Mapping coral reef vulnerability to climate change in Leeward Maui to aid in designing a resilient managed area network

Final Report

Performance period: 09/01/2019-02/28/2021

Award Recipient: Marine Applied Research Center, LLC
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Brief Project Summary: Hawai‘i’s Governor Ige announced an ambitious plan in 2016 to effectively manage 30% of Hawai‘i’s nearshore waters by 2030. To meet this goal, Hawai‘i’s Division of Aquatic Resources (DAR) has initiated a process to develop a statewide network of marine managed areas. The west coast of Hawai‘i Island (West Hawai‘i) and Leeward Maui are priority locations to start the design and implementation of this network. To ensure long-term ecosystem sustainability and resilience, the network’s design must consider climate change effects. The expected outcome of this proposed project is that spatially continuous information on reef vulnerability to climate change will be accessible, understood, and used in the design of a resilient and sustainable managed area network in Leeward Maui. Project objectives/activities include: (1) assessing relative climate resilience for ~100-200 coral reef monitoring sites in Leeward Maui; (2) interpolating resilience assessment results; (3) assessing relative climate vulnerability for all coral reef habitat in Leeward Maui; (4) developing a plan with our manager partners to expand the vulnerability assessments completed for the coral reefs of West Hawai‘i and Leeward Maui into a State-wide climate vulnerability assessment; and, (5) communicating project methods, results, and lessons learned to the Hawaii, US and international scientific and management community. This is a highly collaborative project co-led by the Marine Applied Research Center with The Nature Conservancy and Hawai‘i DAR.

Project Results

Project objectives 1 and 2.

1. Assess relative climate resilience for ~200 coral reef sites in Leeward Maui.
2. Interpolate resilience assessment results; to produce spatially continuous maps of relative resilience of coral reefs to climate change for all coral reef habitat in Leeward Maui.

Resilience assessments allow decision makers to anticipate change and to focus efforts on improving the ability of the system to cope with those changes and unpredictable events. Resilience assessments involve measuring or assessing the attributes (‘resilience indicators’) that contribute to making a coral reef resilient. By looking at the source of resilience at different locations, and the causes of differences in resilience, managers and stakeholders can evaluate the potential for management or stewardship actions to improve resilience in different areas. The resilience indicators we included in the assessment were coral cover, macroalgae cover, reef builder ratio (ratio of cover of accreting organisms ‘reef-builders’ to all other organisms and substrate types), herbivore biomass, coral diversity, rugosity, and temperature variability.

These 7 indicators come from detailed review of the Hawaii Monitoring and Research Collaborative (HIMARC) dataset.

The HIMARC dataset includes includes data from: US National Parks Service, Hawaii DAR, TNC, NOAA Fisheries PIFSC Ecosystem Sciences Division, the Hawaii Coral Reef Assessment and Monitoring Program and the University of Hawaii Fisheries Ecology Research Laboratory.

Data are available from HIMARC for ~3000 reef sites in Hawaii where benthic and fish community data were collected at the same site. However, our team had to set criteria for which sites could be included in the resilience assessment based on: 1) survey year; we decided to include only data collected during the most recent 3 years for which data is available in the HIMARC dataset (during the project period this was 2014-2016; more recent data was not available as of 2/28/2021 when the period of performance for this project ended); and 2) determining which of the desired resilience indicators is most limiting since data were not collected on all indicators at all sites. Limiting the HIMARC database available to us during the project period to 2014-2016 resulted in 767 survey sites near 4 islands (Hawaiʻi, Maui, Oahu and Molokai) for which all 7 of the desired resilience indicators were available. We determined that coral diversity was the most limiting of the resilience indicators. Coral diversity requires coral species-specific information, which was collected at roughly half of the survey sites for which data is within the HIMARC databased. Rugosity data was also only available for roughly half of the survey sites during the project period. Removing coral diversity and rugosity from the desired indicators list left 5 indicators (coral cover, macroalgae cover, reef builder ratio, herbivore biomass, and temperature variability), which were available for 1,467 survey sites near 8 islands (Hawaiʻi, Kahoʻolawe, Kauaʻi, Lanaʻi, Maui, Molokai, Niʻihau, and Oahu). For this project, we assessed relative resilience in Leeward Maui only.

To assess relative resilience, values for each indicator were normalized to a uni-directional scale of 0-1 by dividing by the maximum value for the variable: 1) among all of the sites in the Main Hawaiian Islands (an 'inter-island' analysis), and 2) among only the sites in Leeward Maui. To ensure that high scores always infer higher relative resilience potential, normalized scores were inverted for macroalgae cover, and the reef builder ratio was set to a log10 scale. All indicators were equally weighted. Resilience scores were calculated by averaging the normalized indicator scores for each site and then those site averages were normalized. This expresses resilience of all sites as relative to the site with the highest score (for each analysis type – inter-island and intraisland). The final resilience scores range from 0-1 and represent decimal percentages of the site with the highest score (1.00). Resilience rankings and relative classification are shown in Figure 1.

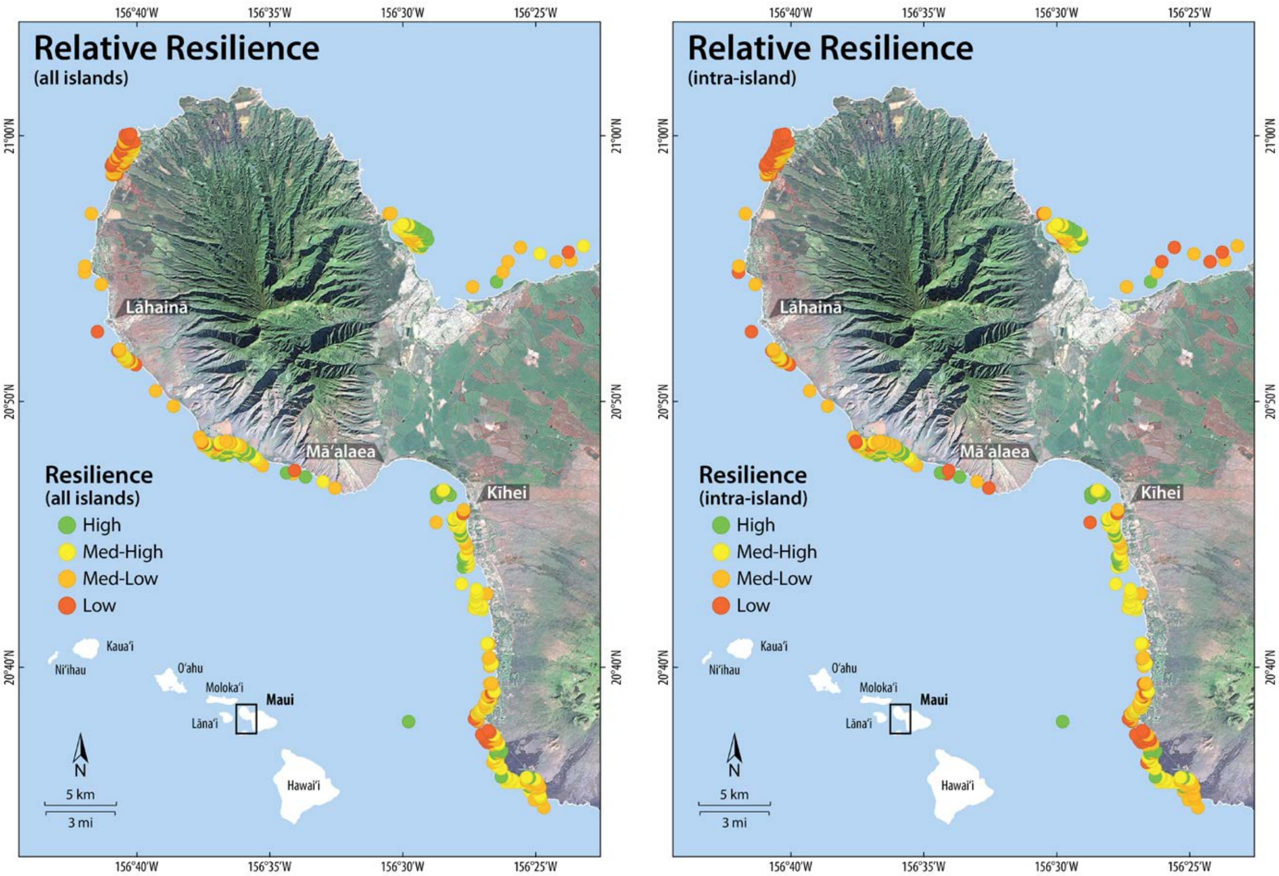


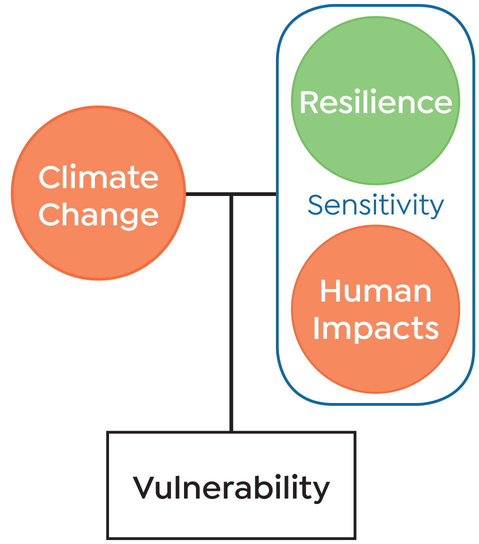
Figure 1. Coral reef (relative) resilience to climate change in Maui – inter-island (Maui sites assessed relative to sites in all islands in the Main Hawaiian Islands) and intra-island analyses. Reef survey data were collected between 2014 and 2016 (1,475 sites). Relative classifications for resilience scores are as follows: high (final scores that are greater than 1 sd above average), medium-high (<avg+1sd and >avg), medium-low (<avg and >avg-1sd), and low (<avg-1sd).

The site-based resilience assessment results were interpolated (our project objective 2) as part of the vulnerability assessment completed as project objective 3.

3. Assess relative climate vulnerability for all coral reef habitat in Leeward Maui by combining resilience, climate exposure, and anthropogenic stress information.

Changes in coral reef condition and ecosystem service provisioning over the coming decades will be determined by coral reef vulnerability, which is only partially determined by reef resilience. Coral reef vulnerability to climate change depends on the frequency and severity of climate disturbances, such as coral bleaching. Vulnerability also depends on sensitivity, which is a combination of coral reef resilience and whether resilience is compromised by human impacts (see top of next page). The data we compiled and generated on relative resilience of reefs to climate change in Maui only provides part of the needed vulnerability picture. We also compiled and generated information on projected spatial variation in future exposure to climate impacts, such as coral bleaching, and human impacts, and then combined those data layers with resilience to assess climate vulnerability.

This proposed vulnerability assessment framework (see right) is an adapted version of a vulnerability assessment framework first published in Turner et al. (2003), and then widely adopted by the Intergovernmental Panel on Climate Change. The version shown here and described in the paragraph above excludes adaptive capacity, which would typically moderate vulnerability (greater the adaptive capacity, the lower the vulnerability, everything else being equal). The adaptive capacity term is excluded because spatial variation in adaptive capacity of coral reefs (the reefs, not nearby human communities) is poorly understood. As an unknown for coral reefs in Hawai‘i, adaptive capacity is removed from the proposed assessment framework. This follows a vulnerability assessment framework this project team published in Johnson et al. (2016).



The data layers required to assess climate vulnerability are relative resilience, which was generated as the output of objectives 1 and 2, projected future ‘exposure’ and human impacts.

Projected future exposure – Our team developed the state-of-art climate model projections of the frequency and timing of exposure to severe bleaching events (van Hooidonk, Maynard et al. 2016). The projections assume severe bleaching could occur when reefs experience 8 Degree Heating Weeks (DHWs) of accumulated thermal stress during a single warm season. 8 DHWs is the upper threshold NOAA Coral Reef Watch uses in the Bleaching Alert products for Alert Level 2, which suggests severe bleaching is very likely. The projections data we generated are global, so the required data for Hawai‘i was extracted from the global dataset (Figure 2) and then combined with the relative resilience and human impacts data layers in the vulnerability assessment.

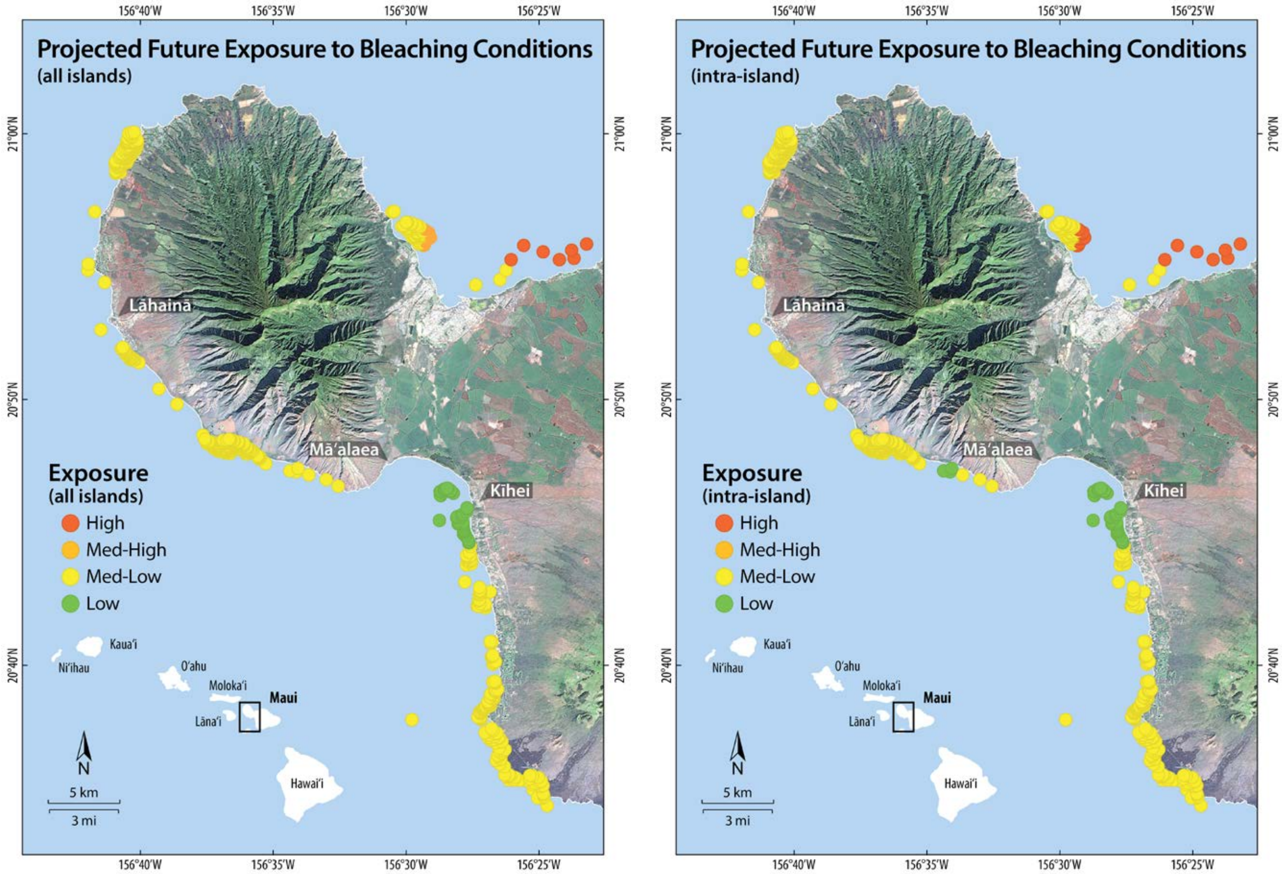


Figure 2. Projected future timing of annual severe bleaching under fossil-fuel aggressive ('business as usual') emissions scenario RCP8.5 as inter-island (all islands) and intra-island analyses. The average for Hawaii is ~2040; sites projected to bleach >5 years later are green, and >5 years earlier are red. Relative classifications follow Figure 1. Data are from van Hooidonk, Maynard et al. 2016.

<u>Human impacts</u> – Collaborators of this project team have developed a cumulative impacts index that combines what is known about spatial patterns in the severity of human impacts on the marine environment in Hawai'i. These human impacts datasets were developed as part of the Ocean Tipping Points project and published in Wedding et al. (2018). The cumulative impacts index combines reef fish fishing, invasive algae species, ship groundings, sediment pollution and tourism (and 11 other impact types) and weights the impacts based on their likely effect on reef vulnerability (see methods in Wedding et al. 2018). Reef fish fishing has the greatest weight in the cumulative impacts index as it is thought to have the greatest impact on coral reef ecosystem function. The final impacts score for each of the ~1,475 sites is a value from 0-1 with high scores meaning high impact (Figure 3).

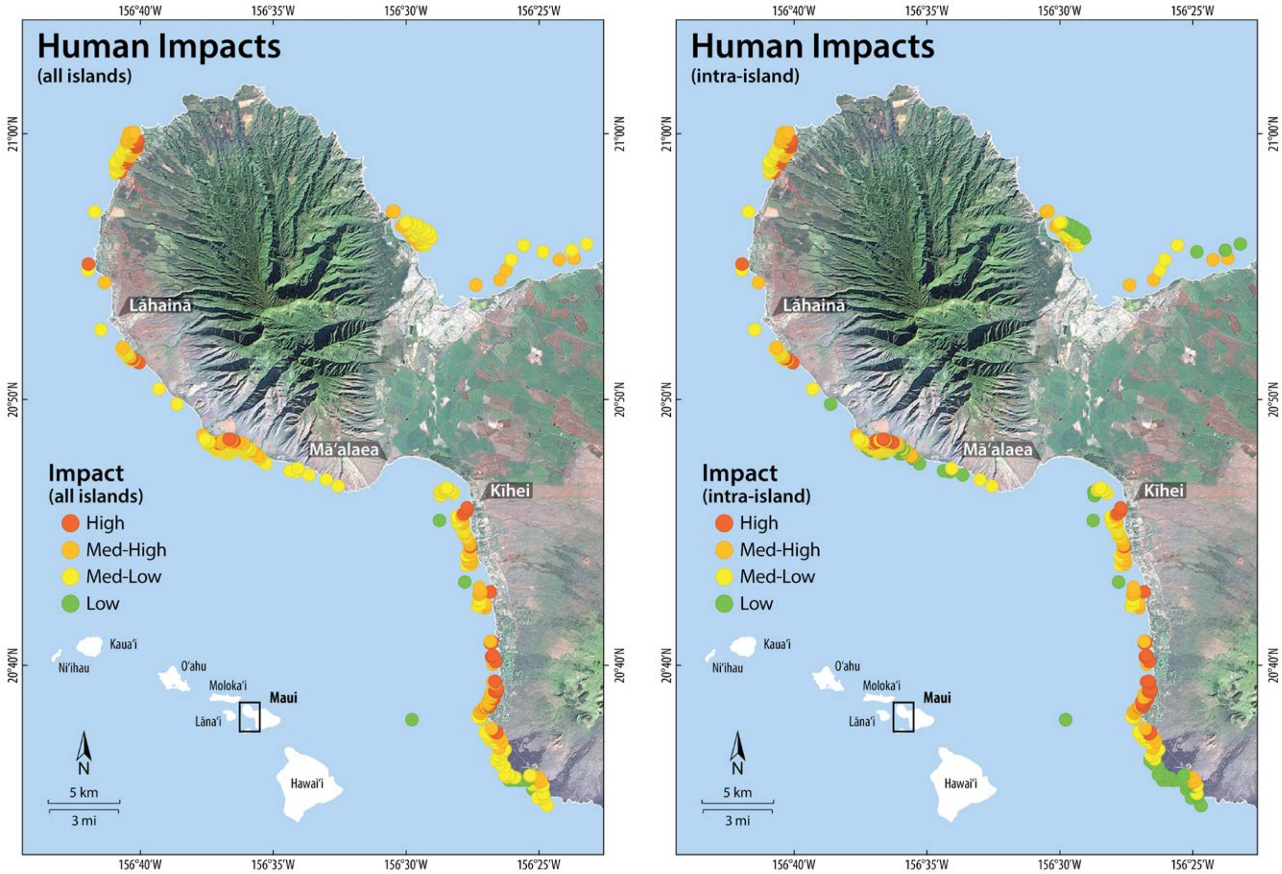


Figure 3. Cumulative human impacts index from the Ocean Tipping Points project (Wedding et al. 2018) for the inter-island (all islands) and intra-island analyses. Relative classifications follow Figure 1.

<u>Climate Vulnerability</u> – Where monitoring programs have excellent spatial coverage, as is the case in Hawai‘i, interpolation can be used to generate information on the potential reef condition and resilience of reef areas *between* surveyed points.

Inverse distance weighted (IDW) interpolation explicitly assumes that places that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW uses the measured values surrounding the prediction location. IDW gives greater weights to points closest to the prediction location, and the weights diminish as a function of distance, hence the name ‘inverse distance weighted’. Weights are proportional to the inverse of the distance (between the data point and the prediction location) raised to the power value p. As a result, as the distance increases, the weights decrease rapidly. The rate at which the weights decrease is dependent on the value of p. If $p = 0$, there is no decrease with distance, and because each weight λi is the same, the prediction will be the mean of all the data values in the search neighborhood. As p increases, the weights for distant points decrease rapidly. If the p value is very high, only the immediate surrounding points will influence the prediction. The p value was explored in our drafts of the IDW interpolation data layer, and was very high, ensuring only immediately surrounding reef areas are used to predict condition and relative resilience in unmeasured areas. The results are spatially continuous estimates of reef condition and relative resilience (and vulnerability, see below) that can ensure all reef areas are considered in management planning exercises. The interpolated data layer can be used with conservation software (e.g., Marxan) to optimize marine management and MPA network design. The results of the methods described just above for projected future exposure to climate impacts and human impacts are spatially continuous data layers we can combine with an IDW interpolation of relative resilience developed under objective 1. Scores or values for each of the three data layers are set to a logical scale where a low score always means lower relative vulnerability. This requires multiplying all normalized scores for Resilience and Projected future exposure by -1. Resilience and projected future exposure can then be added to Human impacts to generate a vulnerability score, where the lower the value (the more negative), the lower the vulnerability. The methods step of multiplying normalized Resilience and Projected future exposure by -1 ensures all four scores in the mathematical vulnerability assessment equation are intuitively set to low scores meaning low vulnerability. The final vulnerability scores for the inter-island and intra-island analyses are shown in Figure 4.

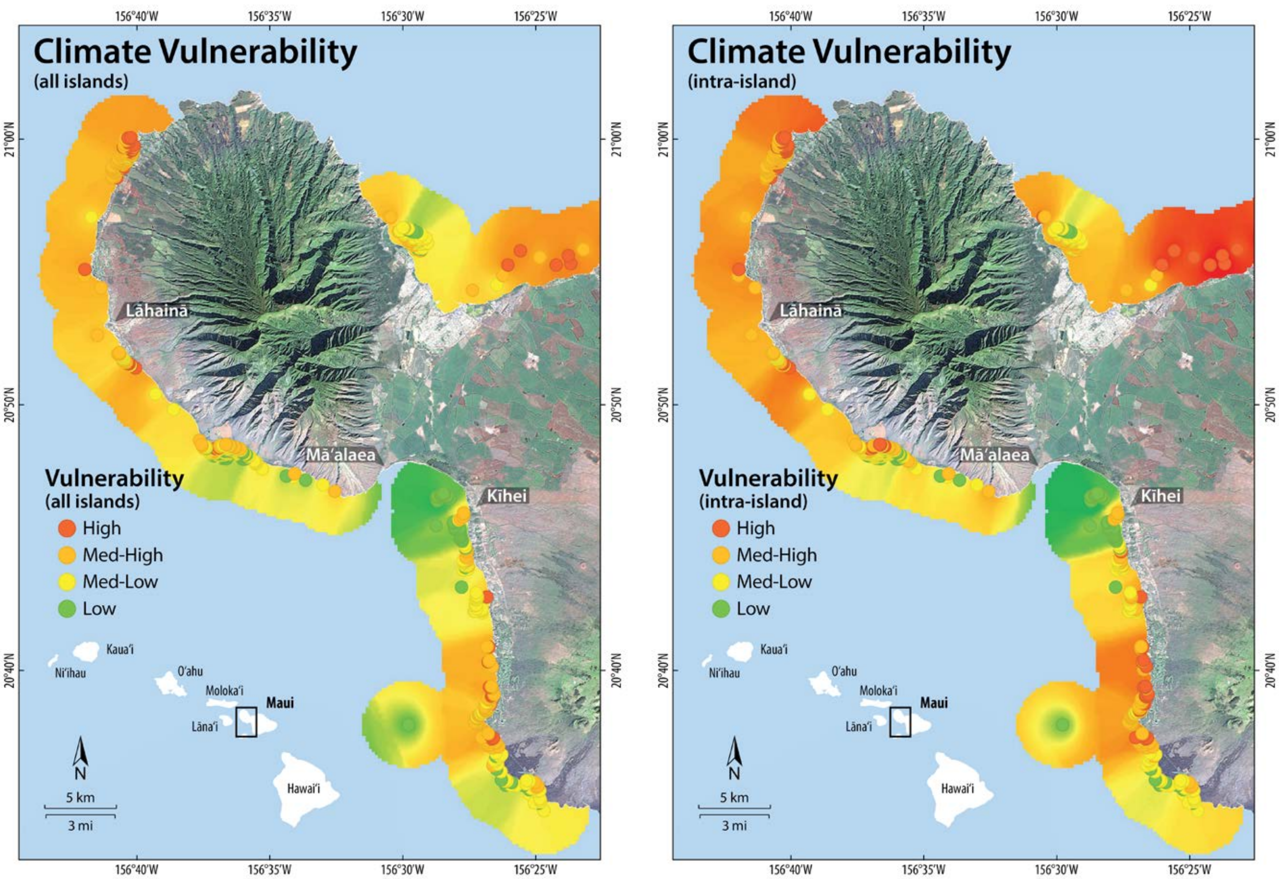


Figure 4. Relative climate vulnerability for the inter-island (all islands) and intra-island analyses. Relative classifications follow Figure 1.

4. Develop plan to expand the vulnerability assessments completed for the coral reefs of West Hawai‘i and Leeward Maui into a State-wide climate vulnerability assessment.

This project team has completed an MHI-wide climate vulnerability assessment using CMIP6 climate model projections as well as NOAA CRCP NCRMP data from 2019 surveys. The statewide vulnerability assessment represents a collaboration among SymbioSeas, NOAA CRCP, NOAA Fisheries, NOAA IEA, The Nature Conservancy, the Division of Aquatic Resources (DAR) in HI and the Lenfest Ocean Program (a Pew Charitable Trust). The results of the MHI-wide vulnerability assessment will be published within NOAA reports and an academic journal late in 2021 or early in 2022.

5. Communicate project results to the scientific and management community in Hawai‘i, nationally and internationally.

We reported on these results at a Bleaching and Restoration Symposium chaired by NOAA CRCP and the NOAA Restoration Center, with partners, at the HIMB facilities in Kaneohe Bay, Oahu in November of 2019. Following the conference, we were invited by DAR Director Brian Neilson to present our results to all of DAR staff via teleconference. The teleconference took place in late January, 2020. Further in-person engagement on these results and their application within the Marine 30 by 30 Initiative were limited during the COVID-19 pandemic.

References

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Turner, Billie L., et al. “A framework for vulnerability analysis in sustainability science.” *Proceedings of the National Academy of Sciences* 100.14 (2003): 8074-8079.

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Thanks for your support of this applied research.