Coral Reefs

Vulnerability to Climate Change in West Hawai‘i

Coral reefs of West Hawai‘i

The west coast of the island of Hawai‘i (West Hawai‘i) is a unique habitat known for its clear waters and vibrant coral reefs. West Hawai‘i contains one of the state's longest contiguous coral reefs, supporting an abundance of corals and fish, of which nearly a quarter are only found in Hawai‘i. Coral reefs are of critical importance to the communities and environment of West Hawai‘i. Reefs in this area are home to culturally significant species, used for recreational and commercial fishing, and provide economic benefits.

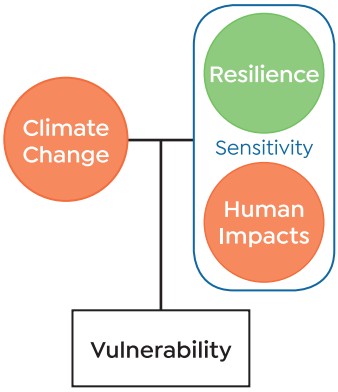
NOAA's Integrated Ecosystem Assessment

The West Hawai‘i Integrated Ecosystem Assessment (WH-IEA) is a program that builds relationships with State and Federal agencies and community organizations to deliver science that meets management needs. Assessing the vulnerability of key ecosystems and species to climate change is a goal of the IEA. The vulnerability assessment process builds understanding of human-environment interactions for coral reef communities, and will help evaluate management scenarios that can increase coral reef resilience.

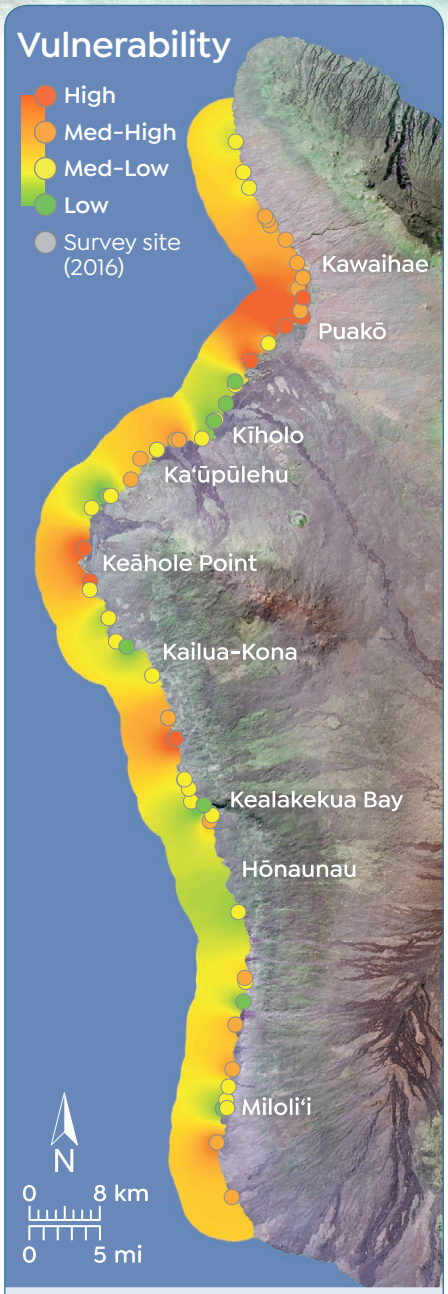
Coral reef vulnerability to climate change

The vulnerability of a coral reef to changes in climate depends on the frequency and severity of climate disturbances, such as coral bleaching. Vulnerability also depends on the sensitivity of coral reefs to these disturbances. Sensitivity is a combination of coral reef resilience – their capacity to resist and recover from disturbance – and whether resilience is compromised by human impacts. Our team has generated information on climate change, resilience, and human impacts, and then combined these inputs to assess coral reef ecosystem vulnerability. The results indicate that vulnerability to climate change varies greatly among the coral reefs of West Hawai‘i. Coral reef vulnerability is relatively low near Kīholo, Kealakekua Bay, Hōnaunau, and Miloli‘i, and relatively high near Puakō, Keāhole Point, and Kailua-Kona. Reef fish productivity is likely to be lower where coral reef vulnerability is high and productivity is likely to be higher where coral reef vulnerability is low.

Coral bleaching in West Hawai‘i in October 2015

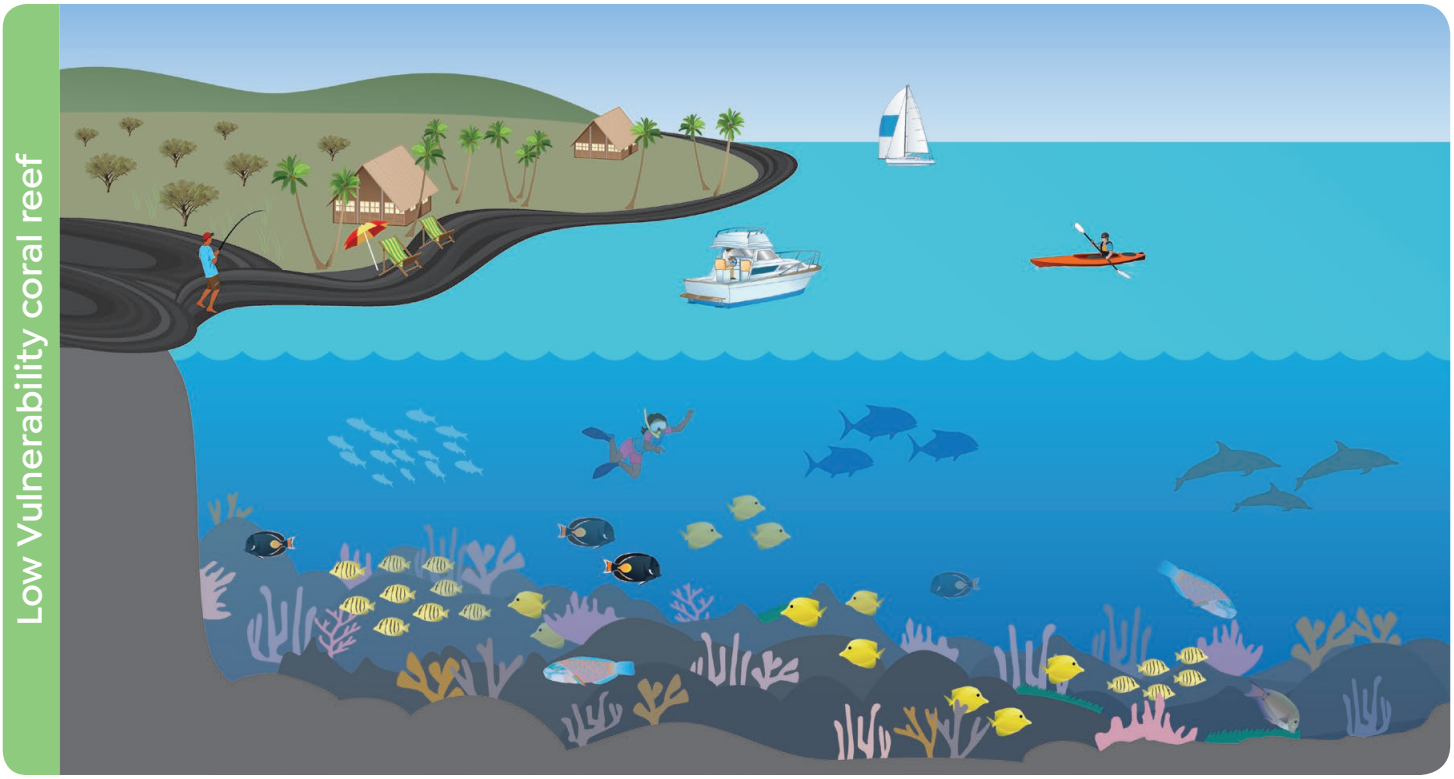


Vulnerability assessment framework



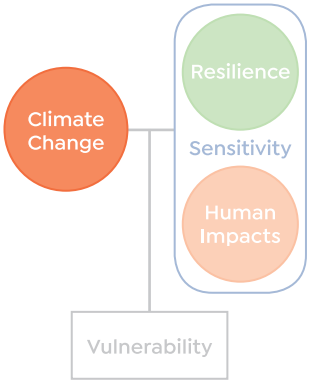
Coral reef vulnerability to climate change in West Hawai‘i

Coral reef vulnerability to climate change in West Hawai'i



Low vulnerability reefs are projected to experience annual severe bleaching 10 years later than high vulnerability reefs. This difference is not as consequential as the differences between low and high vulnerability reefs in resilience and human impacts. Low vulnerability reefs have greater resilience and lower human impacts than high vulnerability reefs. Low vulnerability reefs have 40% more herbivorous fish than high vulnerability reefs (52.7 versus 38.33 g/m^2), twice as much hard coral cover (22.3 versus 11.9% cover) and 50% greater coral richness (3 versus 2 species covering at least 1% of the substrate). High vulnerability reefs have 3 times the direct impacts from tourism than low vulnerability reefs, 4 times greater reef fish fishing pressure, and have poor water quality and some sedimentation.

Exposure to climate change



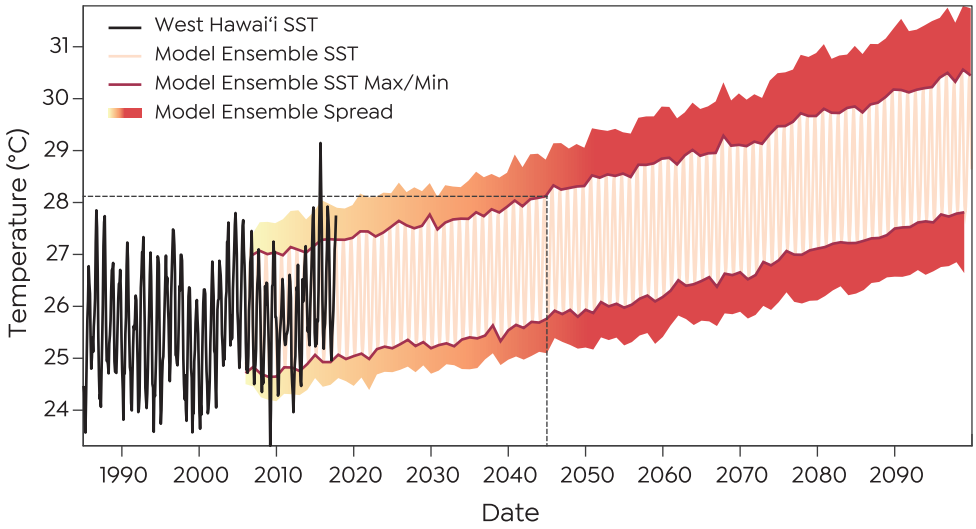
Climate change poses a critical threat to the coral reef ecosystems of West Hawai'i and worldwide. More severe storms are expected and the ocean will become more acidic, making it harder for corals to grow and keep pace with rising sea levels. Climate change is also expected to increase the frequency and severity of coral bleaching events. Coral bleaching is a stress response caused by the breakdown of the symbiotic relationship between coral and the algae (zooxanthellae) that live in its tissues. The algae are expelled making the coral skeleton visible, giving it a pale or "bleached" appearance. Bleached corals may eventually die if ocean temperatures remain high and the symbiosis is not re-established. The highest ocean temperatures ever recorded in West Hawai'i occurred late in 2015 and ~50% of corals in West Hawai'i died due to coral bleaching.

Our approach was to use climate models to project the date (between 2020 and 2100) when coral reefs will start to experience annual severe bleaching (ASB). The climate models used a 'business-as-usual' emissions scenario (IPCC RCP8.5) that assumes climate policy will not be effective. The timing of ASB was projected for each of the 70 survey sites, following the methods in this United Nations Environment Report.

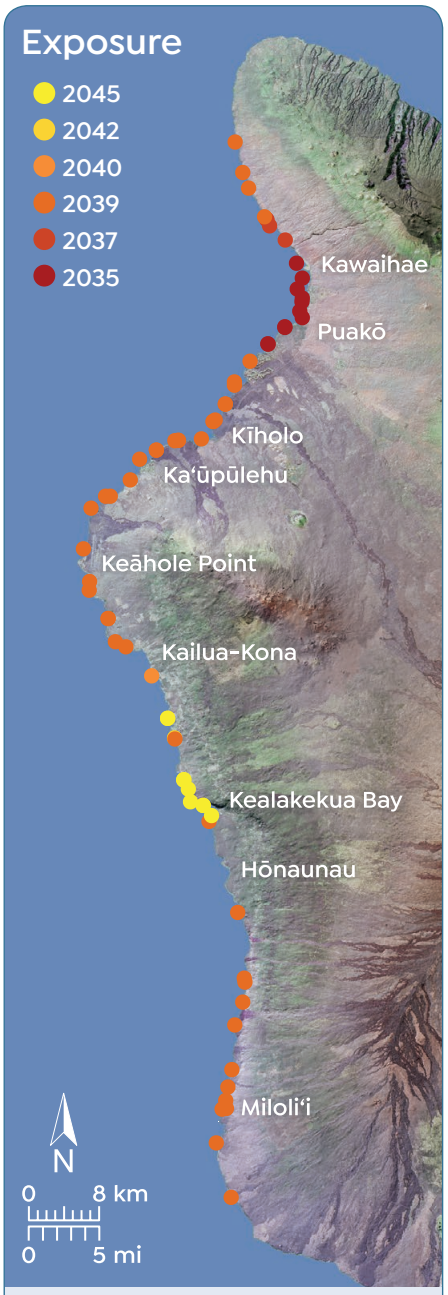
Results suggest all coral reefs in West Hawai'i will experience annual severe bleaching between 2035 and 2045. Successive coral bleaching events are projected to occur earliest (~2035) near Puakō and Kawaihae. Annual severe bleaching is projected to occur latest (~2045) south of Kailua-Kona and near Kealakekua Bay.

Annual coral bleaching events—projected to occur in West Hawai'i by 2045—pose a grave threat to coral reefs and their ability to provide goods and services.

Coral bleaching in West Hawai'i in 2015

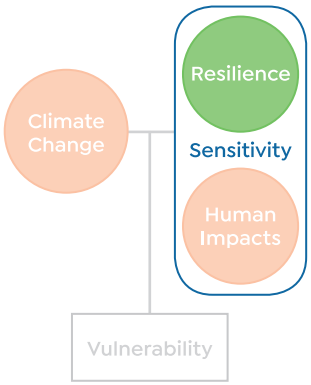


Projected change in sea surface temperature in West Hawai'i this century (from an ensemble of IPCC-approved climate models and based on business-as-usual emissions scenario RCP8.5), suggesting all coral reefs in West Hawai'i will experience annual severe bleaching by 2045.



Projected timing of the onset of annual severe bleaching

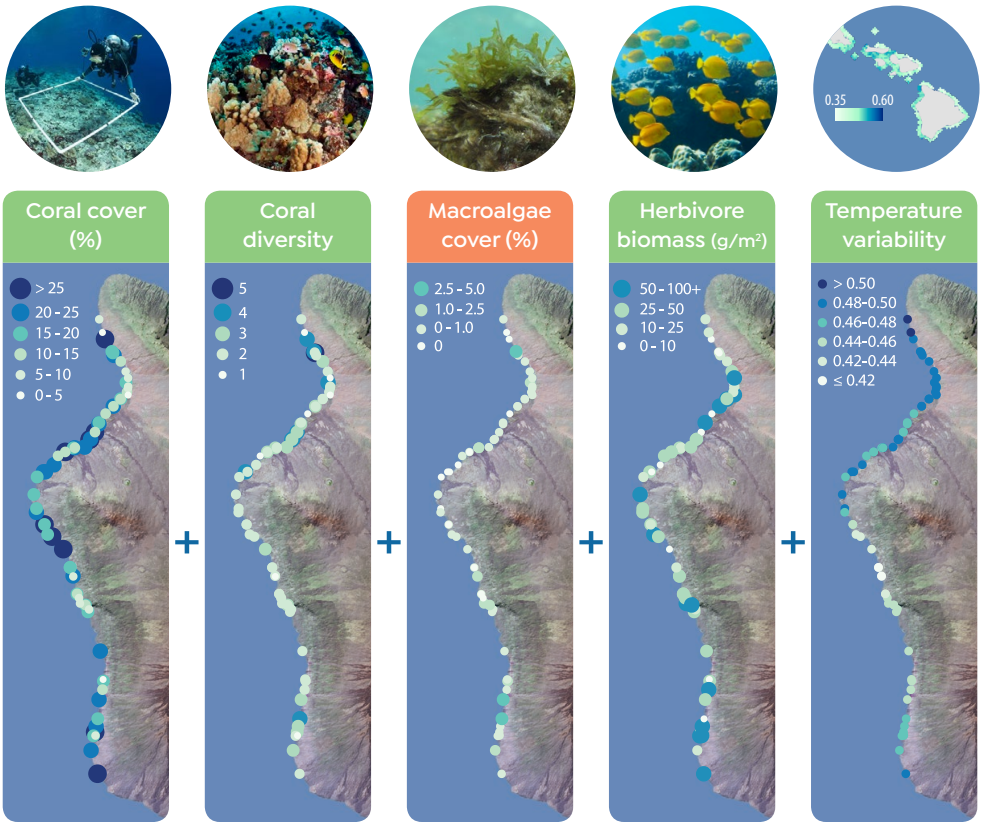
Resilience decreases sensitivity to climate change



Resilience is the capacity to resist and recover from disturbances and other stressors, while maintaining essential functions. Coral reefs are naturally resilient. Reefs are frequently disturbed and regularly go through periods of recovery and regrowth in between disturbance events. Reefs with greater relative resilience may have lower relative vulnerability, depending on the degree to which human activities stress reefs and reduce resilience.

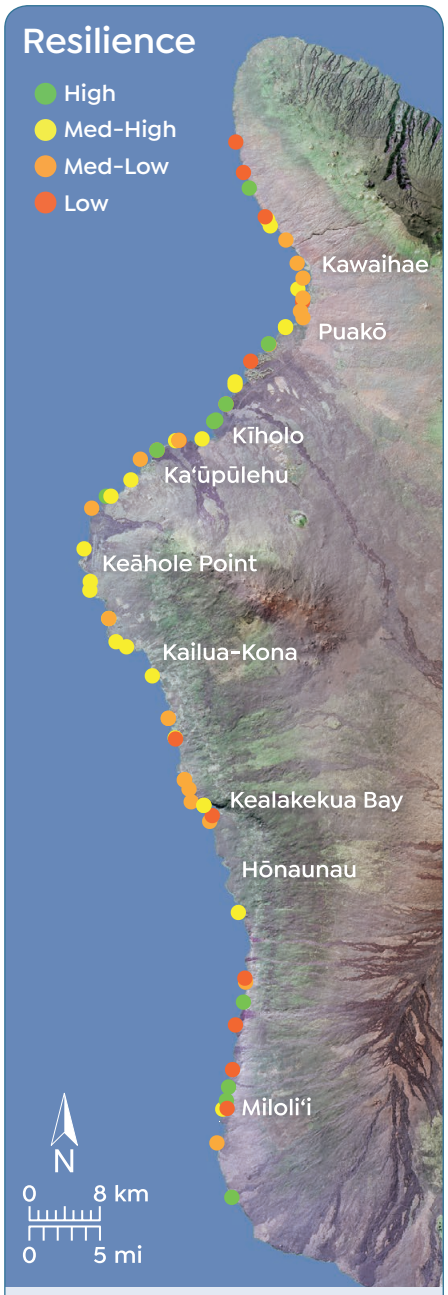
Our approach was to compile reef monitoring and remote sensing data for coral reef sites surveyed in 2016. The analysis includes 70 sites (30-60' deep) surveyed in 2016 by collaborators from NOAA, TNC, and Hawai'i DAR. Scores were generated for the indicators shown below. These scores are normalized to a 0-1 scale by dividing by the maximum value and made unidirectional so that a high score is always a good score. Indicator scores are then averaged and re-normalized to calculate the resilience index, resulting in a resilience score for each of the 70 survey sites that runs from 0 to a maximum value of 1. Sites are then classified as low, medium-low, medium-high, and high relative resilience following this Guide.

Results indicate that values for all resilience indicators vary greatly. Coral cover is greatest along the northern and southern extent of West Hawai'i. Coral diversity is greatest near Kawaihae. Macroalgae cover is low nearly everywhere. Herbivore biomass is greatest near Kīholo and north of Miloli'i. Temperature variability is relatively high all along the coast excepting south of Kailua-Kona. After combining those results into our resilience index, we see that coral reef resilience to climate change varies greatly in West Hawai'i. Reef resilience is highest near Kīholo and Ka'ūpūlehu and north of Miloli'i, and is lowest near Puakō, south of Kailua-Kona, and in Kealakekua Bay.



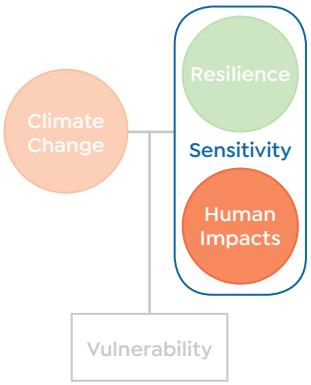
Resilience indicators calculated from data collected by the NOAA ESD, TNC, and Hawai'i DAR in 2016. Scores for these are averaged to produce the resilience index.

Reef resilience varies greatly, driven by variation among coral reefs in key resilience indicators, such as coral diversity and herbivore biomass.



Coral reef resilience to climate change in West Hawai'i

Human impacts increase sensitivity to climate change

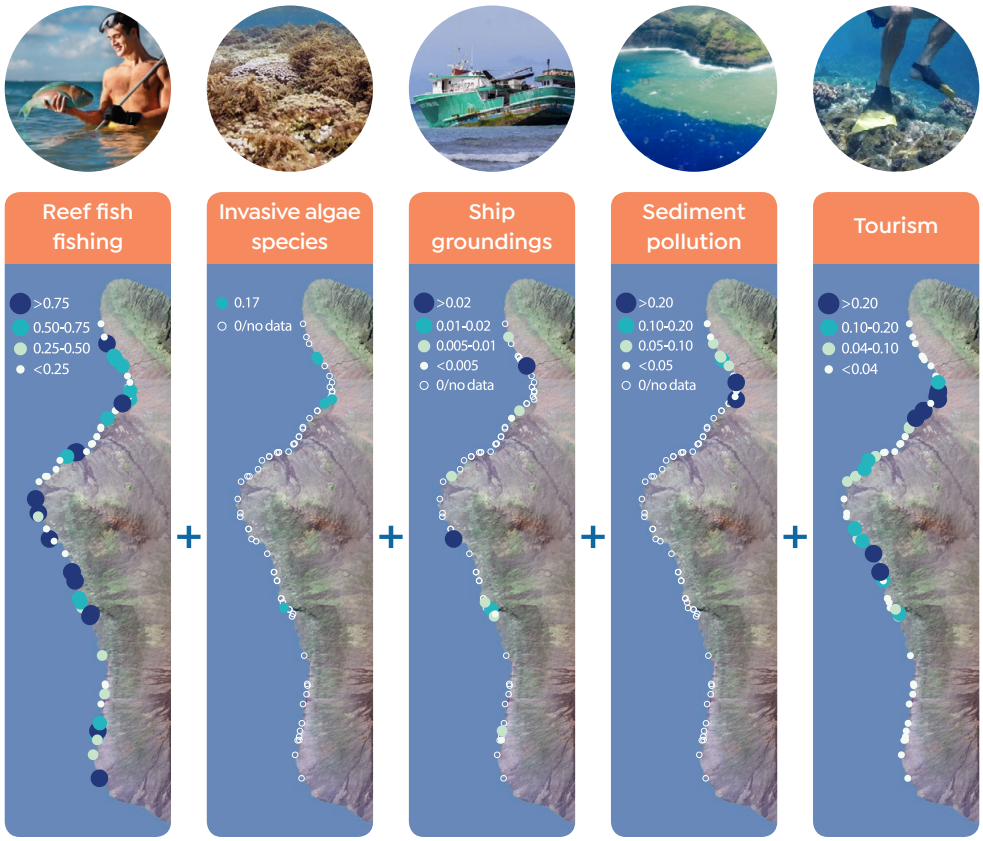


Humans impact coral reefs through many activities and as a consequence of coastal development and lifestyle choices. Critical human impacts on coral reefs in West Hawai'i include reef fish fishing, invasive algae species, ship groundings, sediment and nutrient pollution, and damaging forms of tourism. Fishing pressure on reef fish, especially herbivores, reduces the natural ability of reefs to recover after bleaching events and other disturbances. Ship groundings, dive fin and anchor damage can harm sensitive corals and other reef organisms. Invasive algae species can out-compete naturally occurring species for space on reefs, and sediment and nutrient pollution can stress corals and slow growth.

Our approach was to develop a cumulative impacts index that combines what is known about spatial patterns in the severity of human impacts on the marine environment in West Hawai'i. The index combines the five impacts shown below with 11 others and weights the impacts based on their likely effect on reef vulnerability (using methods following this Report). Reef fish fishing has the greatest weight in the index as it is thought to have the greatest impact on coral reef ecosystem function. The final impacts score for each of the 70 sites is a value from 0-1 with high scores meaning high impact. Sites are then classified as low, medium-low, medium-high, and high relative resilience following this Guide.

Results indicate that the severity of each of the types of human impacts varies along the West Hawai'i coastline. Impacts from reef fish fishing, sedimentation, and tourism are all most severe near Puakō and near Kailua-Kona. These impact severity patterns indicate a strong connection between population density and the severity of human impacts on coral reefs. The cumulative index of human impacts reflects similar spatial patterns – impacts severity is greatest between Kīholo and Puakō and between Kealakekua Bay and Kailua-Kona.

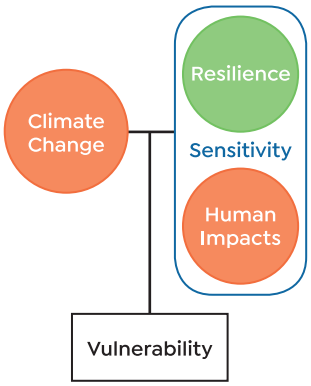
There are many human activities that stress coral reefs and the severity of the impacts caused by these activities varies along the West Hawai'i coastline.



Normalized scores for five human impacts critical to coral reefs in West Hawai'i. Cumulative index also includes: Aquaculture (2 types), Aquarium fishing, Habitat destruction (3 types), Pollution (3 types), Marine Debris, and Shipping and Ship grounding. Cumulative index (right) is shown for pixels along the coast and for reef survey sites.

Cumulative human impacts on coral reefs in West Hawai'i

Vulnerability to climate change



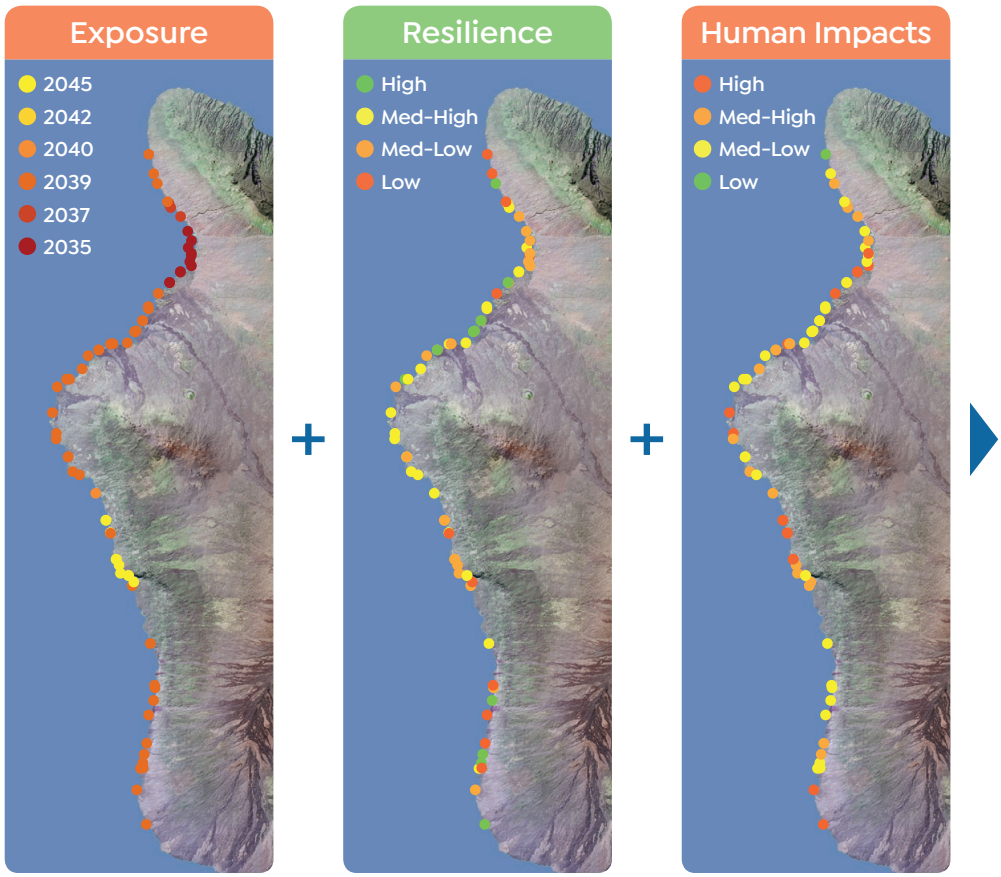
Vulnerability to climate change varies greatly among the coral reefs of West Hawai'i.

Our approach to assessing vulnerability involved combining exposure to climate change, resilience, and human impacts information for the 70 sites surveyed in 2016. Scores for these three inputs were set to a unidirectional scale where a low score is always a good score. Scores for the three inputs were then averaged and the averages were then set to a 0-1 scale where low scores are good scores, meaning lower relative vulnerability (following this Marine Policy paper). Sites are then classified as low, medium-low, medium-high, and high relative vulnerability following this Guide. The vulnerability scores were interpolated to create a relative classification for vulnerability for all reefs in West Hawai'i.

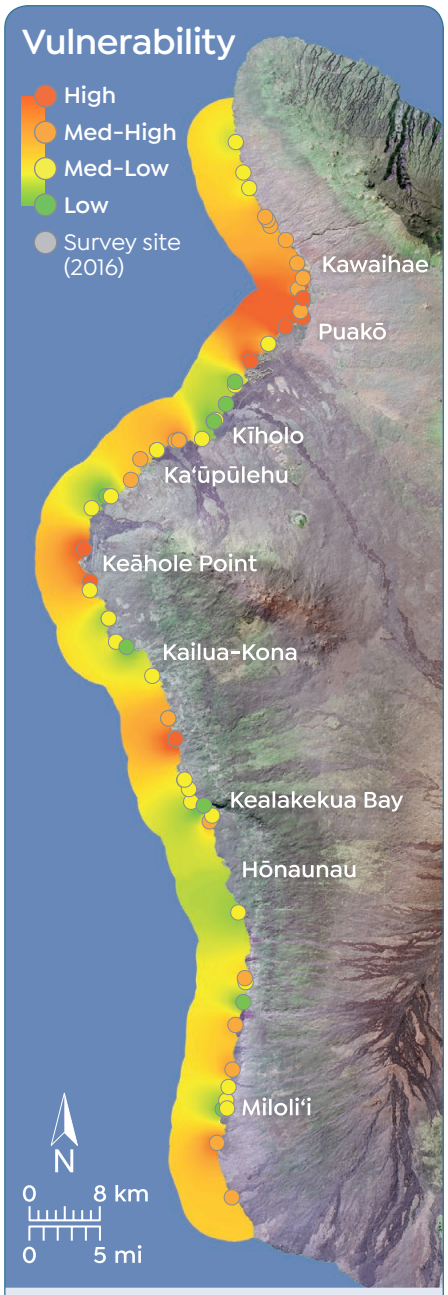
Results indicate coral reef vulnerability to climate change is low near Kīholo, in Kealakekua Bay, Hōnaunau, and Miloli'i. Coral reef vulnerability is high near Puakō, Keāhole Point, and Kailua-Kona.

Management actions that limit or restrict human activities will reduce the sensitivity of coral reefs to disturbance events, such as coral bleaching. As an example, managers can limit herbivore fishing to support recovery following disturbances. The data for the vulnerability inputs (exposure to climate change, resilience, and human impacts) and vulnerability can be used to target and tailor a range of management actions that can give reefs the best chance of coping with climate change.

Reef fishery vulnerability is closely related to the structural complexity of coral reef habitat. As the climate changes, bleaching events, ocean acidification, and severe hurricanes will reduce the structural complexity of coral reef habitat. Small-bodied fish rely upon structurally complex reef areas as refugia from predation. Their increased survival and abundance results in greater fish community productivity. Loss of structural complexity reduces productivity of predatory fish by half and herbivorous fish by more than two and a half times. Reef fish productivity is likely to be lower where coral reef vulnerability is high and productivity is likely to be higher where coral reef vulnerability is low.

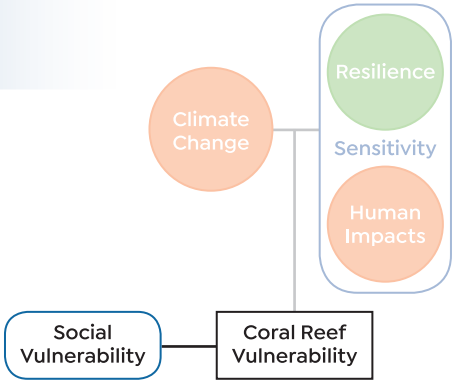


Vulnerability was assessed by combining exposure to climate change, resilience, and human impacts information for the 70 sites surveyed in 2016.



Coral reef vulnerability to climate change in West Hawai'i

Social Vulnerability



Social vulnerability represents a community's reliance on natural resources and ability to adapt to changes in their natural and social environment. Communities in Hawai'i rely on coastal marine ecosystems for a variety of services, including cultural practices, coastal protection, recreation, tourism, and food resources. Communities that are heavily reliant on the local marine ecosystem for their livelihood and well-being may also be more sensitive to ecosystem shifts.

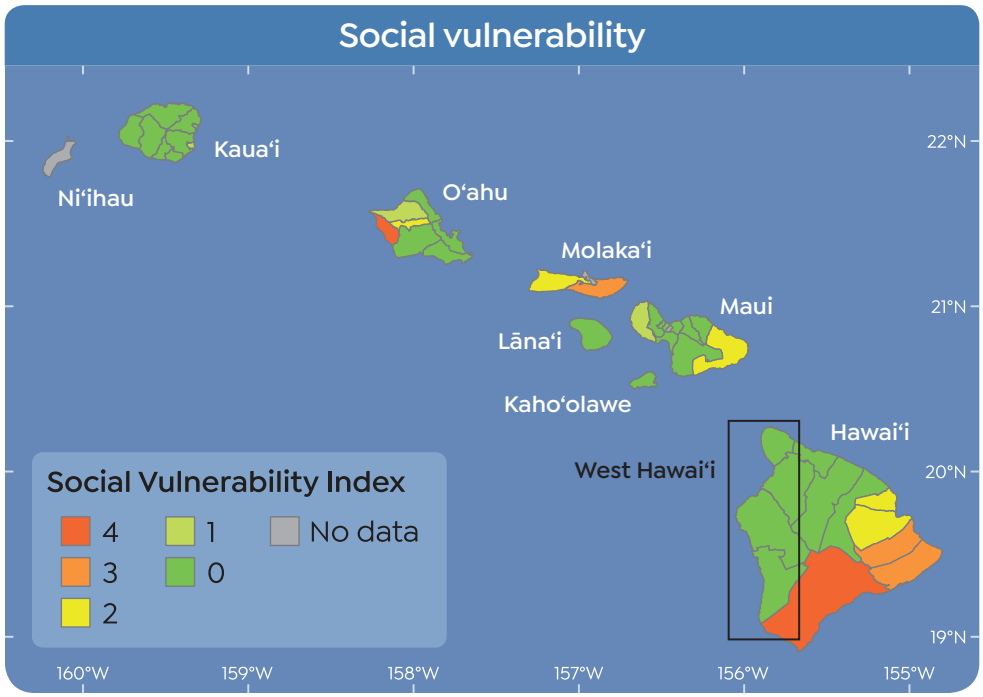
Our approach was to present information on social vulnerability alongside vulnerability of coral reefs to climate change in West Hawai'i. The social vulnerability index we developed incorporates the following five social vulnerability indices developed at the district level from US Census data: Personal disruption, Population composition, Poverty, Labor force structure, and Housing characteristics (following this Report). The index was then renormalized to compare against all other areas in the Main Hawaiian Islands.

Results indicate that social vulnerability is relatively low in North Kohala, South Kohala, North and South Kona, and high in Ka'ū. This pattern is consistent among the indices used as inputs to the vulnerability rating – all 5 indices are low or medium-low for North Kohala, South Kohala, and North Kona, and are high for Ka'ū. Coral reef vulnerability to climate change is also high for the single survey site near Ka'ū, indicating the climate vulnerability of the social-ecological system of Ka'ū is higher than in any other part of West Hawai'i.

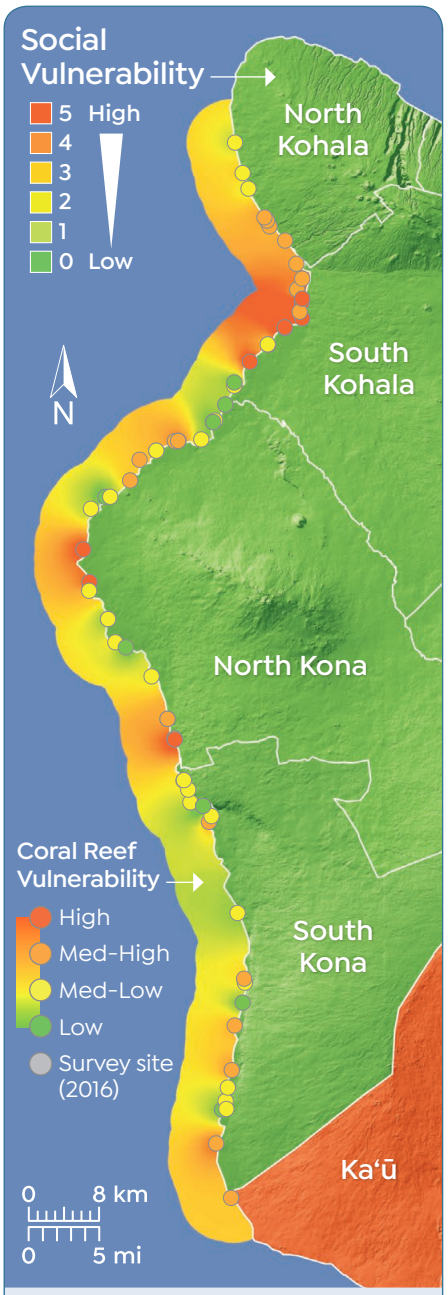
Decreases vulnerability (↓) *Increases vulnerability (↑)*

Social Vulnerability Indices	Definition	Variables included
Personal disruption	Indication of unstable personal circumstances	% total population in poverty (↑), % unemployment (↑), % low educational attainment (↑)
Population composition	Prevalence of socially vulnerable populations	% young children (↑), % female-headed households (↑), % people without a Bachelor's degree (↑)
Poverty	Population in poverty	% total pop. in poverty (↑), % children in poverty (↑), % families with children under 5 in poverty (↑), % single-female headed families in poverty (↑)
Labor force structure	Strength and stability of labor force	% females in the labor force (↓), % people in the service industry (↓), % families with income under $10,000 (↑)
Housing characteristics	Housing type	Median rent (↓), median number of rooms in family dwellings (↓), % houses that lack plumbing facilities (↑)

Social and coral reef vulnerability is highest in Ka'ū, and social vulnerability is relatively low in North Kohala, South Kohala, and North Kona.



Social vulnerability index for the Main Hawaiian Islands derived from the U.S. Census, analyzed following Jepson and Colburn (2013) and Kleiber and Kotowicz (2018).



Aggregate social vulnerability index plus coral reef vulnerability.

Hānau ka ʻUku-koʻakoʻa, hānau kāna, he ʻAkoʻakoʻa, puka

– Kumulipo, the Hawaiian Creation Chant

Born was the coral polyp, born was the coral, came forth

The Kumulipo tells us that the Koʻa, or coral polyp, was the first organism created. The Koʻa was followed by seastars, cucumbers, and urchins, each increasing in complexity. The Kumulipo explains how life began and our shared genealogy. Hawaiian human and coral reef communities have always been connected. Actions taken to reduce coral reef vulnerability are in the spirit of maintaining the strength of these connections as the climate changes.

Mahalo Nui Loa *To all field staff working with NOAA ESD, TNC and Hawaiʻi DAR for collecting coral reef community data.*

Methods and data sources: *Methods for developing: the climate model projections used to examine Exposure to climate change (p. 3) are in this Report[1], the Resilience index (p. 4) are in this Guide[2], the Human Impacts index (p. 5) are in this Report[3], the Vulnerability index (p. 6) are reviewed in this Marine Policy paper[4] and in this Guide[5], and the Social Vulnerability index (p. 7) are in these two Reports[6,7].*

1, 5. https://wedocs.unep.org/handle/20.500.11822/22048, 2. https://wedocs.unep.org/handle/20.500.11822/22046, 3. http://hdl.handle.net/10125/51453, 4. http://www.sciencedirect.com/science/article/pii/S0308597X16304626, 6. https://www.researchgate.net/publication/269632619, 7. https://www.researchgate.net/publication/323428200.

For Additional Information: *Contact Dr. Jamison Gove at jamison.gove@noaa.gov or Dr. Jeffrey Maynard at maynardmarine@gmail.com for additional information on this project and plans to improve and expand upon this assessment.*

Visit www.pifsc.noaa.gov/west_hawaii_iea for additional information on the West Hawaiʻi Integrated Ecosystem Assessment.

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Integrated Ecosystem Assessment