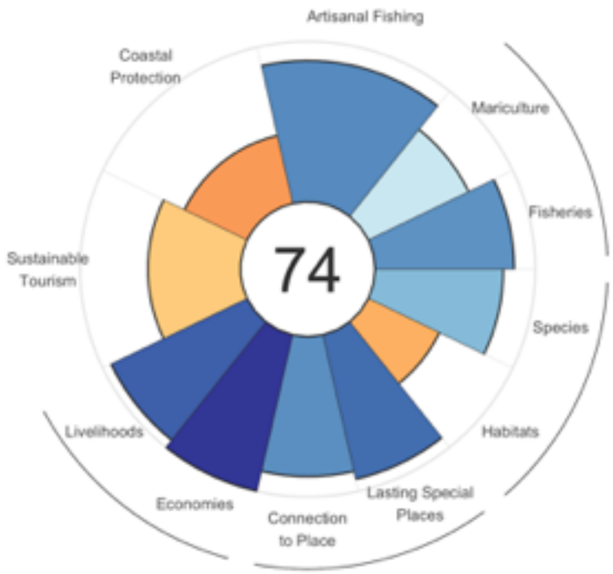


MAIN HAWAIIAN ISLANDS

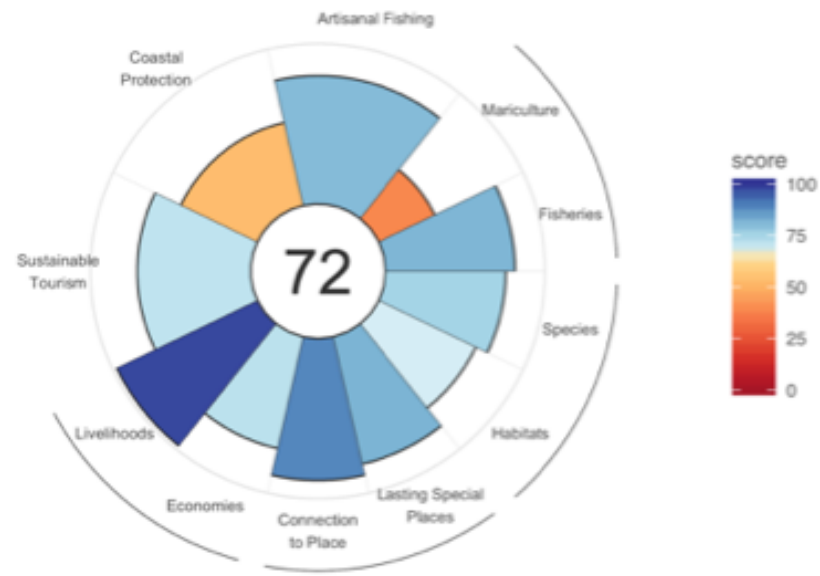
The Main Hawaiian Islands scored 70, with Hawaiʻi Island having the highest regional Ocean Health Index score (74), followed by Maui Nui (72), Kauaʻi (72), and Oʻahu (61). Ocean Livelihoods & Economies received the highest score (93), followed by Artisanal Fishing Opportunities (82), Sense of Place (79), and Food Provision (70) (Table 3). Coastal Protection received the lowest goal score (49) followed by Sustainable Tourism (58) and Biodiversity (67). Goals or subgoals that incorporated ocean and coastal habitat health or protection (Coastal Protection, Biodiversity subgoal Habitats, Sustainable Tourism, and Sense of Place subgoal Lasting Special Places) tended to score the lowest, highlighting the need to protect or restore these habitats ensure the benefits that these goals provide will sustain into the future.

Table 3. Goal scores for the Hawaiʻi Ocean Health Index.

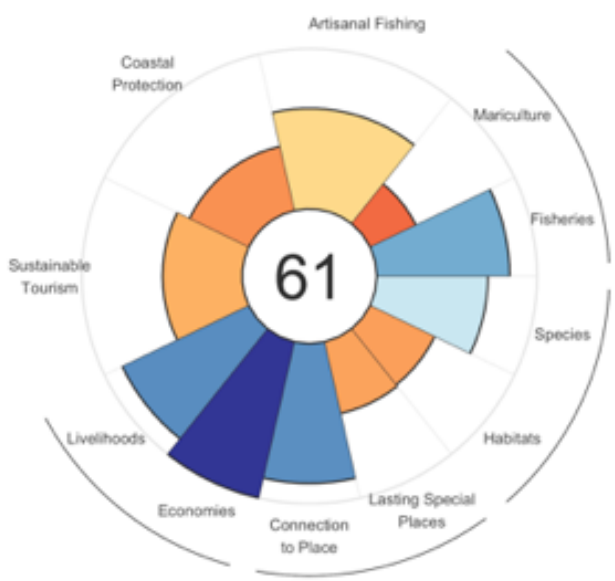
Region	FP		AO	SP		ST	BD		CP	LE	
	FIS	MAR		LSP	CON		HAB	SPP		LIV	ECO
Main Hawaiian Islands	85	51	79	64	88	58	59	77	49	92	92
Hawaiʻi	87	69	88	92	87	58	51	80	43	94	100
Maui Nui	81	39	80	81	89	71	68	75	53	97	72
Oʻahu	82	31	63	46	87	50	46	69	41	87	100
Kauaʻi & Niʻihau	89	62	86	36	90	53	71	82	56	88	100



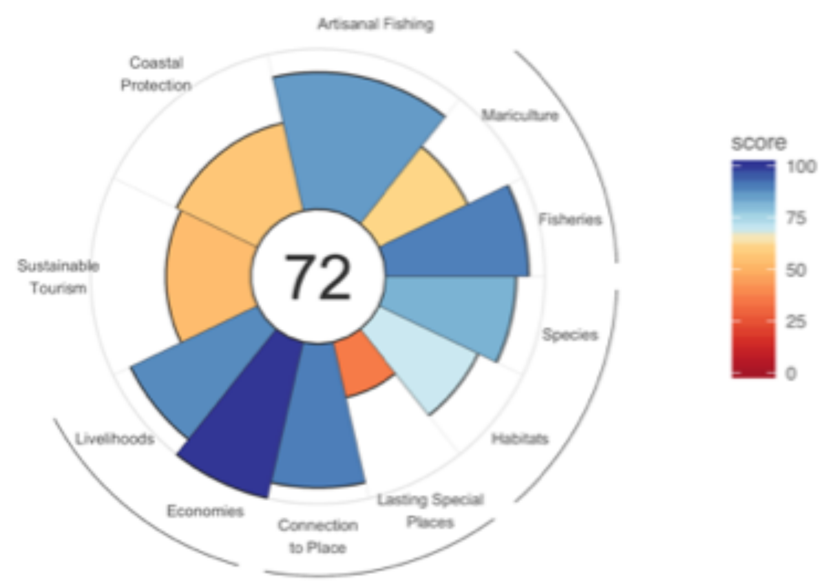
HAWAI‘I



MAUI NUI



O‘AHU



KAUA‘I & NI‘IHAU

Goal Scores

Food Provision | Artisanal Fishing Opportunities | Sense of Place | Sustainable Tourism | Biodiversity | Coastal Protection | Livelihoods & Economies

FOOD PROVISION

Over half (55%) of available seafood in Hawai‘i is locally sourced. Nearly 34 million lbs. (99%) comes from wild caught fisheries and 0.35 million lbs. (1%) comes from mariculture. Of the 34 million pounds of seafood caught in Hawai‘i annually, the majority of the catch is from the pelagic fishery, followed by the reef fishery (commercial & non-commercial catch), coastal pelagic fishery, and bottomfishery (Table 4). Wild caught fisheries received a score of 85 reflecting that the majority of the catch comes from sustainable fisheries, with a score of 100 meaning that harvest for all fish species is done at sustainable level. Sustainability scores varied across species, with several species exploited beyond sustainable biological limits. For the majority of fish species, the sustainability scores are declining over time, reducing the future sustainability of many of the species assessed which has the potential to have larger ecosystem impacts.

Table 4. Total catch (2016) for each fishery (reef, bottom, coastal pelagic, and pelagic) and mean sustainability score.

Fishery	Mean Annual Catch (lbs.)	Mean Sustainability Score
Reef	2,694,641	0.81
Bottomfish	428,181	0.88
Coastal Pelagic	583,030	NA
Pelagic	30,230,053	0.80

Production of edible seafood is relatively low compared to Hawaii’s wild caught fisheries, representing 1% of the total seafood production. Mariculutre production in Hawai‘i comes from contemporary mariculture production (also referred to as aquaculture) and from traditional Hawaiian fishponds, known locally as loko i‘a. Historically, seafood from traditional Hawaiian fishponds played a large role in sustaining Hawaiian populations. In the early 1900s, Hawaiian fishponds produced 400-600 lbs. of seafood per acre (Honua Consulting, 2013). Today, 44 out of the estimated 99 fishponds in the 1900s remain and many are being restored to viable seafood production systems. The number of restored fishponds was used as a metric for seafood production potential and is part of the mariculture score along with contemporary mariculture production system.

Several species of finfish and shellfish are grown in Hawaiʻi for food consumption. However, many of the mariculture species grown in Hawaiʻi do not support local food provision such as microalgae and brood stock shrimp. Therefore, while revenue is high for Hawaii's mariculture industry ($78 Mil in 2014; (HDA)), the yield or production of edible seafood is relatively low compared to Hawaii's wild caught fisheries. Mariculture scored 51, reflecting the sustainability of production from contemporary mariculture systems (consistent production of seafood and species environmental impact and biosecurity risk scores) and the current progress to increase seafood production from Hawaiian fish ponds by restoring 30% of Hawaiian fishponds. Future projections show that local seafood production will meet only 45% of the local seafood demand by 2040. Therefore, mariculture may play a larger role in future seafood production in the future.

ARTISANAL FISHING OPPORTUNITIES

This goal measures the benefits that the ocean provides for artisanal fisheries (also called subsistence fisheries) measured through access to the resource and the status of the nearshore fishery resources. Artisanal fishing is part of Hawaii's unique culture, provides local communities with meals, and is a valued recreational activity. Thirty-three percent of locally caught seafood is estimated to come from the non-commercial or artisanal fishery, with 5% from the nearshore and coral reef fishery. While fisher access to resources is high, the availability of the resource scores are average to poor across Hawaiʻi (Table #). Nearshore fishery resource scores were lowest on Oʻahu (54) where the coral reefs are the most degraded and where there is the highest fishing pressure. Additionally, access to the resource is lowest on Oʻahu due to the larger military zones and no-take marine protected areas on the Island (Table 13). Nearshore fishery recourse scores were highest on Kauaʻi & Niʻihau (72), however access to the resource was highest on Hawai'i Island (Table 5).

Table 5 Artisanal fishing opportunities indicator scores.

Region	Access	Resource
Hawaiʻi	98	66
Maui Nui	91	66
Oʻahu	72	54
Kauaʻi & Niʻihau	92	72

SENSE OF PLACE

Cultural values are expressed in the development of this goal and several of the other goals, as local and cultural values are recognized as important to all aspects of ocean health. This goal stresses the importance of the ocean and coastal areas for maintaining cultural practices, community wellbeing, and general sense of place. Sense of Place is comprised of two subgoals: Lasting Special Places and Connection to Place.

Lasting Special Places measures the importance of maintaining coastal and ocean areas that provide cultural and spiritual value to people. This goal tracks the protection of marine and terrestrial coastal areas. Lasting special places received a score of 64, with 14.1% of nearshore areas protected and 28% of coastlines protected (Table 6). A score of 100 will be achieved when the State of Hawaiʻi meets its Hawaiʻi Sustainability Initiative of 30% of nearshore waters effectively managed by 2030 and 30% of the coastline is protected within conservation districts.

Table 6. Lasting Special Places goal indicators by region.

Region	Percent of Coastline Protected	Percent of Nearshore Waters Protected
Hawaiʻi	28	23
Maui Nui	32	12
Oʻahu	18	6
Kauaʻi & Niʻihau	15	3

Connection to place measures the connection or relationship that people have with the ocean and coastal areas. Hawaiʻi has a strong connection or relationship with the ocean, scoring 88. How we use ocean areas can in part define our connection and values towards them thus Connection to Place is measured through resident participation rates in ocean activities. On average, 89% of Hawaiʻi residents participate in an ocean activity at least once a month (Table 7).

Table 7. Hawaiʻi resident participation rates in ocean activities at least once per month.

Region	Participation Rate
Hawaiʻi	89
Maui Nui	92
Oʻahu	92
Kauaʻi & Niʻihau	94

SUSTAINABLE TOURISM

This goal measures the balance between economic growth through tourism with management and preservation of natural resources and Hawaiian culture. This is measured through tracking visitor generated revenue, ocean and coastal management areas to preserve the environment and provide visitor ecotourism opportunities, and the sentiment of residents towards tourism. Sustainable tourism was scored based on the benefit of visitors to economic growth while taking into account the preservation of social and cultural values of residents and protection of the natural environment.

Scores ranged from 50 to 71 by region, with Oahu receiving the lowest score and Maui Nui receiving the highest score. The relatively low scores reflect the need to balance the economic gains with the preservation of Hawaii's unique cultural and natural environment. Tourism contributed $11.8 billion in visitor generated revenue in 2015, contributing 14% to Hawaii's

GDP from visitor spending alone. However, increased stewardship and protection is needed to balance the increased human use from visitors on ocean and coastal areas. Currently 13% of nearshore are protected by marine management areas, with the target set at 30% protection by 2030 (State of Hawai‘i). Additionally, watershed protection is included in this goal for the benefits that watersheds provide such as freshwater retention and reducing water pollution and soil erosion to the nearshore environment. Currently 15.3% of priority watersheds are protected (Yuen, 2017), the target set at 30% protection by 2030 (State of Hawai‘i). Lastly, resident sentiment is included as a metric in this goal, with resident's sentiment or satisfaction of tourism currently at 61% and has been steadily declining over the past 7 years (HTA, 2017a).

Stakeholders have identified several areas to increase the preservation of social and cultural values and the natural environment. These include increased tourism education programs, increased proportion of the tax revenues generated from the tourism industry allocated to community and environmental preservation and increased freshwater reserves to accommodate both residents and visitors.

BIODIVERSITY

Hawai‘i has unique and diverse coastal habitats and species. Coastal habitats assessed include fishponds, wetlands, beaches, and coral reefs. These habitats and the species that reside in them are the foundation of many of the benefits that we receive from the ocean including food provision, coastal protection, sustainable tourism, sense of place, and our livelihoods and economy. However, our ocean and coastal habitats surrounding the Main Hawaiian Islands are threatened and we are seeing the impacts of coastal pollution, unsustainable development, and climate change on the resulting habitat condition. Hawaii's ocean habitats are in average to poor condition with 54% of historical coastal wetlands intact, coral reef condition declining drastically with increased water pollution and recent coral bleaching events, and the extreme erosion of our coastlines, with 72% of beaches actively eroding (Table 8). Protecting and restoring these habitats is essential to sustaining our community and economy now and into the future.

Table 8. Habitat extent and condition by region.

Region	Habitat	Condition	Extent
Hawai‘i	beach	28	55.9 km
Maui Nui	beach	15	144.1 km
O‘ahu	beach	40	140.8 km
Kaua‘i & Ni‘ihau	beach	29	133.6 km
Hawai‘i	reef	81	238.6 km^2
Maui Nui	reef	70	461.3 km^2
O‘ahu	reef	60	374.2 km^2
Kaua‘i & Ni‘ihau	reef	61	347.3 km^2
Hawai‘i	wetland	25	0.2 km^2
Maui Nui	wetland	75	11.9 km^2
O‘ahu	wetland	29	6.7 km^2
Kaua‘i & Ni‘ihau	wetland	85	3.8 km^2

Hawaii’s ocean is home to over 565 endemic marine species. This equates to over 20% of marine fishes in Hawai’i found nowhere else on earth. The Endangered Species Act (ESA) was established in 1973 to provide for the conservation of species that are endangered or threatened (likely to become endangered in the near future without protection) throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend.

The Species subgoal of Biodiversity measures the species status based on the percent of species listed on the Endangered Species List and on the population status of Hawai’i coral reef fish species. Species received a score of 77, with the majority of marine species (marine, mammals, turtles, shorebirds and seabirds, and coastal sand and dune plants) not listed as threatened or endangered. However, while fish and coastal plants scored fairly well, sea and shore birds and marine mammals and turtles are the most threatened. Seabirds and shorebirds has the highest rate of endangered, threatened, or listed species of concern (53%), followed by marine mammals and turtles with 39% of Hawaii’s marine mammals and turtles listed on the Endangered Species List.

COASTAL PROTECTION

Coral reefs, wetlands, and beaches protect Hawaii’s coastline from flooding and inundation. The protective ability of these habitats depends on their extent and condition. Coastal Protection received a score of 49. A score of 100 would indicate that these habitats are all still intact or have been restored to their reference conditions. Beach habitat was scored based on the percent of beaches that are not actively eroding, receiving very low scores, with over 72% of beaches actively eroding across Hawai‘i. Wetland habitat was scored based on the current coastal wetland habitat compared to historical extents. With many of the historical coastal wetlands filled in and lost through coastal development. Lastly, coral reefs were scored based on several benthic indicators such as coral cover, algae cover, coral mortality, and juvenile and adult coral densities. Coral reefs scored lowest on O‘ahu and highest on Hawai‘i Island.

Coastal protection scores also take into account pressures such as climate change on these coastal habitats. Climate change poses a huge threat to coastal communities and Hawaii’s economy. Sea level rise is protected to cause increased coastal erosion and inundation, furthering the importance of our coastal habitats to buffer against these changing ocean conditions (Hawai‘i Climate Change Mitigation and Adaptation Commission).

LIVELIHOODS & ECONOMY

Ocean revenues contribute over 6 billion to Hawaii’s economy each year and directly provide 16% of jobs (103,427 in 2013) (Table 9). A Livelihoods & Economies score of 92 reflects the ability of ocean sectors to provide livelihood opportunities, and consistent or stable revenue generated from ocean sectors.

Livelihoods measures job quantity and quality for people living on the coast. Livelihoods includes two equally important sub-components, the number of jobs, which is a proxy for livelihood quantity, and the per capita average annual wages, which is a proxy for job quality. The tourism and recreation sector represent between 85% to 99% of the total ocean sector jobs per county. Mean wage is lowest in this sector at $20,919 in 2013. This is 48% lower than the state mean wage (DBEDT) and 36% below the self-sufficiency standard (DBEDT, 2015a).

Table 9. Ocean contribution to Hawaii's livelihoods and economy.

Region	Total Ocean Sector Jobs	Percent of Jobs per Region	Revenue (mil)
Hawai'i	13,576	16%	993.2
Maui Nui	25,423	32%	2,165.5
O'ahu	59,164	13%	2,700.1
Kaua'i & Niihau	5,264	16%	217.9

Economies captures the economic value associated with marine industries using revenue from marine sectors. Ocean revenues contribute over $6 billion to Hawaii's economy annually and have remained stable over the past five years.

Goal Models & Data

The following section outlines the models and data used to develop each goal and subgoal in the Hawai'i Ocean Health Index. All of the data for this assessment is available at ohi-science.org/mhi.

Food Provision

This goal measures the sustainably harvested and produced seafood from fisheries and aquaculture (local production of seafood including shrimp ponds and fishponds) in Hawai'i.

$$X_{FP} = \frac{X_{fis} + X_{mar}}{2}$$

Wild Caught Fisheries

This subgoal of Food Provision measures the amount harvested and sustainability of Hawaii's fisheries. The model generally compares landings with Maximum Sustainable Yield.

$$X_{fis} = \sum_{i=1}^{n} Fishery_i \prod_{i=1}^{n} SS_i^{\frac{C_i}{\sum C_i}}$$

Where *Fishery* is the pelagic, bottomfish, coastal pelagic, or nearshore fishery, *SS* is the stock status scores, and *C* is the catch.

The model assesses the amount of wild-caught seafood that can be sustainably harvested from within the Hawai'i EEZ, with sustainability (stock status scores) based on formal stock assessments. Catch data was provided by The Department of Land and Natural Resources Division of Aquatic Resources (DLNR DAR). A multiplier for reef fish catch was used to estimate non-commercial catch (McCoy et al., 2018).

Stock status scores were calculated as the mean of the all stock status scores for each fishery (pelagic: tuna, swordfish, mahimahi, etc.; bottomfish: deep seven species mainly groupers and snappers; coastal pelagics: jacks, akule, ʻōpelu, etc.; nearshore: surgeonfish, parrotfish, etc.). Longline data for pelagic species landed in Hawaiʻi but caught outside of the OHI assessment region (Main Hawai'i Island EEZ) was not included in the assessment. Each stock is assessed separately based on stock status scores (Biomass at maximum sustainable yield: B/Bmsy; Spawning biomass at maximum sustainable yield: SB/SBmsy; and Spawning Potential Ratio: SPR). We applied a 0.05 upper and lower buffer on the stock status score allowing for error in the stock status.

Stock status reference points used in formal stock assessments vary by the fishery type. The pelagic fish sustainability reference point was SB/SBmsy, with a reference value of 1.0. The bottomfish species sustainability reference point was B/BMS, with a reference value of 1.0. The reef fish sustainability reference point was the spawning potential ratio (SPR), with a reference value of 0.30. The most recent stock assessments for pelagic fish species were 2012-2013 for most species (WCPFC; ISC, 2017). Therefore, the ten most recent years of stock assessment data was used to run a linear regression model to predict stock status to 2016. If stock status was non-linear then the mean stock status was used. Bottomfish stocks were assessed as a species complex (Brodziak et al., 2014). Only one assessment is available for reef fish stock assessments (Nadon, 2017), so the stock status was held constant over the 5 assessment years. We used median scores for each group (pelagic, bottom, coastal pelagic, and reef) to gap fill for species that lacked formal stock assessments. To include these important harvest species, we made the assumption that the unassessed species within each fishery (pelagic, bottomfish, nearshore/reef, coastal pelagic) are faring similarly to the assessed fish stocks. There were no current formal stock assessments for coastal pelagic species and therefore they are not incorporated into the score for this goal, but they are included in the catch data for reference, comprising approximately 2% of commercial catch.

Table 10. Mean annual catch (lbs.) from 2012 to 2016 and sustainability score for reef and nearshore species.

Species	Mean Annual Catch (lbs.)	Score	Species	Mean Annual Catch (lbs.)	Score	Species	Mean Annual Catch (lbs.)	Score
Aawa	25,894	0.81	Kole	21,143	0.53	‘Ōpelu kala	26,052	0.43
Ahaaha	2,562	0.81	Kumu	25,769	0.50	Pakii	46	0.81
Aholehole	14,351	0.81	Kupipi	657	0.81	Pualu	33,252	0.40
Alaihe	3,002	1.00	Kupoupou	37	0.81	Puhi black	2,229	0.81
Alaihe mama	389	1.00	Laenihi	24,306	0.81	Puhi eel-misc.	1,645	0.81
Amaama	17,175	0.81	Maiko	6,591	0.53	Puhi white	872	0.81
Api	532	0.54	Malu	673	0.87	Randall's snapper	646	0.90
Awa	4,590	0.81	Manini	61,199	0.53	Roi	11,528	0.84
Awaawa	2,732	0.81	Maomao	7,215	0.81	Summer mullet	1,574	0.82
Aweoweo	41,588	0.81	Menpachi	381,403	1.00	Tilapia	5,917	0.82
Aweoweo (deepsea)	1,537	0.81	Moana	29,994	0.87	Toau	20,811	1.00
Black kole	1,103	0.53	Moana kale	14,826	0.80	Uhu parrot-misc.	1,077,847	0.97
Ea (wrasse)	1,043	0.81	Moi	1,239	0.81	Umaumalei	21,173	0.83
Golden kali	2,033	0.81	Mu	19,864	1.00	Uouoa	3,229	0.81
Hauliuli	116	0.81	Munu	2,870	1.00	Wahanui	329	0.89
Hinalea	85	0.81	Naenae	21,934	0.53	Weke	2,185	0.87
Hogo	11,572	0.81	Nenue	97,275	0.81	Weke a'a	20,509	1.00
Humuhumu	2,659	0.81	Nohu	8,368	0.81	Weke nono	38,174	1.00
Iheihe	378	0.82	Nunu	872	0.81	Weke pueo	2,083	0.87
Kaku	13,695	0.81	Oio	33,402	0.81	Weke ula	142,784	1.00
Kala	239,064	0.29	Olililepa	3,893	0.81			
Kawelea	18,403	0.81	Oopuhue	3,478	0.82			

Table 11. Mean annual catch (lbs.) from 2012 to 2016 and sustainability score for bottomfish species.

Species	Mean Annual Catch (lbs.)	Score
Alfonsin	35	0.88
Butaguchi ulua	306	0.88
Gunkan ulua	366	0.88
Kahala	15,621	0.88
White ulua	13,177	0.88
Ehu	30,173	0.84
Gindai	3,001	0.84
Kalekale	14,257	0.84
Lehi	10,332	0.84
Onaga	61,830	0.84
Opakapaka	130,982	0.84
Taape	31,373	1.00
Uku	110,802	0.98
Hapuupuu	9,194	0.84

Table 12. Mean annual catch (lbs) from 2012 to 2016 and sustainability score for coastal pelagic species.

Species	Mean Annual Catch (lbs)	Score
Akule	313,584	NA
Barred jack	50	NA
Dobe ulua	3,348	NA
Hahalalu	17,899	NA
Kagami ulua	221	NA
Kamanu	4,355	NA
Lae	254	NA
Omaka	28	NA
Omilu	6,846	NA
Opelu	223,704	NA
Opelu mama	40	NA
Paopao ulua	525	NA
Papa ulua	8,569	NA
Sasa ulua	393	NA
Ulua-misc.	1,751	NA
Shark-misc.	2,346	NA

Table 13. Mean annual catch (lbs) from 2012 to 2016 and sustainability score for pelagic species.

Species	Mean Annual Catch (lbs)	Score
Thresher	20,118	0.80
Monchong	1,168,014	0.80
Blue	17,780	0.93
Oceanic	462	0.93
Mahimahi	1,661,441	0.80
Blue marlin	1,489,631	1.00
Misc Istiophoridae Species	2,234	0.68
Sailfish	46,248	0.68
Striped marlin	1,005,382	0.37
Mako	119,501	0.80
Bigeye tuna	16,523,199	0.82
Bluefin	1,077	0.39
Kawakawa	18,179	0.80
Ono	1,075,297	0.80
Tombo	925,796	1.00
Yellowfin tuna	4,070,707	1.00
Swordfish	2,084,987	1.00

Data Gaps

- Bottom fish taxonomic resolution for the stock assessment was not assessed to species.
- Public perception of fisheries status.
- Catch from recreational fisheries is estimated through a formal scientific study that used social surveys to derive catch estimates. The number of recreational fishers and the recreation catch remains unknown.
- Estimates of non-reported commercial catch.
- Dealer reporting data.
- Lacking stock assessments for many of the harvested fish species and all of the coastal pelagic species.
- Invertebrates are not included such as opihi (limpets), sea cucumbers, he‘e (octopus), lobster, and others. They were excluded from the assessment because there is not an estimate of recreational catch, which is thought to be a large proportion of the catch, and stock assessments are lacking for most of these species.

Mariculture

This subgoal of Food Provision measures the sustainable production potential of seafood from fishponds and current production of seafood weighted by a sustainability score. The scores are an average of the state reported seafood production (aquaculture) and fishpond potential.

$$X_{mar} = \frac{X_c + X_t}{2}$$

$$X_c = \frac{\sum_{i=1}^{n} y_{c,i}}{\sum_{i=1}^{n} y_{r,i}} * S$$

$$X_t = \frac{f_c}{f_r}$$

Where X_c is the contemporary mariculture production and X_t is the traditional production from Hawaiian fishponds. X_c is measured as the sum of the yield (y_c) from each reported mariculture category (finfish and shellfish) compared to the maximum temporal yield (y_c) over the previous 5 years and weighted by the average species sustainability score. The production (yield: lbs. of seafood) is reported at the state level to prevent disclosure of sensitive information (HDA). To get county level estimates of production the yield of finfish and shellfish produced at the state level were multiplied by the estimated number of finfish and shellfish operators by county. The number of operators are reported to USDA via census every 5 years (2002, 2007, 2012) (USDA). To fill in annual data gaps linear regression models were used.

The species that are reported on the State Department of Land and Natural Resources Division of Aquatic Resources that are produced locally for seafood consumption include: Abalone (*Haliotus sp)*, oysters (*Crassostrea gigas* and *Crassostrea sikamea*), clams (*Venerupis philippinarum*), kahala (*Seriola dumerili*), Pacific White Shrimp (*Penaeus vannamei*), and limu (Gracilaria sp.). Moi (Pacific Threadfin) is not on the State of Hawaiʻi Department of Agriculture list but it is produced locally for out planting in fishponds. The sustainability of the species produced was assessed as the average of the feed sustainability score (0 protein based, 1 plant based; 0 imported feed, 1 local feed) and the biosecurity risk scored as species status (1 native, 0.75 introduced, or 0 invasive) and the pathogen and virus susceptibility (0 highly susceptible, 0.5 susceptible but preventative measures in place (biosecurity practices such as sterilization and wastewater treatment practices) (Table 14).

X_t is the production potential of traditional Hawaiian fish ponds measured as the current number of operational or restored fishponds (f_c) compared to the target (f_r) of 30% of historical Hawaiian fishponds restored. The original fishpond data layer (Ogden Environmental Services, 1994) was modified by The Nature Conservancy and used in this analysis.

Table 14. Common mariculture species in Hawai‘i and their corresponding sustainability scores.

Cultured Species	Species Name	Sustainable Feed (0=imported)	Feed Plant Based (0=protein based)	Susceptibility to Disease (0=highly susceptible)	Native (1), Introduced (0.5), Invasive (0)	Sustainability Score
Abalone	*Haliotus refens, Haliotus discus hanai*	1	1	1	0.5	0.88
Broodstock and juvenile shrimp	*Litopenaeus. vanamei, L. monodon, L. stylirostris*	0	0	0	0.5	0.13
Kahala (amberjack)	*Seriola dumerili*	0	0	1	1	0.50
Marine shrimp for food	*Penaeus vannamei*	0	0	0	0.5	0.13
Microalgae	*Spirulina sp, Hematococcus sp*	1	1	1	1	1.00
Seaweed/Limu	*Gracilaria sp*	1	1	1	0.5	0.88
Seed clams	*Mercenaria mercenaria*	1	1	1	0.5	0.88
Seed oysters and clams	*Crassostrea gigas, Venerupis Philippinarum, Crassostrea Sikamea*	1	1	1	0.5	0.88
Tilapia	*Oreochromis* sp	0	0	0	0	0.00

Data Gaps

- Kapuna knowledge on fishpond historical locations, practices, and production.
- Public perceptions of farmed seafood.
- Unknown total lbs. produced some years and some counties due to non-disclosure requirements.
-

Artisanal Fishing Opportunities

This goal measures the benefits that the ocean provides for subsistence or artisanal fisheries and is measured by the access to the resource and the status of the resource.

$$X_{AO} = \frac{\frac{a_c}{a_r} + \frac{b_c}{b_r}}{2}$$

Access was defined as the percent of coastline that is accessible by fishers that is not zones as not-take Marine Protected Areas or military zones (a_c). The reference condition for accessibility is 100% of the fishable shoreline (fishable shoreline excludes high cliffs) (a_r). Resource condition was defined at the current nearshore fish indicator score (based on available fish biomass) (b_c) compared to adjusted fish indicator score modeled on pristine nearshore fish biomass and fish length (b_r).

Access data was modified from the Ocean Tipping Points fishing pressure data layer (OTP). Resource condition comes from the NOAA Coral Reef Ecosystem Program and the NOAA Coral Reef Status Report (in prep). Resource condition was measured through a reef fish indicator. The reef fish indicator is the average of 3 components (Reef Fish Biomass, Reef Fish Sustainability, and Reef Fish Predators). Reef Fish Biomass measures the mean biomass of all reef fishes other than sharks and jacks derived from underwater visual surveys of <30m hardbottom habitats. Survey biomass per location is compared against a meaningful local baseline (to account for inherent environmental and habitat differences among locations). High scores therefore represent populations that are close to their natural carrying capacity. Reef Fish Sustainability represents an index of mean size for targeted reef fish species relative to their size at first maturity. High scores therefore represent assemblages where there are still many of large individuals of targets species, those large fishes being particularly important components of the breeding stock. The Reef Fish Predators indicator is made up of 2 components: ‘reef sharks’ and ‘other reef piscivores’ with data taken respectively from towed-diver and point-count surveys by divers. High scores represent locations where upper trophic level fishes are still a conspicuous and ecologically important component of the reef ecosystem. Trend was calculated as the change in the resource over the past 5 years 2010-2015 (Williams, 2017).

Data Gaps

- Biomass of harvest fish from open access areas (with biomass from MPAs not included in the assessment).
- Number of fishers
- Fish flow
- Catch and effort data

Sense of Place

This goal is composed of two subgoals: Lasting Special Places (X_{lsp}) and Connection to Place (X_{con}). Lasting special places tracks the protection of marine and coastal areas. Connection to place is the connection that people have to coastal and marine environments.

$$X_{sp} = \frac{X_{lsp} + X_{con}}{2}$$

Lasting Special Places

The DLNR Division of Aquatic Resources marine management data layer (Office of Planning) was clipped to 3nm offshore. The score of lasting special places was assessed the mean of the nearshore and coastal protection, calculated as the ratio of the total nearshore protected area (MPA_{3nm}) to the total area (A_{3nm}) within 3nm from shore and the ratio of the coastal protection (*CD*) to the 1 km coastal area (*CA*) weighted by coastal conservation district protective ability (PA) (Table 15).

$$X_{lsp} = \frac{\frac{MPA_{3nm}}{0.3 * A_{3nm}} + \frac{CD * PA}{0.3 * CA}}{2}$$

Table 15. There are five types of conservation districts. Coastal conservation districts were weighted by their protective ability.

Conservation District Type	Weight
Protective	1.0
Limited	0.9
Resource	0.8
General	0.7
Special	0.6

Data Gaps

- Sacred and protected cultural and historical places (wahi pana) were suggested for inclusion in Lasting Special Places however we were not able to include them because we lacked a historical reference point. While there is data on the number protected, it is hard to know how many wahi pana have been lost over the years without an adequate reference.

Connection to Place

There were many very valuable suggestions on how to measure Connection to Place including the use and knowledge of Hawaiian place names. Hawaiian names often reflect the activities, history, and the environment of the place. Unfortunately, there was no available and consistent way to measure the use of Hawaiian place names. This is a data gap and need that was identified during the development process for this goal. Therefore, Connection to Place was measured through activities that take place in each place, assessed as the participation rate in ocean and coastal activities.

$$X_{con} = \frac{a_c}{a_r}$$

Where a_c is the current resident participation rates in any ocean activity and a_r is the reference participation rate, participation in any ocean activity at least once per month.

This information was collected across the state by the NOAA Coral Reef Conservation Program 2014 socioeconomic surveys of human use, knowledge, attitudes, and perceptions in Hawaiʻi (Gorstein et al., 2018). Unfortunately, 2014 was the first year of this assessment so there is not a trend score for this subgoal. NOAA Socio-economic division began surveys to track the frequency of recreational activities in Hawai'i in 2014 and these surveys are planned to be repeated every 5-7 years.

To find opportunities to connect to place and give back please see Hawaiʻi Conservation Alliance's Conservation Connections http://www.conservationconnections.org/.

Data Gaps

- Knowledge and records of Hawaiian place names including information on cultural practices and uses of place.

Sustainable Tourism

This goal measures the balance between economic growth through tourism with management and preservation of natural resources and Hawaiian culture. The Sustainable Tourism goal model is the average of three indicators: *economic (r), sentiment (s)* and *environment (p).*

$$X_T = \frac{\frac{r_c}{r_r} + \frac{s_c}{s_r} + \frac{p_c}{p_{30}}}{3}$$

where

e_c=current annual growth in visitor generated revenue (GDP)

e_r= reference annual growth rate in visitor generated revenue of +2.5%

$r \geq 2.5\% = 1$

$r > 1.5\%$ and $r > 2.5\% = r$

$r \leq 1.5\%$ and $r \geq = -0.3\% = 0.5$

s_c= current sentiment

s_r=reference sentiment target of 80%

p_c =current percent of nearshore waters and priority watersheds protected

p_{30} =30% percent of nearshore waters and priority watersheds protected

The mean of *economic* (visitor generated GDP), *sentiment* (preservation of social and cultural values), and *environment* (protection of key habitats) were used to generate regional scores for sustainable tourism.

Economic was scored based on county estimated visitor generated GDP. Visitor contribution to the economy was measured in USD inflation adjusted (real) GDP. The reference level for visitor contribution to economic growth was set at $13,280 mil by 2020 or 2.5% annual growth rate (HTA, 2016). Visitor generated GDP was estimated to county level by weighting GDP by the average daily number of visitors to each county (visitors defined as overnight stays (DBEDT 2016)).

Sentiment scores the preservation of social and cultural values estimated though HTA visitor sentiment surveys (HTA, 2017a). Three questions have been asked consistently and thus have time-series information. Responses to these questions were used to score the sentiment of residents on the benefits and impact of tourism in Hawai‘i. The three questions were to rate the level of impact and agreement on: 1. Rate the overall impact of tourism on your family, 2. Tourism has brought more benefits than problems, and 3. The island is being run for the tourists at the expense of the local people. The three questions were normalized to a score from 0 to 100 with 100 being positive or agreement on positive impacts of tourism for residence of Hawai‘i. Questions were averaged and scored to a reference value of 80 as set by the Hawai‘i Tourism Authority as their target acceptance rate (HTA, 2017a).

Environment scores the protection of the natural environment including ocean areas (Marine Protected Areas, Fishery Replenishment Areas, and Community Subsistence Fishing Areas) and priority watersheds (watersheds that provide essential freshwater and protect key biodiversity). Environmental protection data comes from DLNR Division of Aquatic Resources Marine Manage Areas database (Hawaii State Office Of Planning) and DLNR Division of Forestry and Wildlife (Yuen, 2017). A reference rate of 30% nearshore areas effectively managed and priority watersheds protected by 2030 is based on the Governor’s Sustainable Hawai’i Initiatives (State of Hawai‘i) (https://governor.Hawai‘i.gov/sustainable-Hawai‘i-initiative/).

Table 16. Regional and yearly Sustainable Tourism component scores (economic, sentiment, and environmental indicators) and combined status score.

Region	Year	Economic	Sentiment	Environment	Status
Hawai‘i	2011	100	67	42	70
	2012	100	61	42	68
	2013	63	64	42	56
	2014	88	64	42	65
	2015	50	61	42	51
Maui Nui	2011	100	67	72	80
	2012	100	61	72	78
	2013	100	64	72	79
	2014	92	64	72	76
	2015	50	61	72	61
O‘ahu	2011	100	67	35	67
	2012	100	61	35	65
	2013	50	64	35	50
	2014	50	64	35	49
	2015	50	61	35	49
Kaua‘i & Ni‘ihau	2011	100	67	34	67
	2012	100	61	34	65

	2013	100	64	34	66
	2014	50	64	34	49
	2015	50	61	34	48

Data Gaps

- While there are several education programs or information for visitors, data on park signage and education programs are not comprehensive or available state wide.
- An agreed upon plan for sustainable tourism, economic growth, and ecotourism has not been established by the State of Hawai‘i.
- Among stakeholders it is unknown how much of the Tourism Accommodation Tax (TAT) goes back to environmental protection and restoration. Clarity and transparincy on the TAT is needed.

Biodiversity

The Biodiversity goal measures the conservation status of species based on two subgoals: Habitats and Species.

$$X_{BD} = \frac{X_{hab} + X_{spp}}{2}$$

Habitats

The Habitats sub-goal of Biodiversity measures the current extent and condition of ocean and coastal habitats (H_c) against a reference habitat extent and condition (H_r).

$$X_{hab} = \sum_{i=1}^{k} \left(\frac{H_c}{H_r}\right)$$

The habitat model assesses all habitats for which data are available to evaluate extent and condition, specifically: coral reefs, coastal wetlands and estuaries, beaches, and subtidal soft-bottom habitats. Status was calculated as the average of the condition estimates for each habitat present in a region. Condition was measured differently depending of the data available for the habitat and therefore was measured as the loss of habitat and/or percent degradation of remaining habitat.

Coral reefs

Coral reef extent was assessed from the cumulative impact mapping layers that combine hard bottom and coral reef habitats to a depth of 30 meters (Lecky, 2016). Coral reef condition was assessed through a coral reef index, which is a measure of coral reef health from combined indicators for coral cover, macroalgae (limu), coralline algae, and the ratio of calcifiers (corals and coralline algae) to non calcifiers (limu), coral mortality, juvenile coral density, and adult coral density. The coral reef index comes from the NOAA Hawai'i coral reef status report (NOAA CREP). Trend in coral reef health comes from the change in coral cover from 2011-2012 to 2016 surveys from the Main Hawaiian Islands (McCoy et al., 2017).

Beaches

Beach condition and trend data comes from Fletcher et al. 2012. Beach erosion is expected to increase with sea level rise and sea level rise acts as a large pressure on this goal. Beach extent is calculated as the total length of classifications 3, 4, and 5 from the National Oceanic and Atmospheric Administration Office of Response and Restoration Environmental Sensitivity Index (NOAA). Beach condition is the percent of beaches remaining stable (not eroding). The beach trend is the long-term erosion rate (past century) calculated from Fletcher et al. 2012. This data may be updated as USGS plans to assess the beach erosional rate every 5-10 years (Fletcher et al. 2012).

Soft Bottom
Near shore soft bottom habitat extent was mapped to a depth of 30 meters (Lecky, 2016). The condition was measured as the proportion of soft bottom habitat that was not dredged. Dredging was defined as activity involving physically removing substrate with machinery typically to allow for safe passage of vessels (Lecky, 2016).

Coastal Wetlands
Coastal wetland extent was assessed from National Oceanic and Atmospheric Administration Coastal Change Analysis Program (NOAA C-CAP) data clipped to within 1 km inland from the coast to capture coastal wetlands extent. Wetland condition information comes from Van Rees and Reed (2014) and was modeled as the percent loss of historical coastal wetlands to an elevation of 304 meters. Trend in coastal wetlands and estuaries was assessed as the difference in area from 1992 to 2010/2011 from NOAA CCAP wetlands extent within 1 km of the coastline.

Mangroves
Mangroves are invasive in Hawaiʻi and pose several negative ecological impacts (Allen, 1998), therefore they are not included in the goal models but they are included as a pressure that is applied to Biodiversity, Artisanal Fishing, Recreation, Sense of Place, and Food Provision.

Data Gaps
- Bioindicators of coral reef health are being developed by DAR and partners and will be used in future assessments of coral reef health.
- Additional habitats such as anchialine ponds, seamonts, deep sea coral reefs, estuaries, open ocean, and seagrass beds had limited information on condition or health and extent for all regions assessed and therefore were not included in the currect assessment. These habitats are considered important and will be incorperated into future assessements as scientific data on these importanct habitats becomes available.
- Estuaries are important habitats and are defined as the transition zone where fresh water from land meets and mixes with seawater creating some of the most productive ecosystems in the world. There are many challenges to mapping and defining estuary types. Currently, there is not a complete database for estuaries in Hawaiʻi. However, this database is currently being developed by the Hawaiʻi Department of Land and Natural Resources Division of Aquatic Resources.

Species
To assess species status, we combined information on local reef fish population status indicators and Endangered Species Act (ESA) status of marine mammals and turtles, seabirds and

shorebirds, and coastal plants. We incorporated reef fish indicators even though many of Hawaii's reef fish are not considered threatened or endangered as local indicators of reef fish populations and status are important for understanding the health of coral reefs.

$$X_{spp} = ESA + Fish$$

ESA status

Hawai'i does not have any listed extinct marine species, however Hawai'i is one of the species extinction capitals of the world due to the high presence of vulnerable endemic species. For a list of extinct species refer to the Bishop Museum Hawaii's Extinct Species (http://hbs.bishopmuseum.org/endangered/extinct.html). Extant species were asigned an ESA listing score based on the severity of the listing status (Table 17).

Table 17. The score given for specific ESA status.

ESA Status	Score
Non-concern or not listed	1.0
Threatened	0.5
Endangered	0.25

Marine Mammals & Turtles

Marine mammal and turtle species lists were from the Marine Biogeographic assessment for the Main Hawaiian Islands (Costa & Kendall, 2016). The status is based on the score given for each ESA category score, with listing status from NOAA Hawai'i Marine Mammal List (NOAA Fisheries) and US Fish and Wildlife Service (US Fish and Wildlife Service) (Table 18).

Seabirds and Shorebirds

Twenty-five seabirds were identified in the Marine Biogeographic assessment for the Main Hawaiian Islands (Costa & Kendall, 2016). There are at least 22 species of seabirds that breed in the Hawaiian Islands. Twenty of these species breed in the Main Hawaiian Islands (Costa & Kendall, 2016). Five shorebirds that are found in the Main Hawaiian Islands were added to the assessment (US Fish and Wildlife Service). Status was determine by ESA listings and from the State of the Birds yellow and red watch lists (US Fish and Wildlife Service; Rosenberg et al., 2010) and weighted by listing rank (Table 19, Table 20).

Table 19. Seabird and shorebird score weighting based on ESA status (https://www.fws.gov/endangered/) and State of the Birds yellow and red watch lists (http://www.stateofthebirds.org/2014/extinctions/watchlist.pdf).

ESA Status	Score
Non-concern or not listed	1.0
Yellow Watch List	0.7
Threatened	0.5
Endangered or Red Watch List	0.25

Table 18. The ESA status of Hawaii's marine mammals and turtles.

Common Name	Species Name	ESA Status
Blainville's beaked whale	*Mesoplodon densirostris*	NC
Blue whale	*Balaenoptera musculus musculus*	E
Bryde's whale	*Balaenoptera edeni*	NC
Common bottlenose dolphin	*Tursiops truncatus truncatus*	NC
Cuvier's beaked whale	*Ziphius cavirostris*	NC
Dwarf sperm whale	*Kogia sima*	NC
False killer whale	*Pseudorca crassidens*	E
Fin whale	*Balaenoptera physalus physalus*	E
Fraser's dolphin	*Lagenodelphis hosei*	NC
Green	*Chelonia mydas*	T
Hawaiian monk seal	*Neomonachus schauinslandi*	E
Hawksbill	*Ertmochelys imbricata*	E
Humpback whale	*Megaptera novaeangliae*	E
Killer whale	*Orcinus orca*	NC
Leatherback	*Dermochelys cariacea*	E
Loggerhead	*Caretta caretta*	E
Longman's beaked whale	*Indopacetus pacificus*	NC
Melon-headed whale	*Peponocephala electra*	NC
Minke whale	*Balaenoptera acutorostrata scammoni*	NC
North Pacific right	*Lissodelphis borealis*	NC
Olive Ridley	*Lepidochelys olivacea*	T
Pantropical spotted dolphin	*Stenella attenuata attenuata*	NC
Pygmy killer whale	*Feresa attenuata*	NC
Pygmy sperm whale	*Kogia breviceps*	NC
Risso's dolphin	*Grampus griseus*	NC
Rough-toothed dolphin	*Steno bredanensis*	NC
Sei whale	*Balaenoptera borealis borealis*	E
Short-finned pilot whale	*Globicephala macrorhynchus*	NC
Sperm whale	*Physeter macrocephalus*	E
Spinner dolphin	*Stenella longirostris longirostris)*	NC
Striped dolphin	*Stenella coeruleoalba*	NC

Table 20. Seabird and shorebird species for the Main Hawaiian Islands with ESA (E= endangered, T= threatened) or State of the Birds Status (Y=yellow watch list; R=red watch list).

Type	Common Name	Hawaiian Name	Species Name	Status
Seabird	Band-rumped storm-petrel		*Oceanodroma castro*	E
Seabird	Black-footed albatross		*Phoebastria nigripes*	Y
Seabird	Black noddy		*Anous stolidus pileatus*	Y
Seabird	Black-winged petrel		*Pterodroma nigripennis*	NC
Seabird	Blue noddy		*Procelesterna cerulean*	Y
Seabird	Brown booby	‘A	*Sula leucogaster*	Y
Seabird	Brown noddy	Noio koha	*Anous stolidus*	NC
Seabird	Bulwer's Petrel	‘Ou	*Bulweria bulwerii*	Y
Seabird	Christmas shearwater		*Puffinus nativitatis*	Y
Seabird	Cook‘s Petrel		*Pterodroma cookii*	NC
Seabird	Gray-backed tern	Pokalakla	*Onychonprion lunatus*	Y
Seabird	Great frigatebird	‘Iwa	*Fregata minor*	Y
Seabird	Hawaiian black noddy		*Anous minutus melanogenys*	Y
Seabird	Hawaiian petrel (dark-rumped petrel)	‘Ua‘u	*Pterodroma phaeopygia sandwichensis*	E(R)
Seabird	Juan Fernandez petrel		*Pterodroma externa*	NC
Seabird	Laysan albatross	Moli	*Phoebastria immutabilis*	Y
Seabird	Masked Booby	‘A	*Sula dactylatra*	Y
Seabird	Mottled petrel		*Pterodroma inexpectata*	NC
Seabird	Newell's shearwater	‘A‘o	*Puffinus newelli*	E
Seabird	Red-footed booby	‘A	*Sula sula*	NC
Seabird	Red-tailed tropicbird		*Phaethon rubricauda*	Y
Seabird	Sooty tern	‘Ewa‘ewa	*Onychoprion fuscata*	NC
Seabird	Wedge-tailed shearwater	‘Ua‘u kani	*Puffinus pacificus*	NC
Seabird	White or ferry tern	Manu-o-ku	*Gygis alba*	NC
Seabird	White-tailed tropic bird		*Phaethon lepturus*	Y
Shorebird	Bristle-thighed curlew	Kioea	*Numenius tahitiensis*	NC
Shorebird	Pacific golden plover	Kolea	*Pluvialis fulva*	NC
Shorebird	Sanderling	Hunakai	*Calidris alba*	NC
Shorebird	Ruddy turnstone	‘Akekeke	*Arenaria interpres*	NC
Shorebird	Wandering tattler	‘Ūlili	*Heteroscelus incanus*	NC

Coastal Plants

Species list and status of coastal plants were sourced from Merlin 1999 and the USFWS (https://ecos.fws.gov/ecp/) (Table 21).

Table 21. List of coastal plants and ESA status.

Common Name	Hawaiian Name	Species name	ESA Status
Beach spurge	Koko, ‘akoko	*Chamaesyce degeneri*	NC
	‘Ākia, kauhi	*Wikstroemia spp*	NC
	Ahuawa	*Mariscus javanicus*	NC
	Akaakai	*Schoenoplectella tabernae-montani*	NC
	Alena	*Boerhavia repens*	NC
	Degener‘s ‘akoko	*Euphorbia degeneri*	V
Dwarf naupaka	Dwarf naupaka	*Scaevola coriacsea*	E
Pandanus	hala/Pu hala	*Pandanus tectorius*	NC
	Hau	*Talipariti tiliaceus*	NC
	Hinahina	*Heliotropium anomalum*	NC
Hawaiian Nama	Hinahina Kahakai	*Nama sandwicensis*	V
Moonseed	Huehue	*Cocculus orbiculatus*	NC
	Hunakai	*Ipomoea imperati*	NC
	Kalo	*Colocasia esculenta*	NC
Alexandrian Laurel	Kamai	*Calophyllum inophyllum*	NC
	Kauna‘oa	*Cuscuta sandwichiana*	NC
	Kāwelu, ‘Emoloa	*Eragrostis variabilis*	NC
	Ka‘ena ‘akoko	*Euphorbia celastroides var. kaenana*	E
Ivy-leaved morning glory	Koali‘ai	*Ipomoea cairica*	NC
Coastal morning glory	Koali‘awa	*Ipomoea littoralis*	NC
Indian morning glory	Koali‘awa	*Ipomoea indica*	NC
	Makaloa	*Cyperus laevigatus*	NC
	Mau‘u/‘Aki‘aki	*Fimbristylis cymosa subsp. Spathacea*	NC
	Mau‘u/‘Aki‘aki	*Fimbristylis cymosa subsp. Umbellato-capitata*	NC
Hawaiian Cotton	Ma‘o	*Gossypium tomentosum*	V
	Milo	*Thespesia populnea*	NC
Bastard sandalwood	Naio	*Myoporum sandwicense*	NC
Beach sandalwood	‘Iliahialo‘e	*Santalum ellipticum*	V
Beach pea	nanea	*Vigna marina*	NC
Beach Naupaka	Naupaka kahakai	*Scaevola sericea*	NC
	Nehe	*Melanthera integrifolia, Lipochaeta integrifolia*	V
	Nehe	*Lipochaeta succulenta*	NC
	neke Fern	*Cyperus interruptus*	NC

Table 21. List of coastal plants and ESA status (continued).

Common Name	Hawaiian Name	Species name	ESA Status
Seaside heliotrope	Nena/Kipukai	*Heliotropium curassavicum*	NC
Coconut palm	Niu	*Cocos nucifera*	NC
Puncture vine	Nohu	*Tribulus cistoides*	NC
	Pa‘uohi‘iaka	*Jacquemontia ovalifolia*	NC
Beach vitex	Pohinahina	*Vitex rotundifolia*	NC
Beach morning glory	Pohuehue	*Ipomoea pes-caprae*	NC
	Pōpolo	*Solanum nelsonii*	E
Caper bush,	Pua pilo or Maiapilo	*Capparis sandwichiana*	V
Prickly poppy	Pua kala	*Aregemone glauca*	NC
	Puukaa	*Cyperus trachysanthos*	E
Schiedea		*Schiedea globosa*	V
	Uki	*Cladium jamaicense*	NC
Water Hyssop	‘Ae‘ae	*Bacopa monnieri*	NC
Seashore rushgrass	‘Aki‘aki	*Sporobolus virginicus*	NC
East Maui ‘Akoko	‘Akoko	*Euphorbia celastroides var. laechiensis*	E
Sea purslane	‘Akulikuli	*Sesuvium portulacastrum*	NC
	‘Anaunau	*Lepidium bedentatum*	V
	‘Ena‘ena	*Psuedognaphalium sandwicensium*	NC
	‘Ihi	*Portulaca molokiniensis*	E
Pigweed	‘Ihi	*Portulaca lutea*	NC
Hairy Purslane	‘Ihi	*Portulaca villosa*	E
Kilauea Portulaca	‘Ihi makole	*Portulaca sclerocarpa*	E
	‘Ilima	*Sida fallax*	NC
	‘Ohai	*Sesbania tomentosa*	E
	‘Ohelo kai	*Lycium sandwicense*	NC
	‘Ōhi‘a lehua	*Metrosideros polymorpha*	NC
	‘Ūlei, eluehe, u‘ulei	*Osteomeles anthyllidifolia*	NC
	Wiliwili	*Erythrina sandwicensis*	NC
	‘Uhaloa/Hi‘aloa	*Waltheria indica*	NC

Fish

The reef fish indicator is the average of 3 components (Reef Fish Biomass, Reef Fish Sustainability, and Reef Fish Predators) (Williams, 2017). Reef Fish Biomass measures the mean biomass of all reef fishes other than sharks and jacks derived from underwater visual surveys of <30m hard bottom habitats. Survey biomass per location is compared against a meaningful local baseline (to account for inherent environmental and habitat differences among locations). High scores therefore represent populations that are close to their natural carrying capacity. Reef Fish Sustainability represents an index of mean size for targeted reef fish species relative to their size at first maturity. High scores therefore represent assemblages where there are still many of large individuals of targets species, those large fishes being particularly important components of the breeding stock. The Reef Fish Predators indicator is made up of 2 components: 'reef sharks' and 'other reef piscivores' with data taken respectively from towed-diver and point-count surveys by divers. High scores represent locations where upper trophic level fishes are still a conspicuous and ecologically important component of the reef ecosystem.

Data Gaps

- Population assessments are not available for every marine species and tend to be focused on iconic and resource species.
- Eels and other cryptic species are not accurately assessed in standard marine monitoring surveys and are not represented in the reef fish indicator.

Coastal Protection

This goal aims to assess the amount of protection provided by marine and coastal habitats against flooding and erosion to coastal areas. The condition of each habitat was calculated with various methods depending on data availability, which are mostly based on coverage area. Habitats that are included and provide substantial coastal protection are: beaches, coral reefs, and wetlands. A score of 100 would indicate that these habitats are all still intact or have been restored to their reference conditions.

$$X_{CP} = \sum_{i=1}^{k} \left(\frac{C_c}{C_r}\right)$$

C is the current (c) condition and reference (r) condition.

Coral reefs

Coral reef extent was assessed from the cumulative impact mapping layers that combine hard bottom and coral reef habitats to a depth of 30 meters (Lecky, 2016). Coral reef condition was assessed through a coral reef index, which is a measure of coral reef health from combined indicators for coral cover, macroalgae (limu), coralline algae, and the ratio of calcifiers (corals and coralline algae) to non calcifiers (limu), coral mortality, juvenile coral density, and adult coral density. The coral reef index comes from the NOAA Hawai'i coral reef status report (NOAA CREP). Trend in coral reef health comes from the change in coral cover from 2011-2012 to 2016 surveys from the Main Hawaiian Islands (NOAA CREP 2016).

Beaches

Beach condition and trend data comes from Fletcher et al. 2012. Beach erosion is expected to increase with sea level rise and sea level rise acts as a large pressure on this goal. Beach extent is calculated as the total length of classifications 3, 4, and 5 types of beaches from the National Oceanic and Atmospheric Administration Office of Response and Restoration Environmental Sensitivity Index (NOAA). Beach condition is the percent of beaches remaining stable (not eroding). The beach trend is the long term erosion rate (past century) calculated from Fletcher et al. 2012. This data may be updated as USGS plans to assess the beach erosional rate every 5-10 years (Fletcher et al. 2012).

Wetlands

Wetlands are classified based on soil saturation, percent of herbaceous vegetation, trees and shrubs, locality (riverine), and salinity. Along with providing coastal protection, wetlands are important habitats which are crtitical habitats for many endemic and endangered plants and animals. Pressures to wetlands include invasive species (including mangroves), land development, and land-based sources of pollution.

Coastal wetland extent was assessed from National Oceanic and Atmospheric Administration Coastal Change Analysis Program (NOAA C-CAP) data clipped to within 1 km inland from the coast to capture coastal wetlands extent. All estuary categories were included in this assessment that were within 1km of the coastline as these habitats within 1km of the shoreline will mitigate against flooding and wave inundation. Wetland condition information comes from Van Rees and Reed (2014) and was modeled as the percent loss of historical coastal wetlands to an elevation of 304 meters. Trend in coastal wetlands was assessed as the difference in area from 2010/2011 to 1992 NOAA CCAP wetlands extent within 1 km of the coastline (NOAA Office for Coastal Management).

Mangroves

While mangroves are considered unique and integral ecosystems in their native range they can be a huge threat to areas where they are introduced and invasive, such as Hawaiʻi. While they do offer coastal protection, we did not include them in this assessment as they are considered to do more harm than good. Mangroves have especially large impacts to native biodiversity and traditional Hawaiian fishponds (loko iʻa) (Allen, 1998). Removal efforts are underway to remove and clear mangroves and restore native estuaries and fishponds.

Fishponds (Loko iʻa)

Hawaiian fishponds are historic structures built in estuary habitats that provide coastal protection along with seafood production (Honua Consulting, 2013). Fishponds are considered habitats that provide coastal protection and therefore were included in this goal. The condition of fishponds was assessed based on their current extent compared to a set target of 30% of thier historical extent (Ogden Environmental Services, 1994).

Data Gaps

- Sand dune habitats are also important for coastal protection and will be incorperated with beach habitats once data becomes available on their extent, condition, and trend.
- Future models could be improved by incorperating estimates of shoreline protective ability based on slope or shoreline relief or aspect ratios.
- Scientific analysis or information on the protective ability or importance of each habitat for coastal protection in Hawaiʻi.
- Updated inventory on coastal wetlands and estuaries is currently being developed by the Hawaiʻi Department of Land and Natural Resources Division of Aquatic Resources.

Livelihoods & Economies

The goal includes the two subgoals: Livelihoods (X_{LIV}) and Economy (X_{ECO}).

$$X_{LE} = \frac{X_{liv} + X_{eco}}{2}$$

Data on ocean livelihoods and economies comes from the NOAA ENOW for employment (jobs), wages, and revenue by ocean sector (ENOW, 2017). Sectors include: Marine Construction, Living Resources, Ship and Boat Building, Tourism and Recreation, and Marine Transportation (Table 22). Self-employed and state employed data sets were aggregated and summarized by county. However, when aggregated to county some of the information was undisclosed therefore this data represents a conservative estimate of ocean livelihoods and economies. Industry multipliers were applied to represent indirect benefits (Table 23).

Table 22. Ocean livelihood and economy sectors (ENOW, 2017).

Sector	Industry
Ship and Boat Building	Boat Building and Repair Ship Building and Repair
Tourism and Recreation	Boat Dealers Eating and Drinking Places Hotels and Lodging Marinas Recreational Vehicle Parks and Campsites Scenic Water Tours Sporting Goods Amusement and Recreation Services Zoos, Aquaria
Living Resources	Fish Hatcheries and Aquaculture Fishing Seafood Processing Seafood Markets
Marine Construction	Marine Related Construction
Marine Transportation	Deep Sea Freight Marine Passenger Transportation Marine Transportation Services Search and Navigation Equipment Warehousing

Table 23. Industry multipliers for indirect jobs and revenue (DBEDT, 2013). Sectors were assigned a value of 1.00 if industry multipliers were not available for the sector.

Ocean Sector	Jobs	Revenue
Tourism & Recreation	1.27	1.32
Living Resources	1.76	1.58
Marine Construction	1.00	1.00

Ship & Boat Building	1.00	1.00
Marine Transportation	1.69	1.63

Livelihoods

$$X_{liv} = \frac{\frac{\sum_k j_{c,k}}{\sum_k j_{r,k}} + \sum_k \frac{g_{c,k}}{g_r} * w}{2}$$

Livelihoods was measured as the mean of ocean jobs and wages measured as the current number of jobs (j_c) per marine and ocean sector (k) in relation to a reference year (j_r; 5 year moving window) and the sector average wage referenced to the county average wage and weighted by the proportion of jobs per sector (w). Current year (c) is the most recent year with available data (2013). Data on ocean sector employment and wage comes from NOAA Office for Coastal Management (ENOW, 2017) and was adjusted by state unemployment rate (DBEDT).

Data Gaps

- Some sectors are not well represented in Livelihoods and Economies, such as pro-surfers and marine and ocean scientists.
- The reference for wages is the bare minimum salary to live on without needing governmental aid. A livable wage is another possible reference point but is difficult to measure. Another alternative reference point could be annual per capita average consumption expenditures by county.

Economies

$$X_{eco} = \frac{\sum_{k=1}^{n} e_{c,k}}{\sum_{k=1}^{n} e_{r,k}}$$

Economies model is composed of a single component, revenue, where e is the total adjusted revenue generated directly and indirectly from each marine and ocean sector (k), at current (c), and reference (r), time points. Data on ocean revenue comes from NOAA Office for Coastal Management (ENOW, 2017).

Data Gaps

- Some ocean sectors are not represented in Livelihoods and Economies, such as pro-surfers and marine and ocean scientists.
- Sector evenness is not taken into account in the model.

Data Layers

Data layers used in each goal are listed in Table 24. Pressure categories and how each pressure layer was applied to each goal can be found in Table 25 and Table 26. Resilience categories and how each resilience layer was applied to each goal can be found in Table 27 and Table 28. The full data used in the assessment and links to the original data source can be found at ohi-science.org/mhi.

Table 24. Data layers, description, and reference for each goal (AO= Artisanal Fishing Opportunities, BD=Biodiversity, CP=Coastal Protection; FP=Food Provision, LE=Livelihoods & Economies, SP=Sense of Place, ST=Sustainable Tourism), pressure, and resilience dimension of the Hawai‘i Ocean Health Index.

Targets	Layer	Description	Reference
AO	access	Estimated fishery access for boat based and land based fishing based on boat ramps, shoreline access, roads, and steepness of shoreline.	(OTP)
AO	resource	The average of 3 components of fish ecosystem health (Reef Fish Biomass, Reef Fish Sustainability, and Reef Fish Predators).	(Williams et al., 2015; Williams, 2017); NOAA Status Report in prep
CON	participation in recreational activities	The NOAA Coral Reef Conservation Program 2014 socioeconomic surveys of human use, knowledge, attitudes, and perceptions in Hawaii.	(Gorstein et al., 2018)
CP	beach condition	The condition of coastal habitats measured as the percent of beaches erroding per region.	(Fletcher et al., 2012)
CP	beach extent	Beach extent was caluclated from the from ESI GIS layer (Beaches (3,4,5 classifications)). The data units are in km not km2 like other habitats.	(NOAA)
CP	beach trend	The average short-term errosine rate of beaches, estimated at -0.06 m per year.	(Fletcher et al., 2012)
CP	coastal wetland condition	Wetland condition was calculated based on percent of historical extent.	(Van Rees & Reed, 2014)
CP	coastal wetland extent	The area of coastal wetlands (within 1 km of the coastline).	(NOAA Office for Coastal Management)
CP	fishpond condition	The ratio of current to historic fishpond area.	(Ogden Environmental Services, 1994)
CP	fishpond extent	The current area of fishponds.	(Ogden Environmental Services, 1994)
CP	fishpond trend	No trend data is available for this layer	(Ogden Environmental Services, 1994)
CP	reef condition	The benthic condition of coral reefs assessed through a combination of variables including percent coral cover, percent macroalgae cover, demography, and mortality.	NOAA Coral Reef Status Report; NOAA CREP

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
CP	reef extent	The hardbottom extent out to 80 meters modified from NOAA habitat maps.	(Lecky, 2016)
CP	reef trend	The estimated change in percent coral cover calculated from the past 5 years of available monitoring data from NOAA Coral Reef Ecosystem Program.	(McCoy et al., 2017)
CP	wetland trend	The annual percent change in wetland extend based on NOAA C-CAP data comparisions from 2005 to 2010/2011.	(NOAA Office for Coastal Management)
ECO	ocean and coastal revenue	The revenue generated per ocean sector for each county.	(ENOW, 2017)
FIS	bottom fisheries commercial catch	Bottomfish catch (lbs) reported in the commercial fishery.	(DLNR DAR)
FIS	commercial reef fisheries catch	Reef fish catch (lbs) reported in the commercial fishery.	(DLNR DAR)
FIS	commerical coastal pelagic fisheries catch	Coastal pelagic fish catch (lbs) reported in the commercial fishery.	(DLNR DAR)
FIS	pelagic fisheries commerical catch	Pelagic fish catch (lbs) reported in the commercial fishery.	(DLNR DAR)
FIS	recreational catch multiplier	A multiplier for reported commercial catch of nearshore fish used to estimate the contribution of non-commercial (recreation & subsistence) catch.	(McCoy et al., 2018)
FIS	sustainability of bottomfishery	Bottomfish stock assessment.	(Brodziak J. et al., 2014))
FIS	sustainability of pelagic fishery	Pelagic (tuna and swordfish) stock assessments.	WCPFC (n.d.); ISC (2017)
FIS	sustainability of reef fishery	Reef fish stock assessment.	Nadon (2017)
HAB	beach condition	The condition of coastal habitats measured as the percent of beaches erroding per region.	(Fletcher et al., 2012)
HAB	beach extent	Beach extent was caluclated from the from ESI GIS layer (Beaches (3,4,5 classifications)). The data units are in km not km2 like other habitats.	(NOAA)
HAB	beach trend	The average short-term errosine rate of beaches, estimated at -0.06 m per year.	(Fletcher et al., 2012)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
HAB	coastal wetland extent	The area of coastal wetlands (within 1 km of the coastline).	(NOAA Office for Coastal Management)
HAB	reef condition	The benthic condition of coral reefs assessed through a combination of variables including percent coral cover, percent macroalgae cover, demography, and mortality.	NOAA Coral Reef Status Report; NOAA CREP
HAB	reef extent	The hardbottom extent out to 80 meters modified from NOAA habitat maps.	(Lecky, 2016)
HAB	reef trend	The estimated change in percent coral cover calculated from the past 5 years of available monitoring data from NOAA Coral Reef Ecosystem Program.	(McCoy et al., 2017)
HAB	soft bottom condition	The percent of softbottom habitat not impacted by dredging.	(Lecky, 2016)
HAB	soft bottom extent	Soft bottom habitat extent was derived from the cumulative impact habitat maps.	(Lecky, 2016)
HAB	soft bottom trend	Trend was not evaluated for soft bottom habitats.	
HAB	wetland condition	Wetland condition was calculated based on percent of historical extent.	(Van Rees & Reed, 2014)
HAB	wetland trend	The annual percent change in wetland extend based on NOAA C-CAP data comparisions from 2005 to 2010/2011.	(NOAA Office for Coastal Management)
LE	ocean sector weight	The proportion of jobs in each sector per region.	(ENOW, 2017)
LIV	Hawaii average wage	The Hawaii average annual wage by county	(DBEDT)
LIV	ocean and coastal jobs	The total number of jobs per ocean sector for each county.	(ENOW, 2017)
LIV	ocean and coastal sector mean wages	The mean wage per ocean sector by county	(ENOW, 2017)
LIV	resident population	The number of residents per county.	(DBEDT, 2015b)
LIV	unemployment	The unemployment rate.	(DBEDT)
LIV	workforce	The total number of jobs per county.	(DBEDT)
LSP	area within 1 km of the shore	The coastal area within 1 km of the shore.	(Hawaii State Office Of Planning)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
LSP	coastal conservation districts	The conservation district type and area within 1km of the coastline.	(Hawaii State Office Of Planning)
LSP	marine managed areas	The offshore areas protected to 3nm, including CBSFA, FRA, BFA, and MPA classifications.	(Hawaii State Office Of Planning)
LSP	offshore area to 3nm	The offshore area to 3nm.	(Hawaii State Office Of Planning)
MAR	area of active fishponds	The area of current fishponds per county.	(Ogden Environmental Services, 1994)
MAR	fishpond status	Ratio of active fishponds to historical number	(Ogden Environmental Services, 1994)
MAR	mariculture yield	Production of shellfish and foodfish from mariculture facilities	(US DOA, 2015)
MAR	number of fishponds	The current number of fishponds.	(Ogden Environmental Services, 1994)
MAR	operations	The number of mariculture operators.	(USDA)
SPP	ESA coastal plant status	The list of Hawaii coastal plant species and status of coastal sand-dune plants scored based on ESA status.	(US Fish and Wildlife Service; Merlin, 1999)
SPP	ESA marine mammal status	The list of marine mammals found in Hawaii and status of marine mammals scored based on ESA status.	(NOAA Fisheries; Costa & Kendall, 2016)
SPP	ESA seabird and coastal bird status	The list of seabirds and coastal birds scored based on ESA status and State of the Birds watch lists.	(US Fish and Wildlife Service; Rosenberg et al., 2010)
SPP	fish indicator	The reef fish indicator is the average of 3 components (Reef Fish Biomass, Reef Fish Sustainability, and Reef Fish Predators).	(Williams et al., 2015; Williams, 2017); NOAA Status Report in prep
TR	environmental protection	The percent of nearhsore areas priority watersheds protected in reference to Hawaii Stanability Initatives (30 by 30 targets). This data may change as the State DLNR Division of Aquatic Resources develops the 30 by 30 initative.	(Hawaii State Office Of Planning)
TR	resident sentiment	The Hawaii Tourism Authority's survey on resident sentiment to tourism.	(HTA, 2017b)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
TR	visitor contributed GDP	Visitor generated GDP with a target set by the Hawaii Tourism Authority of 2.5% annual growth.	(HTA, 2016)
pressure	aquarium fishing	The pressure on the nearshore from aquarium fishing estimated as the reported take to DAR, standardized to km2 of hardbottom habitat.	(OTP)
pressure	commercial fishery hi-bycatcb	The ratio of catch to bycatch for the tuna fishery (deep set longlines).	(Benaka et al., 2013)
pressure	commercial fishery lo-bycatcb	The ratio of catch to bycatch for swordfish fishery (shallow set longlines).	(Benaka et al., 2013)
pressure	coral bleaching	Mean degree heating weeks (DHW) for nearshore areas (wihting 10 km of the coastlint), with coral bleaching expected after 4 DHW. Scores of 1 indicate that coral bleaching is expected or occured.	(NOAA Satelite and Information Service)
pressure	direct impacts from humans (trampling, recreation, etc)	InVEST recreation model was run statewide at 1 km resolution for the years 2005 - 2014. This model uses publicly visible geotagged photos posted to the photo-sharing website Flickr to calculate the annual average number of photo users per day per grid cell. This is a proxy for direct human impact to nearshore and coastal environments.	(OTP)
pressure	economic loss from sea level rise	The estimated economic loss from a predicted near future 3.2 ft sea level rise.	(Hawai‘i Climate Change Mitigation and Adaptation Commission)
pressure	forest/watershed health	The percent of native forests dominated by non-native species.	
pressure	habitat destruction caused by coastal engineering	Coastal engineering consisted of shoreline armoring structures (e.g., seawalls, revetments, groins, break waters), artificial land (i.e., land fill), and piers.	(OTP)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
pressure	habitat destruction from dredging	Dredging was defined as activity involving physically removing substrate with machinery typically to allow for safe passage of vessels.	(OTP)
pressure	habitat destruction of benthic structures	Benthic structures were defined as manmade features in the offshore environment that disrupt benthic habitat and include moored buoys, channel markers, offshore cables and pipelines.	(OTP)
pressure	invasive species (algae and mangroves)	Represents presence-only of invasive algae species in nearshore waters and mangroves along the shoreline.	(OTP)
pressure	land-based sediment export to nearshore water	Mean sediment load to nearshore waters (1.5km).	(OTP)
pressure	land-based source of pollution from agriculture and golf courses	The proxy for agricultural and landscaping runoff (nutrients from fertilizers; chemicals like pesticides and herbicides), calculated as the area of agricultural land and golf courses by watershed with a maximum stresser level set at 10% of watershed area.	(OTP)
pressure	land-based source of pollution from urban runoff	A proxy for nutrient and chemical pollution measured as the percent of impervious surfaces per watershed with a maximum stresser level set at 10% of watershed area.	(OTP)
pressure	landbased source of pollution nitrogen	Mean nitrogen flux from on site disposal sytems (OSDS) into nearshore waters (1.5 km from shore).	(OTP)
pressure	marine debris	The State of Hawaii Division of Aquatic Resources aerial imagery of marine debris from 2015.	(OTP)
pressure	ocean acidification	Ocean acidification pressure scaled using biological thresholds.	(Halpern et al., 2008)
pressure	proxy for intertidal habitat destruction	The coastal population density (withing 25 mi from shore) as a proxy for intertidal habitat destruction, calculated as resident population per km of shoreline and standardized by maximum regional score.	DBEDT (2015b)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
pressure	reef fishing catch	The modeled reef fish catch from commercial and recreational fishery taking into account shoreline accessibility.	(OTP)
pressure	sea level rise	The estimated pressure on coastal areas from a 3.2 ft prediction of the near future sea level rise.	(Hawai‘i Climate Change Mitigation and Adaptation Commission)
pressure	sea surface temperature	The difference in the annual mean sea surface temperature for Hawaii eez waters compared to the 20th century mean sea surface temperature.	NOAA: National Centers for Environmental Information (n.d.)
pressure	ship-based groundings	To represent the risk of ship groundings and wrecks to coastal waters, the footprint of this ship traffic layer was clipped to 9 m depth.	(OTP)
pressure	ship-based pollution	Ship traffic layer was used as a proxy for ship-based pollution.	(OTP)
pressure	terrestrial aquaculture	The environmental footprint of terrestrial aquaculture facilities.	(OTP)
pressure	uv radiation	The modeled UV radiation based on Erythemal UV Irradiance data provided by GES DISC.	(Halpern et al., 2008)
pressure	visitors participating in kayaking	The number of visitors per km of coastline that kayak or canoe per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)
pressure	visitors participating in snorkeling or scuba diving	The number of visitors per km of coastline that use thrill craft per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)
pressure	visitors participating in surfing	The number of visitors per km of coastline that surf or body-board per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)
pressure	visitors participating in swimming	The number of visitors per km of coastline that swim and go to the beach per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
pressure	visitors participating in thrill craft	The number of visitors per km of coastline that whale watch per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)
pressure	visitors participating in whale watching	The number of visitors per km of coastline that whale watch per county standardized to the regional maximum which occurs on Oahu.	(HTA, 2015)
pressure	weakness of governance	The Inverse of World Governance Indicators (WGI) calculated as the six combined scores.	(Halpern et al., 2008)
pressure	weakness of social progress	The inverse of the Social Progress Index scores.	(Halpern et al., 2008)
pressure resilience	habitat weights	This is a list of habitats in each region weighted by proportion of the total area for each habitat.	
resilience	artisanal fisheries management effectiveness and opportunity	The opportunity for artisanal and recreational fishing based on the quality of management of the small-scale fishing sector.	(Halpern et al., 2008)
resilience	CITES signatories	The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) signatories.	(Halpern et al., 2008)
resilience	coastal MPAs fisheries resilience	The ratio of management areas to total coastal area within 3nm.	(Hawaii State Office Of Planning)
resilience	coastal MPAs habitat resilience	The ratio of management areas to total coastal area within 3nm.	(Hawaii State Office Of Planning)
resilience	commercial fishing management	The estimated management effectiveness of regulations and management of commercial fishing.	(Halpern et al., 2008)
resilience	EEZ MPAs fisheries resilience	The ratio of management areas (BRFA, Longline, Monument) to the total ocean area with the EEZ and divided into OHI regions.	(Hawaii State Office Of Planning)
resilience	EEZ MPAs habitat resilience	The ratio of management areas (BRFA, Longline, Monument) to the total ocean area with the EEZ and divided into OHI regions.	(Hawaii State Office Of Planning)
resilience	experience of visitors	The percent of visitors that report having an excellent experience.	(DBEDT, 2015c)

Table 24. Data layers, description, and reference for each goal (continued).

Targets	Layer	Description	Reference
resilience	habitat health	The scores from the habitats subgoal of biodiversity are used as resilience for Livelihoods and Economies and the Sustainable Tourism goals.	
resilience	management of nonindigenous species	The survey responses by country to the Convention on Biologicial Diversity (CBD) Third National Report: invasive species related questions.	(Halpern et al., 2008)
resilience	Mo'omeheu - Value of History and Culture	The preservation of culture. Mo'omeheu - Value of History and Culture.	(Office of Hawaiian Affairs)
resilience	sector evenness as a measure of economic diversity	The Shannon's Diversity Index calculated sector evenness based on the total number of sectors and the proportion of jobs belonging to any sector.	(Halpern et al., 2008)
resilience	Social Progress Index	The Social Progress Index scores.	(Halpern et al., 2008)
resilience	State New Economy Index	The State New Economy Index uses 25 indicators to measure the extent to which state economies are knowledge-based, globalized, entrepreneurial, IT-driven, and innovation-oriented.	(The Information Technology and Innovation Foundation, 2014)
resilience	strength of governance	The World Governance Indicators (WGI) six combined scores.	(Halpern et al., 2008)
resilience	watershed partnerships	The ratio of watershed partnerships to historic native forest extent.	(Hawaii State Office Of Planning)
resilience	watersheds protected	The percent of priority watersheds that are fenced to protect againts invasive animals.	(Yuen, 2017)

Table 25. Pressure layers and categories

Data Layer	Short Name	Category	Subcategory
ocean acidification	cc_acid	ecological	climate change
sea level rise	cc_sealevel	social	climate change
economic loss from sea level rise	cc_slr_eco	ecological	social
sea surface temperature	cc_sst_eez	ecological	climate change
coral bleaching	cc_sst_nearshore	ecological	climate change
ocean warming	cc_uv	ecological	climate change
forest/watershed health	forest_health	ecological	habitat destruction
commercial fishery hi-bycatcb	fp_com_hb	ecological	fishing pressure
commercial fishery lo-bycatcb	fp_com_lb	ecological	fishing pressure
aquarium fishing	fp_fish_aquarium	ecological	fishing pressure
reef fishing catch	fp_reeffish_t	ecological	fishing pressure
habitat destruction of benthic structures	hd_benstr	ecological	habitat destruction
habitat destruction caused by coastal engineering	hd_coasteng	ecological	habitat destruction
habitat destruction from dredging	hd_dredging	ecological	habitat destruction
proxy for intertidal habitat destruction	hd_intertidal	ecological	habitat destruction
ship-based groundings	hd_shipbased_ground	ecological	habitat destruction
direct impacts from humans (trampling, recreation, etc)	hd_tourrec_direct_h	ecological	habitat destruction
landbased source of pathogens	po_lbspnosds_nflux	ecological	pollution
land-based sediment export to nearshore water	po_lbsp_sed	ecological	pollution
land-based source of pollution from agriculture and golf courses	po_lbspaggolfrunoff	ecological	pollution
land-based source of pollution from urban runoff	po_lbspurbanrunoff	ecological	pollution
marine debris	po_marinedebris	ecological	pollution
ship-based pollution	po_shipbased_shipp	ecological	pollution

Table 25. Pressure layers and categories (continued).

Data Layer	Short Name	Category	Subcategory
terrestrial aquaculture	sp_aquacul_terrest	ecological	alien_species
invasive species (algae and mangroves)	sp_ispp_a_m	ecological	alien_species
weakness of social progress	ss_spi	social	social
weakness of governance	ss_wgi	social	social
visitors participating in snorkeling or scuba diving	t_ snorkel_scuba	ecological	habitat destruction
visitors participating in surfing	t_boarding	ecological	habitat destruction
visitors participating in kayaking	t_kayaking	ecological	habitat destruction
visitors participating in swimming	t_swimming	ecological	habitat destruction
visitors participating in thrill craft	t_thrill_craft	ecological	habitat destruction
visitors participating in whale watching	t_whale_watching	ecological	habitat destruction

Table 26. Pressure layers and weights applied to each goal and element.

goal	element	t_snorkel_scuba	t_whale_watching	t_swimming	t_boarding	t_kayaking	t_thrill_craft	forest_health	po_lbsp_sed	po_lbspurbanrunoff	po_lbspnosds_nflux
AO				1			2	3	1	1	
CON								2	2	2	3
CP	beach							1		2	2
CP	reef						1	3	2	2	2
CP	wetland							2		2	2
ECO	Living Resources							2	1		
ECO	Marine Construction								2		
ECO	Marine Transportation								1		
ECO	Ship and Boat Building										
ECO	Tourism and Recreation							2		2	2
FIS									1	1	1
HAB	beach			1				1			
HAB	reef	1		1	1		1	3	2	2	2
HAB	soft_bottom							1		2	2
HAB	wetland							2		2	2
LIV	Living Resources							2		3	3
LIV	Marine Construction								1		
LIV	Marine Transportation										
LIV	Ship and Boat Building										
LIV	Tourism and Recreation							2	1	3	3
LSP								3		2	
MAR										3	
SPP		1		1			2	3	1		
TR								2	2	3	3

Table 26. Pressure layers and weights applied to each goal and element (continued).

goal	element	po_lbspaggolfrunoff	po_marinedebris	po_shipbased_shipp	sp_aquacul_terrest	sp_ispp_a_m	hd_tourrec_direct_h	hd_shipbased_ground	hd_dredging	hd_coasteng	hd_benstr
AO		1	1	1	1	1	2	1		1	
CON		2	3								
CP	beach	2		1	1	1				1	1
CP	reef	2	1	1	1	1	2	3		1	2
CP	wetland	2		1	1	1				1	1
ECO	Living Resources			1		1	1	1			1
ECO	Marine Construction			1		1	2	2			1
ECO	Marine Transportation		2								
ECO	Ship and Boat Building	3									
ECO	Tourism and Recreation		2								
FIS		1	2	1		1	1	1	1		
HAB	beach		3	1							1
HAB	reef	2	3	1	1	1	2	3			2
HAB	soft_bottom	2		1		1			3		1
HAB	wetland	2	2	1	1	1					1
LIV	Living Resources	3									
LIV	Marine Construction			1		1	1	1			1
LIV	Marine Transportation			1		1	1	1			
LIV	Ship and Boat Building		2								
LIV	Tourism and Recreation	3									
LSP		2	3			1					
MAR		3									
SPP			2	1	1	1					
TR		3	3								

Table 26. Pressure layers and weights applied to each goal and element (continued).

goal	element	hd_intertidal	fp_reeffish_t	fp_fish_aquarium	fp_com_hb	fp_com_lb	cc_sst_eez	cc_sst_nearshore	cc_acid	cc_uv	cc_sealevel
AO		1	1	1	2	1					
CON											
CP	beach	3									3
CP	reef		3	1				3	1	1	
CP	wetland	3									1
ECO	Living Resources	1	1		3	1	1				
ECO	Marine Construction								1		
ECO	Marine Transportation			1							
ECO	Ship and Boat Building										
ECO	Tourism and Recreation				1		1	2			
FIS		1	1		3	1	3	3	3		
HAB	beach										3
HAB	reef		3	1				3	1	1	
HAB	soft_bottom				3	1					
HAB	wetland	3									1
LIV	Living Resources										
LIV	Marine Construction	1	1		3	1					
LIV	Marine Transportation		1						1		
LIV	Ship and Boat Building				1						
LIV	Tourism and Recreation			1							
LSP		3									3
MAR											1
SPP		2	1	1	3	1	3	3	1	1	
TR			1	1							2

Table 26. Pressure layers and weights applied to each goal and element (continued).

goal	element	cc_slr_eco	ss_wgi	ss_spi
AO			1	1
CON				
CP	beach		1	1
CP	reef		1	1
CP	wetland		1	1
ECO	Living Resources	3	1	1
ECO	Marine Construction	3	1	1
ECO	Marine Transportation	3	1	1
ECO	Ship and Boat Building	3	1	1
ECO	Tourism and Recreation	3	1	1
FIS			1	1
HAB	beach		1	1
HAB	reef		1	1
HAB	soft_bottom		1	1
HAB	wetland		1	1
LIV	Living Resources	3	1	1
LIV	Marine Construction	3	1	1
LIV	Marine Transportation	3	1	1
LIV	Ship and Boat Building	3	1	1
LIV	Tourism and Recreation	3	1	1
LSP			1	1
MAR			1	1
SPP			1	1
TR			1	1

Table 27. Resilience layers and categories.

Data Layer	Short Name	Category	Category Type	Subcategory	Weight
artisanal fisheries management effectiveness and opportunity	fp_mora_artisanal	ecological	regulatory	fishing pressure	1
CITES signatories	g_cites	ecological	regulatory	goal	0.5
coastal MPAs fisheries resilience	fp_MPA_3nm	ecological	regulatory	fishing pressure	1
coastal MPAs habitat resilience	hd_MPA_3nm	ecological	regulatory	habitat destruction	1
commercial fishing management	fp_mora	ecological	regulatory	fishing pressure	1
community stewardship	community_stewardship	ecological	regulatory	fishing pressure	
community stewardship	community_stewardship	social	social	social	1
EEZ MPAs fisheries resilience	fp_MPA_eez	ecological	regulatory	fishing pressure	1
EEZ MPAs habitat resilience	hd_MPA_eez	ecological	regulatory	habitat destruction	1
experience of visitors	tourism_experience	ecological	social	social	1
habitat health	res_hab_health	ecological	ecosystem	ecological	1
management of nonindigenous species	sp_alien_species	ecological	regulatory	alien species	1
Mo'omeheu - Value of History and Culture	sp_OHA_culture	social	social	social	1
sector evenness as a measure of economic diversity	li_sector_evenness	social	social	social	1
Social Progress Index	res_spi	social	social	social	1
State New Economy Index	li_economic_index	social	social	social	1
strength of governance	wgi_all	social	social	social	1
watershed partnerships	watershed_partnerships	ecological	regulatory	habitat destruction	1
watersheds protected	hd_watersheds	ecological	regulatory	habitat destruction	1

Table 28. Resilience applied to each goal and element.

goal	element	hd_watersheds	res_hab_health	community_stewardship	sp_OHA_culture	watershed_partnerships	hd_MPA_3nm	hd_MPA_eez	sp_alien_species	fp_MPA_3nm	fp_MPA_eez	fp_mora
AO		x	x	x			x			x		x
CP	reef	x		x	x	x	x					
CP	beach	x		x	x		x					
CP	wetland	x		x	x	x	x					
CS	wetland	x		x	x	x	x					
CW		x	x	x								
ECO		x	x							x		
FIS		x	x					x		x	x	x
HAB	reef	x		x	x	x	x					
HAB	wetland	x		x	x	x	x					
HAB	beach	x		x	x		x					
HAB	soft_bottom	x		x	x		x	x			x	x
SPP		x	x	x	x		x	x			x	x
LIV		x	x								x	
LSP		x	x	x	x							
MAR			x	x								
TR			x			x	x	x		x	x	
CON			x			x	x					

Table 28. Resilience applied to each goal and element (continued).

goal	element	fp_mora_artisanal	tourism_experience	g_cites	wgi_all	res_spi	li_economic_index	li_sector_evenness
AO								
CP	reef							
CP	beach							
CP	wetland							
CS	wetland							
CW								
ECO							x	
FIS		x						
HAB	reef	x						
HAB	wetland							
HAB	beach							
HAB	soft_bottom							
SPP		x		x				
LIV			x				x	x
LSP								
MAR								
TR			x					
CON								

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